Module 5

THE MODERATOR PURIFICATION SYSTEM

OBJECTIVES:

After completing this module you will be able to:

5.1 a) State three reasons why it is important to maintain moderator purity. ⇔ *Page 2*

b) State three ways in which moderator purity is controlled. ⇔ *Page 2*

c) Describe the term 'purification half life'. ⇔ *Page 3*

d) State the primary control for the rate of gadolinium poison removal. ⇔ *Pages 3-4*

5.2 Explain the reason why a multistage ion exchange technique is required for boron removal. ⇔ *Page 5*

5.3 State three reasons why boron or gadolinium should be removed when their reactivity effects are no longer required. ⇔ *Page 6*

5.4 State how each of the following moderator purification parameters is maintained:

a) Purification flow, ⇔ *Page 6*

b) Ion exchange inlet temperature, ⇔ *Page 7*

c) Purification pressure, ⇔ *Page 7*

d) Conductivity. ⇔ *Page 7*

5.5 State the indicated number of significant operating consequences for each of the following situations:

a) High purification flow (2), ⇔ *Page 7*

b) Low purification flow (1), ⇔ *Page 7*

c) High purification system inlet temperature (2), ⇔ *Page 7*

d) IX column differential pressure high (1), ⇔ *Page 7*

e) Continued use of spent resin for purification (1), ⇔ *Page 8*

f) Use of a saturated boron column for boron cleanup (1), and ⇔ *Page 8*

g) Escape of resin into the main moderator system (1). ⇔ *Page 8*

5.6 State the reason why the moderator purification system must be isolated during unit overpoison guaranteed shutdown state. ⇔ *Page 8*

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INSTRUCTIONAL TEXT

INTRODUCTION

The purification system maintains the purity of moderator heavy water within specified limits by removing dissolved ions and suspended material. How the system performs this function as well as its limitations are discussed in the following major topics:

- Normal system operation;
- Operation during unit guaranteed shutdown state.

NORMAL SYSTEM OPERATION

In this section, you will learn about methods used to remove moderator impurities. Three modes of system operation described are:

- Normal cleanup;
- Gadolinium removal;
- Boron removal.

Finally, important operating parameters that must be maintained in any of the above modes of operation will be discussed. A simplified pullout diagram of a typical system, Figure 5.1, is placed at the module end showing the main components and system flow.

Moderator Purity

Obj. 5.1 a) ⇔

Corrosion products, as impurities to the system, appear as suspended material and dissolved ions. Ions may also be purposely added as neutron absorbing poisons for reactivity control or shutdown. Over the long term, the function of the purification system is to keep the moderator D_2O relatively free of foreign material to ensure: D_2 explosion hazard is minimized by **reduced radiolysis**, **low corrosion**, and **low neutron absorption.**

Obj. 5.1 b) ⇔

This function is accomplished in three ways by:

1) **controlling pH,**
2) **using strainers and filters,**
3) **using ion exchange columns.**

The **pH** is maintained around 7*, mainly to ensure that moderator poisons do not precipitate out of solution, but also to minimize corrosion of stainless steel components.

* A pH of 7 is neutral on the acid-base scale. More information is available on pH in the 224 course.

There are **strainers** situated on the inlet and outlet of the ion exchange columns are shown in Figure 5.1. They will remove particulate material that may be in the system, especially any resin fines. Some stations have a **filter** at the inlet to the purification loop as well, to collect any corrosion products or suspended material.

The **ion exchange columns** will remove soluble impurities to reduce conductivity as discussed under the heading "conductivity", on page 8. These are usually mixed bed resins removing positive and negative ions (anions and cations).

Modes of System Operation

Removal of gadolinium and boron may employ strong acid/strong base resins as well as different removal techniques. Because of the fact that gadolinium forms strongly charged ions in solution, these are easily attracted to ion exchange columns. Boron, however, forms weakly charged ions in solution which are not as easily removed by ion exchange columns.

