Module 17

FUEL HANDLING

OBJECTIVES:

After completing this module you will be able to:

17.1 Explain the reason why each of the following is a factor that is used to determine if a channel can be fuelled.

- a) Channel burn-up, *⇔ Page 3*
- b) Power distribution, *⇔ Page 3*
- c) Reactivity gain, *⇔ Page 3*
- d) Channel abnormal conditions, *⇔ Page 3*
- e) Defective fuel in the core, *⇔ Page 3*
- f) Proximity to recently fuelled channels, *⇔ Page 3*
- g) Abnormal operating conditions, *⇔ Page 4*
- h) Liquid zone levels. *⇔ Page 4*

17.2

- a) State the preferred reactor state during refuelling. *⇔ Page 4*
- b) Explain three reasons why the state given in (a) is preferred. *⇔ Page 4*
- c) State the required approval authority for fuelling while in a state other than the preferred state. *⇔ Page 5*

17.3 Explain three methods that are used in CANDU reactors to detect flow blockages while fuelling. *⇔ Pages 6-7*

17.4

- a) Explain the three concerns when handling irradiated fuel. *⇔ Pages 7-8*
- b) Explain the additional precaution taken when handling failed fuel. *⇔ Page 8*

17.5

- a) State the four parameters monitored for the Irradiated Fuel Bay water and explain the reason why they are monitored. *⇔ Pages 9-10*
- b) State the parameter monitored for the Irradiated Fuel Bay atmosphere and explain why it is monitored. *⇔ Page 10*

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INSTRUCTIONAL TEXT

INTRODUCTION

The operating life of a CANDU reactor can be divided into three distinct periods from the point of view of fuel management:

1) The period from first criticality when the reactor is loaded only with fresh fuel to the onset of fuelling.
2) The period from the onset of fuelling, necessary to maintain the reactor critical, to the final or equilibrium core state.
3) The equilibrium period, which is characterized by a relatively stable distribution of the overall core power and burn-up. This equilibrium period covers most of the reactor life.

It is this last period that we are interested in with regards to fuelling criteria:

This module will discuss fuelling considerations, channel blockage detection while fuelling and handling and storage of irradiated fuel.

Fuelling Considerations

The Fuelling Engineer provides a fuelling list specifying the channels to be fuelled. This list is produced by running the computer program SORO or RFSP (Simulation Of Reactor Operation/Reactor Fuelling and Simulation Program), depending on the station. The channels to be fuelled are determined on the basis of such factors as power distribution, zone levels, fuel burnup, Channel Power Peaking Factor (CPPF – the ratio of actual channel power to a reference channel power, also referred to as 'ripple'), position of reactivity mechanisms, number and types of fuel bundles last inserted in the core, etc.

Only channels which appear in the fuelling list may be fuelled.

While in general the information provided by SORO/RFSP is valid, changes in the core conditions may have occurred since the simulation was performed. These changes would require that SORO/RFSP be run again to provide updated information. Depending on the station, these programs are run a minimum of three times per week, and more often when core conditions are changing, ie. adjusters driving etc.

The following are considerations used for the selection of channels to be fuelled:

1) Higher **burnup channels** shall be fuelled first. The reason is that in these channels the fuel is depleted and reactivity is low. Higher burn-up channels are underpowered, and should be fuelled preferentially. *⇔ Obj. 17.1 a)*

2) **Reactor power distribution** shall be kept symmetrical. Asymmetry in power distribution increases the load on the Reactor Regulating System (RRS) which has to maintain a zone reactivity balance. This increases the probability of a reactor trip (Neutron Over Power/Regional Over Power Trips will occur if a zone power is too high). To achieve axial flux symmetry, equal numbers of channels shall be fuelled from each end of the reactor. To achieve radial (and azimuthal) symmetry, proportional numbers of channels shall be fuelled in each zone controller region. *⇔ Obj. 17.1 b)*

3) The channels with the largest **reactivity gain** on fuelling may be selected if the overall core reactivity is low. *⇔ Obj. 17.1 c)*

   The core reactivity is maintained by compensating the reactivity loss due to fuel burn-up with the reactivity gain due to fuelling rate. When the fuelling rate cannot be maintained, it is necessary to fuel channels with high reactivity gain on fuelling, ie, high burnup channels in the innermost part of the core.

