Module 12

EMERGENCY COOLANT INJECTION

OBJECTIVES:

After completing this module you will be able to:

12.1 State the purpose of the Emergency Coolant Injection System (ECIS). *⇔ Page 2*

12.2 State what is meant by a Loss of Coolant Accident (LOCA). *⇔ Page 3*

12.3 a) State the key parameter that will cause a reactor trip for: *⇔ Page 3*

i) A large LOCA,

ii) A small LOCA.

b) State the parameters that must be satisfied before ECI will be initiated. *⇔ Page 4*

12.4 State the other safety system (beside SDSs or ECIS) which may be activated following a LOCA. *⇔ Page 4*

12.5 State, in the order in which they occur, the three operational phases of the ECIS and explain their purpose. *⇔ Pages 5-7*

12.6 Explain three reasons why ECIS initiates a crash cooldown. *⇔ Page 5*

12.7 Explain two reasons for continued HT pump operation for as long as possible following a LOCA. *⇔ Pages 5-6*

12.8 Describe the sequence of operation of the following major components and their function in the operation of ECIS: *⇔ Pages 8-9*

a) ECI water storage tank,

b) Accumulator tank or injection pump(s),

c) Injection valves,

d) Recovery sump,

e) Recovery pumps,

f) Recovery heat exchangers.

NOTES & REFERENCES

Page 10 ⇔ 12.9 List three features incorporated in a typical ECIS to increase its reliability.

12.10 State what is meant by the terms:

Page 10 ⇔ a) Poised,

Page 10 ⇔ b) Blocked,

Page 11 ⇔ c) Recallable.

Page 10 ⇔ 12.11 State the two major consequences or concerns associated with a failure to block ECIS before depressurization of the heat transport system.

Page 11 ⇔ 12.12 List the required reactor state when the ECIS is blocked.

Page 11 ⇔ 12.13 State two reasons why ECI can be initiated manually.

* * *

INSTRUCTIONAL TEXT

INTRODUCTION

This module will cover the purpose of the ECIS system, its initiation and operation. A typical system is shown in Figure 12.1, which is at the end of the module. This figure can be unfolded and kept in sight for your reference.

PURPOSE OF THE ECIS

The Emergency Coolant Injection System (ECIS) is an integral part of the "Defence in Depth" philosophy which governs the operation of CANDU reactors. Recall that this philosophy considers the presence of five separate barriers designed to minimize the release of fission products to the environment. These are:

- Ceramic Fuel,
- Fuel Sheath,
- Pressure Tube,
- Containment,
- Exclusion Zone.

Obj. 12.1 ⇔ The ECI system is poised with the unit in a normal operational state. It will automatically operate to cool the heat transport system in the event of a loss of coolant accident. A flow of light water is injected to refill the HT system; re-wet the fuel and **provide a heat sink** for any residual and decay heat.

Note for large breaks, the coolant discharged from the break will be sufficient to carry heat from the fuel (although the boilers are still the primary heat sink). In the case of smaller breaks, where the discharge of coolant is not sufficient to cool the fuel, alternate methods of heat removal must be used (eg. in the boilers by maintaining coolant circulation as long as possible *).

* This is discussed in more detail on page 5 of this module.

The amount of fission products released from the fuel after a LOCA will depend on the size of the LOCA and how well ECIS has performed. When ECIS is fully functional and copes with a LOCA, a large number of fuel failures is not expected *.

* This assumes that the SDSs quickly reduce reactor power to decay levels.

If for any reason the automatic operation of ECIS fails, the operator can intervene at any point in the sequence of operations and manually initiate ECI.

LOSS OF COOLANT ACCIDENT (LOCA)

⇔ *Obj. 12.2*

A **LOCA** is defined as a leak of D_2O from the HT system causing sustained low HT pressure. This would mean that normal HT pressure cannot be maintained or pressure recovery to normal levels is not anticipated within a defined time, usually five to ten minutes.