Normal Cleanup

To ensure that the ion exchange column removes all ions during normal cleanup, the specification of overall conductivity is monitored. Some specific ions* of concern are also monitored including chloride, nitrate, gadolinium, and radionuclides. Continuous flow through one IX column is adequate to maintain these specifications. The actual flow rate varies from station to station but is most often in the 5 to 7 kg/s range per column. Exceeding this may lead to resin damage and subsequent dispersal of resin fines into the moderator system. If increased flow is required for cleanup, an additional column must be valved into service.

* Ions and concentration may vary, depending upon the station.

A normal cleanup IX column will not be very efficient in removing boron, but will remove any of the above mentioned ions.

Gadolinium Removal

⇔ ***Obj. 5.1 c)***

Gadolinium, being a strong ion, is easily removed by the IX resin. For strong ions, the concept of **purification half life** applies. This term refers to the time required to reduce the ion concentration to one half of the starting value. The time for gadolinium cleanup half life will depend upon the purification flow rate and the total mass of the moderator D_2O. For any unit, the **only** normal **variable is purification flow rate**, which in turn is dependent upon the number of columns in service.

⇔ ***Obj. 5.1 d)***

Figure 5.2 is a typical curve showing gadolinium concentration versus time for different purification flows. The time to reduce the initial concentration to one half is indicated as purification half life for different purification flows. Of course, to increase the purification flow significantly, the number of parallel IX columns in service must also increase.

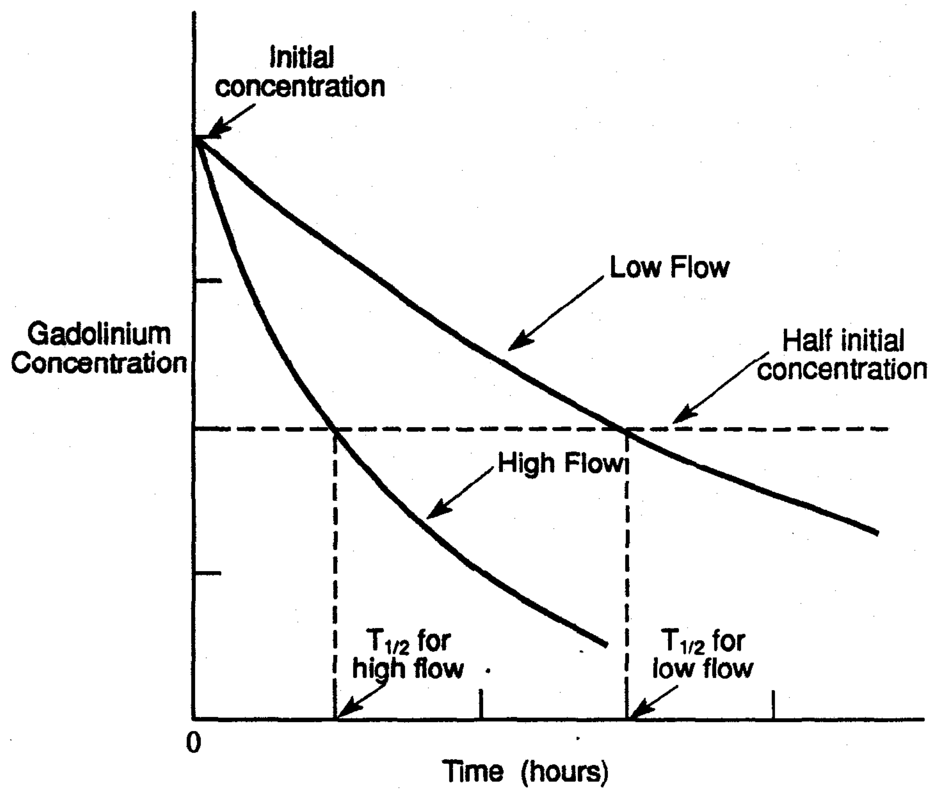

Figure 5.2 Typical Moderator Purification Half Life For Different Purification Flows.