   If margin to trip * is low for such a high reactivity gain channel, two actions may be taken:

   - Derate (or be prepared to derate) the reactor,
   - Prior to fuelling, calibrate the NOP/ROP (Neutron OverPower/Region OverPower) detectors to restore the appropriate margin to trip.

   * Margin to trip is covered in more detail in your Reactor Safety course.

4) The channels to be fuelled should not have known **abnormal conditions** that will hinder fuelling, such as closure plug or seal face problems. This means the fuelling machine may have problems attaching to the channel, sealing against the channel, reseating the channel closure, etc. These conditions could cause a unit to be shut down for repairs. *⇔ Obj. 17.1 d)*

5) **Defective fuel** bundles shall be removed as soon as possible. Fission product releases to the HTS must be prevented, as was discussed in Module 16. *⇔ Obj. 17.1 e)*

6) Avoid fuelling channels **close to recently refuelled channels.** *⇔ Obj. 17.1 f)*

   Excessive fuelling in one region of the core may lead to high fuel bundle powers (due to high neutron flux), leading to overheating and fuel failures.

Obj. 17.1 g) ⇔

7) There shall be no fuelling with control absorbers (CAs) in the core. CAs drop in the core only during **abnormal operating conditions** (such as reactor trips, stepbacks, etc). Fuelling operations are to be performed only during normal operating conditions, ie. reactor operating at a steady power level.

   During fuelling operations, reactivity changes should be avoided, ie. poison removal/addition, moving adjusters, etc. Adjuster position imposes no restriction on fuelling.

   Fuelling operations shall not take place during reactor power increases.

   During the transients mentioned above, Xenon transients will occur. This can result in the formation of flux tilts. As discussed in the preceding module, flux tilts can cause bundle overheating and/or bundle overpowering. With the addition of the positive reactivity of a new fuel bundle, the previously mentioned problems are compounded, and hence, must be avoided.

Obj. 17.1 h) ⇔

8) All factors being equal, in practice the channels with low **zone levels** should be fuelled first. Fuelling zones with high levels can possibly cause flooded zones, and therefore, ineffective flux tilt control. Liquid zone levels must be kept within their correct operating range.

The fuelling list provides for more channels to be fuelled than scheduled. Hence, the operator is allowed some choice in the selection of the fuel channels for items 4 through 8 on the list above (with the approval of their Shift Supervisor).

Preferred Operating State During Refuelling

Obj. 17.2 a) ⇔

The preferred state during refuelling operations is with the **reactor critical and operating**. The reasons are that:

Obj. 17.2 b) ⇔

a) **RRS is functional** with the reactor critical. It can **detect, and immediately compensate for changes in reactivity** to limit possible overpower transients. When the reactor is subcritical, the reactivity insertions are not observable. This could cause the reactor to go critical earlier than expected, when a reactor restart is initiated.

b) Additionally, if fuelling is performed while the unit is shut down, there may be **no indications of flow blockage.**

c) Zirconium under irradiation becomes brittle, and is even more **brittle when cold.** This increases the chances of fuel damage due to handling.

However, we should remember that performing on-power fuelling does present some operational concerns such as:

1) Opening the HT system pressure boundary (potential for a LOCA).
2) Insertion of a foreign object in the channel (possible flow blockage causing fuel overheating).
3) Local flux distortions (place demands on RRS).

The **Station Manager** must approve fuelling of the reactor in any state other than the preferred state.

⇔ ***Obj. 17.2 c)***

SUMMARY OF THE KEY CONCEPTS

- Considerations used to select channels for fuelling are:
  - Channel abnormal conditions, to ensure that the fuelling process can safely take place;
  - Defective fuel in the core must be removed to prevent releases to the HTS;
  - Proximity to recently fuelled channels, to ensure that bundle overpowering and overheating does not occur;
  - Abnormal operating conditions, to ensure that bundle overpowering and overheating does not occur due to the influence of Xe transients;
  - Channel burn-up, to ensure channels are not underpowered;
  - Power distribution, to ensure that zone reactivity balance is maintained;
  - Reactivity gain, to ensure the reactor can remain critical
  - Liquid zone levels, to ensure that liquid zones remain within their control range.
- The preferred state for fuelling the reactor is with the reactor critical and the unit operating. This allows RRS to detect and compensate for changes in reactivity. While shut down, flow blockage detection may also be unavailable. Also, zirconium is brittle when cold, which makes fuel damage due to handling more likely.
- The Station Manager must authorize fuelling in any other state than the preferred state.