Examples of a loss of coolant (LOCA) from the HT system could be:

- A header break.
- A pressure tube or feeder break.
- Failure of an ice plug while the system is open for maintenance during a shutdown.

The operator can detect a LOCA during a shutdown by a loss of HT inventory.

Support System Requirements

⇔ *Obj. 12.3 a)*

Effective operation of the ECIS must follow operation of either or both Shutdown Systems (SDSs). On **large LOCAs**, the leak will cause the HT pressure to fall, which will cause the coolant in the HTS to flash to steam (voiding). The void coefficient results in a large positive reactivity increase and a rapid rise in reactor power. The reactor regulating system tries to control this power increase, but is not designed to handle such rapid insertions of positive reactivity. Consequently, there will be an automatic shutdown of the reactor by SDS1 and/or SDS2 initiated by a log rate and/or high neutron power trip.

For **smaller LOCAs**, eg. rupture of a small feeder or instrument line, the loss of HT inventory will be slow enough that the regulating system can cope with the resultant power increases.

Under these conditions, the reactor trip will be initiated by non-neutronic trips, such as low HT pressure or low pressurizer level.

Obj. 12.4 ⇔

For the larger LOCAs, the resultant rise in reactor vault pressure due to the escaping coolant flashing to steam will almost certainly cause features of the **containment system** to come into operation. This action further reduces the risk of large quantities of radioactive fission products being released to the environment. This issue will be discussed further in the module on containment.

ECI System Initiation

Obj. 12.3 b) ⇔

The ECI system will automatically operate when a majority vote (2 out of 3, or 3 out of 4 channels, depending on the station) is received on the **primary <u>and</u> at least one conditioning parameter** (which are also channelized). For all CANDU stations, the primary parameter is **low HT system pressure**. The pressure, (typically ~5 MPa), is well below the HT pressure that would cause a reactor trip (typically 7 to 8 MPa).

The conditioning parameter distinguishes the event as a LOCA, as opposed to a process failure. For example, low HT pressure can be caused by a loss of HT feed, but low HT pressure in conjunction with rising vault pressure could indicate that a loss of coolant is occuring to the vault.

The conditioning parameters in use vary with the station, but may include high vault temperature or high vault/boiler room pressure, high moderator level (for LOCA into the moderator), sustained low HT pressure and low HT flow.

SUMMARY OF THE KEY CONCEPTS

- The purpose of the ECI system is to provide a heat sink to the fuel in the event of a LOCA to protect the first two barriers to fission product release.
- A loss of coolant accident (LOCA) is defined as a leak of D_2O from the HTS causing sustained low pressure.
- SDS trip parameters for large LOCA's are neutronic trips. SDS trip parameters for small LOCA's are low HT pressure or low pressurizer level.
- Containment system actions will be required for a LOCAs into containment.
- The major ECI initiating parameter for a LOCA will be low HTS pressure combined with at least one conditioning parameter. Typical conditioning parameters are high reactor vault temperatures and pressures, boiler room high pressure, high moderator level, low HT flow and sustained low HT pressure.

ECI SYSTEM PHASES

There are three principal operational phases: ⇔ *Obj. 12.5*

a) **Blowdown,**
b) **Injection,**
c) **Recovery.**

Blowdown

Once the reactor has tripped, the primary requirement is to provide an alternate source of cooling water to the fuel (now approaching decay heat levels) as quickly as possible. ECIS injection can only commence when the HT system pressure has fallen to the ECIS injection setpoint. This **depressurizing period** is typically referred to as **blowdown.** Initially, a HT pressure reduction occurs due to the leak and due to the shrinkage of D_2O after a reactor trip. The rate of depressurization will then slow down as the pressure in the HTS reaches the saturation pressure associated with the HTS temperature. At this pressure, the coolant flashes to steam to prevent total collapse of HTS pressure. The time taken for this to occur is largely dependent upon the size of the LOCA, hence, blowdown times can vary greatly.