When the poison injection system operates to shut down the reactor, it inserts as much as 600 mk of negative reactivity into the moderator. For example, with a flow rate of 20 kg/s, one cleanup half life will take about 3 1/2 hours. Five half lives will reduce the gadolinium to -19 mk.* Five half lives would take 17 1/2 hours at this flow rate. This cleanup time is too long to prevent a poison outage. However, when this cleanup time is combined with the time to repoise SDS2, 40 to 45 hours will have elapsed. This is enough time to allow the xenon to decay to startup levels.

* Total poison and xenon negative reactivity must be -28mk or -45mk with adjuster removed.

When gadolinium has been added for xenon simulation, the burnup rate closely matches the rate at which xenon reactivity builds up, so that purification removal is not initially required. Gadolinium poison concentration naturally decreases in neutron fields, with a burnout half life of about 8 hours initially, and longer as the largest cross section isotope burns up. Any imbalance between the two rates will be detected by a rise or fall of the average zone level. When the poison has burned out and xenon has built up to its normal level, the gadolinium isotopes must be removed by normal cleanup to keep the moderator D_2O conductivity within specification.

Boron Removal

Because boron forms a weak ion in solution, its removal is more difficult and time consuming. The removal rate depends upon the difference between the boron concentration in solution and the boron concentration in the IX column. An IX column removing boron from the moderator will, over time, form an equilibrium with the boron in solution, so that no further boron can be removed. The column is said to be **saturated or borated**. In the same way, an IX column with a boron concentration higher than that of the moderator will form an equilibrium concentration with the solution and give off boron to the moderator water. Establishing equilibrium concentrations with the solution only occurs with weakly ionized substances and does not occur when a strong ion, such as gadolinium, is attached to an IX column.

⇔ ***Obj. 5.2***

Because boron (B) establishes a equilibrium concentration with the solution, it is removed from the moderator in a **multistage IX technique** using 2 or 3 IX columns operating on different moderator boron concentrations. An example of this would be a two stage removal of 3mg B/kg D_2O or 28 mk worth. One column may reduce the concentration down to 0.5 mg B/kg D_2O at which point it becomes saturated. The column is then isolated and a fresh column is used for the second stage of boron removal to reduce the boron concentration further. This column is then used the next time for first stage boron removal, to maximize the use of the resin. A general rule of thumb for boron removal is that a fresh IX column will leave at least 1/7th of the original boron concentration after the column saturates.

Thus the rate of Boron removal cannot be determined by the normal half life curve of Figure 5.2, since there are other factors beside purification flow rate and total mass of moderator D_2O. Boron removal capacity of the IX columns is also sensitive to temperature. An increase of a few degrees in the IX column will lower the equilibrium concentration in the IX column, reducing its capacity for boron. In fact, it may even release boron from the resin.

Boron concentrations decrease slowly in neutron fields, with a burnout half life of 15 to 20 days depending upon reactor flux. Because of the long burnout time period, IX columns may be required to remove boron. Normal cleanup is required when boron is burned out to reduce the conductivity effects on the moderator.

Obj. 5.3 ⇔

If **boron or gadolinium** are kept in the moderator when their **reactivity effects are no longer required**, additional positive reactivity must be provided to counter the poison effects. The **normal reactivity control span** of the average liquid zone level may **not** allow the zones to **accommodate all reactivity effects.** Keeping gadolinium in the moderator when it is no longer required will **also keep the conductivity high, contributing to increased radiolysis products**. The third concern is **financial.** Fuel costs increase when operating with extra poison.

Operating Parameters

In this section, four important parameters that characterize system operation, are discussed:

- Purification flow,
- Inlet temperature,
- Pressure,
- Moderator conductivity.