Channel Blockages

One of the concerns while fuelling is channel blockage. The chances of a channel blockage during refuelling are increased due to the insertion of fuel, rams etc. into the channel. If a blockage occurs, coolant circulation is reduced, with the potential for fuel overheating. This could result in fuel damage and release of fission products to the HTS.

Obj. 17.3 ⇔

A flow blockage in a channel can be determined in a number of ways:

1) If the channel being fuelled is a **fully instrumented channel, direct flow indication** is available. A flow blockage would be directly seen as a reduction of flow. As very few channels are fully instrumented, (no fully instrumented channels are installed in some CANDU units) other methods of flow blockage detection are required for the other channels.

2) The **channel outlet temperature** is measured for each outlet feeder pipe. This is performed with RTDs (Resistance Temperature Detectors). During fuelling, many changes in channel flow and temperature will occur. Some of these changes occur due to shield plug removal, fuel carrier and ram insertion into the channel and fuelling machine cooling effects and flows. If channel outlet temperature rises more than expected * (as compared to a routine fuelling operation), it is likely that a coolant flow reduction has occurred.

   * This may also be indicated by various temperature alarms, which will be covered in your station specific training.

   Of course, this method is only valid for non boiling channels, since channel outlet temperature will not increase above saturation temperature corresponding to HTS pressure. (One note to make here is that for some CANDU units with boiling channels, cool D_2O is injected by the fuelling machine to take a boiling channel out of boiling while being fuelled. This allows the channel ΔT to be used for flow blockage detection during fuelling.)

3) For channels in boiling, a method of determining if a flow blockage has occurred is by monitoring **ΔP across the channel** (measured on the fuelling machines). The measurement of coolant ΔP across the channel will correspond to a certain coolant flow. If the ΔP changes dramatically, a flow blockage has likely occurred. The change in ΔP will indicate the location of the blockage.

   - For example, if the ΔP across the channel **decreases** dramatically, a flow **blockage** has likely occurred in the inlet or outlet **feeder**. Say there is a 95% flow blockage in the channel inlet feeder. The reduced flow will reduce frictional losses in the channel and feeders. The pressure at the channel outlet will be very close to the outlet header pressure. The pressure at the channel inlet will not be as influenced by the inlet header due to the blockage, hence channel inlet pressure will also approach the pressure at the channel outlet. As you can see, the ΔP across the channel has decreased (ie. ΔP will approach zero as flow reduces (caused by a feeder blockage)). Similarly, a channel outlet feeder blockage will cause pressures to approach the channel inlet pressures, and have a similar decrease in channel ΔP.

- For example, if the ΔP across the channel **increases** dramatically, a flow **blockage** has likely occurred **in the channel**. Say there is a 95% flow blockage in the channel. The reduced flow will reduce frictional losses in the channel and feeders. The pressure at the channel outlet will be very close to the outlet header pressure. The pressure at the channel inlet will be very close to the pressure of the inlet header. As you can see, the ΔP across the channel has increased (ie. ΔP will approach the inlet to outlet header ΔP as flow reduces (caused by a channel blockage)).

Detection of a flow blockage on each channel during operation is not practical, since blockages during operations, other than fuelling, are unlikely. Detection is especially difficult if the channel is a boiling channel, in which a blockage would not increase the channel's outlet temperature. In this situation a blockage would be detected by a flow verification procedure. In this procedure, the reactor output is periodically reduced, reducing the channel outlet temperatures below the saturation temperature. At that point of the procedure, the channel outlet temperatures will be checked that they are reading correctly and that they respond to the changes in reactor power. If no changes are occurring, or the temperature remains at saturation temperature, a flow blockage may be suspected. Corrective actions will be required (eg. verify channel conditions with fuelling machines, attempt to clear a blockage, reduce power further, shutdown, etc.).

Handling Irradiated Fuel

Irradiated fuel discharged from the reactor continues to produce significant amounts of heat. A fuel bundle produces a few kW **decay heat** for several hours following discharge. For example, a typical irradiated fuel bundle produces about 10 kW of heat 1 hour after discharge. Natural air cooling can remove only 1 kW of this heat*. If the decay heat is not removed, the sheath will deteriorate due to high temperature oxidation.