⇔ *Obj. 12.6*

Once the HTS reaches ECIS initiation pressure, a crash cooldown of the boilers is initiated. All boiler safety valves (or large steam reject valves, in some stations) are opened to reduce boiler pressure (hence boiler temperature) causing HTS shrinkage. This **further lowering of HTS pressure** will allow the colder ECI **water to enter the reactor** and will also **reduce** the **leakage rate** of inventory from the HT system. This effectively **removes the boilers as a heat source,** which could maintain HT pressure and temperature, hence slowing the depressurization. (Once the cold ECI water is injected into the HTS, its main purpose is to cool the fuel. If cold water is injected without crash cooling, the hot feedwater in the boilers will transfer heat to the injected water and the HTS). This is especially useful for small LOCAs, when the depressurization of the HTS can be slow. This allows cold ECIS water to be injected sooner.

⇔ *Obj. 12.7*

Circulation through the HT system is maintained by the **main HT pumps** for as long as possible. A higher flow rate of coolant from the core to the boilers is achieved with these pumps running. This results in a **higher rate of heat removal** from the heat transport system and hence, a faster depressurization to injection pressure. Forced circulation also **mixes liquid and vapour** (retarding vapour pocket formation) which aids in keeping the fuel wet, thus minimizing fuel failures. The pumping of two phase flow and/or pump cavitation due to low suction pressure will cause severe vibrations in the HT circulation pumps. To prevent further loss of inventory due to pump seal damage, the pumps may have to be tripped (in some stations the failure of pump seals will cause a breach of containment). As mentioned for thermosyphoning, the inertia of the main HTS pump motors or flywheels will continue circulating the coolant for some time after the pumps are tripped (but may be opposed by ECIS injection).

In some stations, low speed drives are installed on main HT pumps, which continue circulation of the coolant to maintain fuel cooling (these low speed drives will allow the pump to operate without cavitation). This is especially useful for small breaks, where the discharge of the coolant from the break is not sufficient to carry heat from the fuel (as mentioned earlier in this module).

Injection

At the ECIS injection pressure, **injection of water** into the system commences to restore coolant inventory. This is referred to as the **injection phase**. Light water injection from one or more storage tank (s) continues until the inventory from the tank(s) has been depleted. The injection phase can vary in duration, depending on the break size and the water inventory available.

High pressure injection is accomplished by one of two methods. Some stations use high pressure pumps to inject the light water coolant to the core. The other stations use a pressurized gas (N_2) to drive the injection water into the core.

At some stations, a grade elevation water tank and/or an elevated emergency water storage tank (part of the dousing tank reserved for injection) exists to supplement the inventory of water available for injection. Once the high pressure injection phase is over, **low pressure pumped injection** begins from these tanks. This extra water is particularly useful in bridging the period between the high pressure injection and the recovery phase.

Typical high pressure ECIS injection pressures range between 4.2 and 5.5 MPa depending on the station and delivery method used.

This range of injection pressures is chosen for three main reasons:

a) The extra system cost needed to provide equivalent flow at higher pressure (particularly for a pump system) is not warranted.

b) To reduce the amount of time and number of occasions that the ECIS must be blocked when operating at reduced HT pressures.

c) To reduce water hammer effects.

Point (b) is important since one of the logic decisions required for injection is to determine if the HT pressure is less than ECIS injection pressure.

The system size and injection pressure is optimized to provide adequate injection flow and pressure before the HT inventory has been depleted. This prevents fuel failures that may occur during blowdown.

Recovery

The light and heavy water mixture which has discharged from the break as a result of the HT system blowdown and ECIS injection is **collected in the ECI recovery sumps** in the containment floor. It is then **cooled** in heat exchangers and **re-injected** into the HT system by recovery pumps (or in some stations, to the suction of the HP injection pumps). This is referred to as the **recovery phase** (or post accident water cooling, in some stations). In most stations this is accomplished by a dedicated recovery system. This maintains adequate cooling in the HT system and provides a long-term heat sink for the reactor to prevent fuel failures (due to overheating from decay heat).