For each of these parameters, you will learn how it is maintained and what adverse consequences occur when this parameter goes beyond its limit.

Purification Flow

CANDU stations use a bypass flow purification system around the moderator circulating pumps as shown in Figure 5.1.

Obj. 5.4 a) ⇔

Usually, the purification inlet is downstream from the moderator heat exchanger discharge. The **moderator pump differential pressure** is used as the **driving force for the purification loop**. Typically 4 to 6 columns are available for use in parallel. The extra columns allow for slurrying of resin from a spent column while purification is ongoing. The number of columns in service depends on the poison removal requirements.

Typical purification flows range from 5 to 25 kg/s, depending upon the number of IX columns in service (and station). Exceeding recommended flow rates can lead to resin damage. An individual column inlet motorized valve is the isolation for the column.

NOTES & REFERENCES

In some stations, it has been found that with **high flows**, the quantity of resin fines increase due to mechanical breakdown. The fines can be carried through to the **IX discharge strainer** and cause it to **clog**. The ion **exchange process is** also **less efficient** at higher flows.

⇔ ***Obj. 5.5 a)***

Low purification flow would take a **longer time for moderator cleanup.** In fact, for very low flows, the **rate** at which **impurities are produced may exceed the purification rate** so that even though purification is occurring, the impurity level may be increasing.

⇔ ***Obj. 5.5 b)***

Inlet Temperature

Most stations take advantage of the **cooling provided by the moderator heat exchanger.** The purification inlet is downstream of the main moderator heat exchanger outlet. IX resins are temperature sensitive. They should be kept below about 60°C to **prevent damage and subsequent release of contaminants** such as chlorides, boron, and gadolinium. Borated IX columns are particularly sensitive to temperature changes when they are at equilibrium with the moderator D_2O. **A small temperature increase can release boron poison into the system.** Typical purification inlet temperatures are 30°C to 35°C.

⇔ ***Obj. 5.4 b)***

⇔ ***Obj. 5.5 c)***

Pressure

The moderator purification **pressure is maintained** by the **moderator circulation pumps.** The pump differential pressure is at least 650 kPa with the pressure reduced at the calandria by flow restricting devices. Since a typical system purification pressure drop is about 400 kPa, the pump differential pressure will provide sufficient pressure for an adequate flow. When the **ΔP** across an individual strainer (filter) **increases, this component requires changing or cleaning.** If they are not changed, the **flow will gradually decrease** until no purification flow occurs.

⇔ ***Obj. 5.4 c)***

⇔ ***Obj. 5.5 d)***

Conductivity

Moderator conductivity is a measure of the concentration of ionic impurities. It is **monitored by in line conductivity cells and by chem lab sampling.** Conductivity must be kept low because as dissolved impurities increase, the natural rate of D_2 and O_2 recombination decreases. In addition, increased neutron absorption and possible corrosion will result.

⇔ ***Obj. 5.4 d)***

NOTES & REFERENCES

The conductivity is usually kept below 0.1 mS/m by continuous IX purification. An increase in moderator conductivity normally indicates spent IX resin in the column. Other methods which may identify that an IX column is spent are:

- Checking for high ΔP across the IX column (plugging),
- Observing average zone level reduction (boron leaching from resin),
- Checking for increased chloride readings at the column outlet.

Obj. 5.5 e) ⇔

The **continued use of spent resin** for purification **will result in increased conductivity at the outlet which in turn can cause a D_2 excursion.** This is because impurities are not removed or further impurities may be released from the resins. Other ways of detecting spent resin are indicated above.

Obj. 5.5 f) ⇔

Continued use of a **saturated boron column will not reduce the boron content further**. In fact, as ionic impurities replace the loosely bonded boron, more **boron poison and contaminant is released** to the system.