* without causing bundle overheating.

An irradiated fuel bundle is **extremely radioactive**. For example, the dose rate 1 metre from a typical bundle in air is ~100 000 rem/hr after 1 day following discharge. A 20 second exposure at 1 metre would result in a dose of 600 rem, which is for all practical purposes, <u>lethal</u>. Obviously, protection against such high doses is also necessary.

⇔ *Obj. 17.4 a)*

For these two reasons, the irradiated fuel shall be **adequately cooled and shielded at all times**. Therefore, adequate cooling and shielding are provided during the residence time of the fuel bundles, both within the fuelling machine (F/M) and during the transfer process to the irradiated fuel bay.

At some point in the fuel handling process, while transferring the fuel from the fuelling machine to the irradiated fuel bay, the fuel bundle may be exposed to air. However, this happens for a short while only (minutes at the most) and will not result in a fuel failure if cooling is resumed.

As mentioned earlier, another concern about irradiated fuel is that the sheath **becomes brittle** with irradiation and is particularly brittle when cold. **Special care** should be exercised in handling irradiated fuel throughout the fuelling process.

Handling Failed Fuel

Obj. 17.4 b) ⇔

Particular problems are encountered when handling failed fuel bundles due to the potential for **spread of contamination**.

Fuel bundles can fail while in the core, or during the fuel handling process. The detection and location of failed fuel has been described in the Module 16.

As mentioned above, at some point in the irradiated fuel handling process, the fuel bundles may be exposed to air. At this point, airborne particulates and iodine samples are taken to determine the presence of failed fuel. When airborne sample fields increase a couple of times over their normal values, failed fuel is suspected. (Note, this can be used to identify a failed bundle or at least narrow the failures down to a pair of bundles. Monitoring during the defuelling process could also be used to attempt to identify the failed fuel bundle(s).)

In most stations, the failed fuel is processed normally and sent to the Irradiated Fuel Bay (IFB). In some stations the defective fuel is left in the fuelling machine while it still clamped onto the reactor. This allows the HTS purification circuit to remove a large portion of the escaping fission products.

In the IFB, the failed bundle will be identified/examined and can be **stored in specially designed failed fuel cans**, or, for small defects, can be stored with the rest of the irradiated fuel.

Monitoring the Irradiated Fuel Bay

The irradiated fuel is extremely radioactive and hot. Both the radioactivity and heat are caused mostly by the decay of fission products.

The **radioactivity** of irradiated fuel bundles is mainly γ. There is a lot of α activity (from the products of the U_{238} decay) and β activity (from the decay of fission products) in the bundles, but both particles are short range and absorbed within the bundles. As mentioned previously the γ from a fuel bundle after 1 day will be ~100,000 rem/hr at 1 metre. Even after longer periods, these γ fields can be very high (1,000 rem/hr @ 1 metre after 1 month, 10 rem/hr @ 1 metre after 1 year).

The decay heat is also quite significant. Remember that a typical fuel bundle produces about 10 kW of **decay heat** 1 hour after discharge. Even after 2 weeks, the decay heat production will be approximately 1 kW. This heat input for the IFB could be very high when the reactor has to be completely defuelled as in the case of an accident. (Note that long term cooling requirements are not as demanding, as decay heat from a bundle after 1 year will be ~1Watt.)

It is clear then that the IFB should provide **adequate shielding and cooling at all times**. The IFB is filled with demineralized water because demineralized water does not contain suspended or dissolved impurities. This minimizes corrosion of the fuel and IFB systems and keeps the IFB clear to allow for the inspection and handling of the fuel. The demineralized water in the IFB provides the following:

- Shielding against radiation
- Cooling medium to remove decay heat;
- Purification circulation.

Shielding against gamma radiation is best provided by heavy elements like lead. However, the same amount of shielding can be provided by sufficient thickness of lighter elements. Therefore, a few meters of water act as a very efficient shield*.

The IFB cooling system should be able to remove all the decay heat from all the fuel bundles stored. This IFB cooling circuit is composed of circulation pumps, HXs, inlet and outlet headers. Sufficient redundancy is provided for reliability purposes.