The heat removal mechanism from decay heat levels is shown in Figure 12.2.

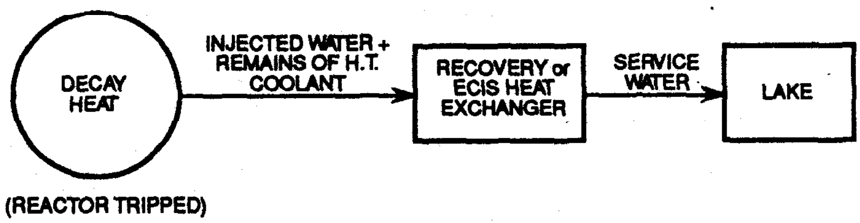

Figure 12.2 : ECIS Heat Removal Chain

The quantity of water injected during the HP and LP injection phases must be sufficient to accommodate water lost due to holdup in the recovery flow path. It must also provide sufficient recovery pump suction head to prevent cavitation and possible vapour locking of the recovery pumps. Water recovered from the recovery sumps must be screened and filtered to prevent debris from blocking the pump inlets and thereby impairing the recovery phase. For this reason, housekeeping inside the reactor vaults is very important.

The recovery pumps do not require the higher pressure (and flow) delivery capability of the injection phase since the HT system is operating at reduced pressure. Also, the decay heat produced by the reactor is substantially reduced in the long term. The recovery system is therefore sized accordingly, for long-term performance with reduced flow and pressure requirements.

The duration of the recovery phase can be up to three months. For this reason, it is important that there is a secure electrical supply to the recovery pumps, ie. hence Class III power is used.

SUMMARY OF THE KEY CONCEPTS

- The blowdown phase of ECI is the phase that allows the HTS to depressurize to ECI injection pressure.
- The injection phase is the period where injection of stored water takes place.
- The recovery phase is the period that the water recovered from the LOCA is cooled and re-injected (via pumps) into the reactor to maintain long term fuel cooling.
- ECI initiates a crash cooldown to remove the boilers as a heat source. This could prevent depressurization of the HTS.
- The crash cooldown lowers the HTS pressure by causing HTS shrinkage. This reduces the leakage rate from the HTS. This also ensures pressure reduces to allow injection of cold water into the HTS for fuel cooling.
- HTS coolant circulation is maintained as long as possible to maximize coolant circulation for fuel cooling. This results in a higher rate of heat transfer to the boilers and ensures that depressurization to ECI injection pressure will occur as fast as possible. The flow of coolant also mixes liquids and vapours to prevent vapour pocket formation, hence keeping fuel wet.

ECIS System Operation

Obj. 12.8 ⇔

Note that the ECI system in your station may vary from the system(s) desccribed below. The intent is to generically describe the actions of a typical ECI system. Any differences will be discussed in your station specific training.

Once the ECI initiation pressure is reached and at least one conditioning parameter is satisfied, the following major actions occur simultaneously:

- Crash cooldown, which was discussed earlier in the module,
- Preparation for HP injection (and LP pumped injection),
- Preparation for the recovery phase of system operation.

For systems using gas accumulators, fast acting valves open to allow the pressurized gas in the accumulators to pressurize the water held in the accumulator water storage tanks. The unit H_2O and D_2O injection valves will open (in the affected unit only, in a multi-unit station) to allow injection flow to commence. ECIS valve sequence and operation are designed to minimize the effects of water hammer, which could be caused by the rapid injection of the water (ie. valves open slowly, system is vented to remove air gaps, etc). Injection will continue until a low level in the accumulator water storage tank is reached. The isolation valves will then close to prevent gas ingress into the HT system. The recovery pumps are also started when ECI is initiated, in preparation for the recovery flow.