Obj. 5.5 g) ⇔

Another contributing factor to conductivity is **resin fines escaping into the main moderator system.** If not removed, they will increase conductivity by releasing ions to solution. Increased conductivity results in increased radiolysis products, producing a higher D_2 concentration and possible **D_2 excursion.** If D_2 levels in the cover gas are high, an explosion hazard may exist prompting a unit shutdown.

System Operation During Unit Guaranteed Shutdown State

Obj. 5.6 ⇔

One method of placing the reactor in the guaranteed shutdown state is by adding an excess of neutron absorbing poison to the moderator to ensure that the reactor will not reach criticality. During this state, the **moderator purification system must be isolated** as part of the guaranteed shutdown state. This is to **ensure** that the **poison** will **not be removed inadvertently.**

SUMMARY OF THE KEY CONCEPTS

- Moderator purity is maintained to minimize radiolysis products, corrosion, and neutron absorption. Moderator purity is controlled by neutral pH control, strainers and filters, and ion exchange columns.
- Purification half-life refers to the time required to reduce the ion concentration to one half of its original value.
- Gadolinium removal depends upon purification flow rate.
- Boron is removed in a multistage technique because ion exchange columns easily saturate with boron.
- Boron or gadolinium should be removed when they are no longer required because the normal reactivity control span may be affected. Gadolinium nitrate contributes to the conductivity which in turn causes increased radiolysis products. Both poisons can produce increased fuel costs.
- Flow is maintained by using the main moderator circulation pump ΔP as the driving force for the purification loop. High purification flows result in a less efficient exchange process and may damage resin leading to plugged strainers or filters and increased impurities in the moderator. Low purification flow may not remove impurities as fast as they are formed.
- Ion exchange inlet temperature must be controlled to ensure high inlet temperature does not damage the resin. Boron removal columns are particularly sensitive to boron release when temperature is increased.
- Purification pressure is maintained by using the main moderator pump discharge pressure and monitoring the ΔP across components in the purification loop. High ΔP will result in reduced purification flow.
- Low conductivity is maintained by the IX columns. Outlet conductivity and other parameters are sampled by the Chem Lab to determine if the column is spent. Continued use of a spent resin will result in increased outlet conductivity. Other indications of a spent resin include reduced IX flow (damaged resin), decreasing zone levels, or increased chloride levels. Continued use of a saturated boron column may release more boron into the system as it is displaced by stronger ionic impurities on the column.
- Resin escape into the moderator may contribute to cover gas D_2 excursions.

NOTES & REFERENCES

- The moderator purification system is isolated as part of the overpoisoned guaranteed shutdown state to ensure the poison will not be removed inadvertently.

Page 11 ⇔

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

ASSIGNMENT

1. a) State three reasons for keeping moderator water pure?

   i) ____

   ii) ____

   iii) ____

   b) Indicate three ways moderator water purity is maintained.

   i) ____

   ii) ____

   iii) ____

2. How would you increase the rate of gadolinium removal?

   ____

3. Why is a multistage technique required for boron removal?

   ____

   ____

   ____

4. Why should boron or gadolinium be removed when their reactivity effects are no longer required?

   ____

   ____

   ____

5. a) How is purification flow maintained?

   ____

   b) What are two consequences of high purification flow?

   i) ____

   ii) ____

   c) What is the consequence of low purification flow?

   ____

6. a) How is the ion exchange inlet temperature maintained?

   ____

NOTES & REFERENCES

b) What are three consequences of a high purification inlet temperature?

i) ______________________________

ii) ______________________________

iii) ______________________________

7. a) What provides the driving force for flow through purification?

____

b) What is the consequence of high differential pressure across a purification system component?

____

8. a) How is low conductivity maintained?

____

b) What is the consequence of continued use of spent resin for purification?______________________________

____

c) How would you know if you valved in a boron saturated column?

____

d) What is the consequence of resin escape into the main moderator system?

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9. Why must the moderator purification be isolated during the overpoison guaranteed shutdown state?

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

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