⇔ ***Obj. 17.5 a)***

The following parameters are monitored for the IFB water:

a) To maintain water **purity**, a small portion of the total inventory is passed through the purification circuit. The role of the purification circuit is to remove suspended solids, to reduce dissolved solids, and to remove corrosion products (including contaminants brought into the IFB on the transferred bundles). These substances can foul the components of the circuit. The purification circuit also serves to remove the excess water in the IFB and route it to the active liquid waste system. The circuit consists of skimmers, pump(s), filters, and IXs.

The conductivity and turbidity * in the IFB are monitored to ensure that the concentration of impurities are acceptably low. When these parameters exceed their upper limits, filters and IX resins shall be replaced.

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* Equivalent shielding is provided by 8mm of lead or 98mm of water for a γ energy of 1Mev. These thicknesses will reduce fields in half.

* These parameters are discussed in more detail in the Chemistry 224 course.

b) The **temperature** of the IFB shall be monitored and maintained within limits, typically around 30°C. If the IFB water exceeds the limits, the IFB walls can be damaged (in some stations an epoxy liner is used, which can be damaged by high temperature and rate of temperature change). The temperature control is automatically performed by throttling the LPSW valves on the secondary side of IFB HXs.

c) The water in the IFB shall be maintained at a **level** high enough to provide adequate shielding. If the water level is too low, the shielding will not be sufficient. If the water level is too high, it causes diversion (at the IX column outlet) of cleaned water to the active liquid waste system. Therefore, the water level should be monitored and controlled. Level control is achieved with an upper and lower level switch. If the level is too low, the make-up demineralized water valves open more. If the level is too high, the IX effluent valves open more.

d) The **flow** of IFB water through the cooling and purification circuits is monitored and controlled to ensure that cooling and purification requirements can be met.

Obj. 17.5 b) ⇔

The IFB room is provided with a ventilation and filtration system to remove radioactive particulates and exhaust the gases. The failed fuel in the IFB will release fission products which can contaminate the IFB. Gas bubbles rising to the surface of the water indicate the release of gaseous fission products, and therefore, the **presence of radioactive gases in the IFB is monitored** (the IFB has area γ monitors, as well as monitoring the exhaust for gross activity). Hydrazine can be added to suppress the release of gaseous fission products from the IFB water surface. This gives the IFB purification system more time to remove them since hydrazine will combine with radioiodines and form chemical products which are less volatile and more soluble in IFB water.

SUMMARY OF THE KEY CONCEPTS

- Flow blockages can be detected by fully instrumented channel flow indications, channel outlet temperatures for non-boiling channels and ΔP measurements for boiling channels.
- Irradiated fuel requires shielding and cooling at all times. Care must be given to physical handling of the fuel because the sheath has become brittle.
- In most cases, defect fuel will be placed in specially designed canisters for storage to minimize the spread of contamination.
- IFB water is monitored for temperature, flow, level and purity.

- The IFB atmosphere is monitored for radioactive gases. These gases indicate the presence of failed fuel.

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

⇔ ***Page 13***

ASSIGNMENT

1. Explain why the following factors are used to determine if a pre-selected channel can be fuelled.

   a) Channel abnormal conditions, ____________________________

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   b) Defective fuel in core, ____________________________

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   c) Proximity to recently refuelled channels, ______________

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   d) Abnormal operating conditions, ______________________

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   e) Channel burn-up, ____________________________

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f) Power distribution, ____________________

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g) Reactivity Gain, ____________________

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h) Liquid zone levels, ____________________

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2. a) The preferred state for refuelling is ____________.
This state is chosen because:

i) ____________________

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ii) ____________________

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b) The ______________ must approve fuelling in any other state.

3. Explain how flow blockages during fuelling can be detected by the following methods:

a) Channel ΔT: ____________________

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b) In fully instrumented channels in the reactor: ____________

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c) Channel ΔP: ________________________________

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4. a) Irradiated fuel must be ____________________ and ______________________ at all times. Also, care must be taken when physically handling irradiated fuel (via fuel handling equipment) because ____________________

____.

b) Failed fuel must be placed in ______________ to minimize the spread of ____________________.

5. Four parameters monitored for IFB water are:

a) ________________. This parameter is monitored because

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b) ________________. This parameter is monitored because

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c) ________________. This parameter is monitored because

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d) ________________. This parameter is monitored because

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6. The IFB atmosphere is monitored for ________________________.

   This parameter is monitored because ________________________

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

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