For systems using high pressure water pumps, water in the ECI storage tank(s) feed the suction of these pumps. These pumps are started when ECI is initiated (or when conditioning parameter is satisfied, depending on the station), in preparation for the injection flow. The recovery pumps are also started and will recirculate injection water (depending on the station, they may feed the high pressure injection pumps, this arrangement is not shown in Figure 12.1). The unit H_2O and D_2O injection valves will open (in the affected unit only, in a multi-unit station) to allow injection flow to commence (water hammer preventive measures are as mentioned above). Injection will continue until a low level in the water storage tank is reached (or in some stations, a preset time limit is exceeded). The isolation valves close to prevent air ingress into the pumps and ECI system.

In some stations, after the initial high pressure injection is completed, additional water is provided by a grade level storage tank or an emergency water storage tank. The valves from the tank will open and this water is then pumped by the recovery pumps into the reactor core. This continues until a preset low level in the tank is reached or a preset high level in the recovery sump is reached (which ensures adequate water is available for the recovery phase). The storage tank isolation valves will then close.

Once the above injections are completed, the recovery phase (post-accident water cooling) begins. Water that has spilled from the reactor has been collected in the recovery sump. The recovery sump isolation valves will then open and the recovery flow will start. Water will be pumped from the recovery sump to the recovery heat exchangers. Then the water is returned to the reactor core for fuel cooling. In the recovery heat exchangers, the reactor decay heat is transferred to cooling water.

SUMMARY OF THE KEY CONCEPTS

- For systems using gas accumulators, fast acting valves open to allow the pressurized gas in the accumulators to pressurize the water held in the accumulator water storage tanks. For systems using high pressure water pumps, valves open to allow the water in the ECI storage tank(s) to feed the suction of these pumps. The pumps are started in preparation for the injection flow.
- The unit H_2O and D_2O injection valves will open (in the affected unit only, in a multi-unit station) to allow injection flow to commence.
- In some stations, after the initial high pressure injection is completed, additional water is provided by other storage tanks. This water is pumped by the recovery pumps into the reactor core.
- Once the above injections are completed, the recovery phase (post accident water cooling) begins. Water that has spilled from the reactor has been collected in the recovery sump. The recovery sump isolation valves will open and the recovery flow will start . Water will be taken from the recovery sump, pumped to the recovery heat exchangers and then the water is returned to the reactor core for fuel cooling. The recovery heat exchangers will remove the decay heat from the coolant.

Emergency Coolant Injection System Reliability

Obj. 12.9 ⇔

Like the two shutdown systems, high reliability is maintained independence, redundance and selection of high quality components for construction and maintenance of the system *.

* More details were provided in Module 11.

Emergency Coolant Injection System States

Let us consider the following states of "readiness" in which the ECIS can exist:

Obj. 12.10 a) ⇔

a) **Poised**

While poised, the system is available to operate automatically when the initiating parameter setpoints are reached on the correct number of channels. No operator action is required.

Obj. 12.10 b) ⇔

b) **Blocked**

Obj. 12.11 ⇔

When blocked, the system will not operate automatically. When the heat transport main system is being depressurized, automatic injection is prevented by a blocking handswitch, which overrides the automatic opening of the injection control valve(s). This prevents an initiation when heat transport pressure drops below ECI injection pressure. The result of injection would be addition of H_2O and **down-**

grading of the HT heavy water which would result in a considerable **economic penalty**.

However, blocking of ECIS is only **permissible** once heat transport temperature is below a specified value (typically <90°C) or when HT pressure is at or below injection pressure (this must be performed before ECI conditioning parameters are satisfied). A blocked system needs only simple control room action to return it to the poised state.

⇔ *Obj. 12.12*

When the heat transport system is depressurized for maintenance and ECI is blocked, ECI can be **manually initiated** in the event of a LOCA. Recall also from page 3 that if for any reason the automatic operation of ECIS fails, the operator can manually initiate ECI.

⇔ *Obj. 12.13*

c) **Recallable**

⇔ *Obj. 12.10 c)*

The system will not operate automatically or manually.

The ECI system can only be made recallable with the unit(s) in a specified shutdown and cooldown state. It must always be possible to restore it to service within a predefined time which depends upon the status of the unit, and is specified in your station operating manual.

SUMMARY OF THE KEY CONCEPTS

- The reliability of the ECI system is increased by the use of:
  - Redundant components,
  - Quality components,
  - Independence.
- The term "poised" refers to the state when ECI is ready to operate automatically, in the event of a LOCA.
- The term "blocked" refers to the prevention of the system from operating automatically as designed. In this state the system can be returned to service (ie. poised) by simple control room action.
- The ECI system can also be fired manually in case:
  - A LOCA occurs while depressurized for maintenance (ie. while blocked).
  - Automatic actions do not occur as designed (ie. while poised).
- The term "recallable" refers to a state when the system cannot be activated manually or automatically. While in this state, the system must be able to be returned to service within a predetermined time limit.

- The HTS must be below a certain temperature (typically 90°C) before the ECI system can be blocked.
- If the HTS is depressurized before the ECI system is blocked, ECI will operate as designed when conditioning parameters are met. This would downgrade the HTS, resulting in a severe economic penalty.

Page 13 ⇔

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

ASSIGNMENT

1. The purpose of the Emergency Coolant Injection System is to___

   ____

   ____

   ____

   ____

2. A Loss of Coolant Accident (LOCA) is defined as __________

   ____

   ____

   ____

3. The typical shutdown system trip parameters which occur prior to ECI:

   a) For a large LOCA are _________________________,

   ____

   ____

   b) For a small LOCA are _________________________,

   ____

   ____

4. The primary ECI initiating parameter for a LOCA is __________

   ______________________________. Three examples of conditioning parameters are:

   a) ______________________________________

   b) ______________________________________

   c) ______________________________________

5. The other special safety system (besides SDS1, SDS2 and ECIS) that may be activated following a large LOCA is __________

   ____.

6. The three operational phases of ECIS are:

   a) ____________________. The purpose of this phase is ____

   b) ____________________. The purpose of this phase is ____

   c) ____________________. The purpose of this phase is ____

7. Two reasons that the HT pumped circulation is maintained as long as possible are:

   a) ____

   b) ____

8. Three reasons why ECIS initiates a crash cooldown are:

   a) ____

   b) ____

   c) ____

9. a) Describe the functions of the following major components:

   i) ECI water storage tank, ______________________

   ____

   ____

   ii) Accumulator tank or injection pump(s), ______________________

   ____

   ____

   iii) Injection valves, ______________________

   ____

   ____

   iv) Recovery sump, ______________________

   ____

   ____

   v) Recovery pumps, ______________________

   ____

   ____

   vi) Recovery heat exchangers, ______________________

   ____

   ____

   b) Describe the sequence of operation of the following major components:

   i) ECI water storage tank,
   ii) Accumulator tank or injection pump(s),
   iii) Injection valves,
   iv) Recovery sump,
   v) Recovery pumps,
   vi) Recovery heat exchangers.

   ____

   ____

   ____

____

10. Three features typically incorporated to enhance ECIS availability are:

    i) ____

    ii) ____

    iii) ____

11. The availability the ECIS must have when the unit is in the "at power" state is ______________________________.

12. a) When ECI is poised it means ____________________________________

b) When ECI is blocked it means ______________________

____

____

c) When ECI is recallable it means ____________________

____

____

13. The ECIS can be blocked only when the HT system is__________

____.

14. The heat transport system is about to be depressurized. The action required before the HTS reaches ECI initiation pressure is

____.

Failure to do this will result in ______________________

____

____.

15. The ECI system can be actuated manually to protect against:

a) ____

____

b) ____

____

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

Prepared by: D. Tennant, N. Ritter, WNTD

Revised by: P. Bird, WNTD

Revision date: June, 1992