Reactor, Boiler & Auxiliaries - Course 233

EMERGENCY COOLANT INJECTION SYSTEM*

1. Purpose of System

The ECI System is one of the special safety systems of the reactor. These special safety systems comprise:

(a) Shutdown System #1,
(b) Shutdown System #2,
(c) Emergency Coolant Injection System,
(d) Containment System.

The overall purpose of these safety systems is to minimize the chance of release of fission products to the environment.

The specific purpose of the ECI system is to remove decay heat from the fuel following a LOCA, after the reactor has shut down. Shutting down of the reactor on a LOCA, rapidly removes most (∿93%) of the heat production inside the fuel, but the remaining fission product decay heat still requires cooling to prevent fuel failure and, eventually, pressure tube failure. Rupture of the fuel sheath would then lead to release of fission products within containment, as the heat transport pressure boundary has failed. Hence failure of the ECI system to operate would leave the containment as the last remaining barrier against environmental release.

2. ECI System Operation

The various phases of operation of the ECI system during a LOCA will now be discussed. The discussion is sufficiently general to be applicable to all plants.

Three basic operational phases exist:

- blowdown of heat transport D_2O,
- initial injection of ECI water onto the fuel,
- recovery and recirculation of ECI water.

These are illustrated in Figure 1, and discussed below. A discussion of the Pickering and Bruce ECI designs to illustrate the principles of these phases is given later.

*Depending upon the station, it is also called the Emergency Injection System (EIS) or the Emergency Core Cooling System (ECCS).

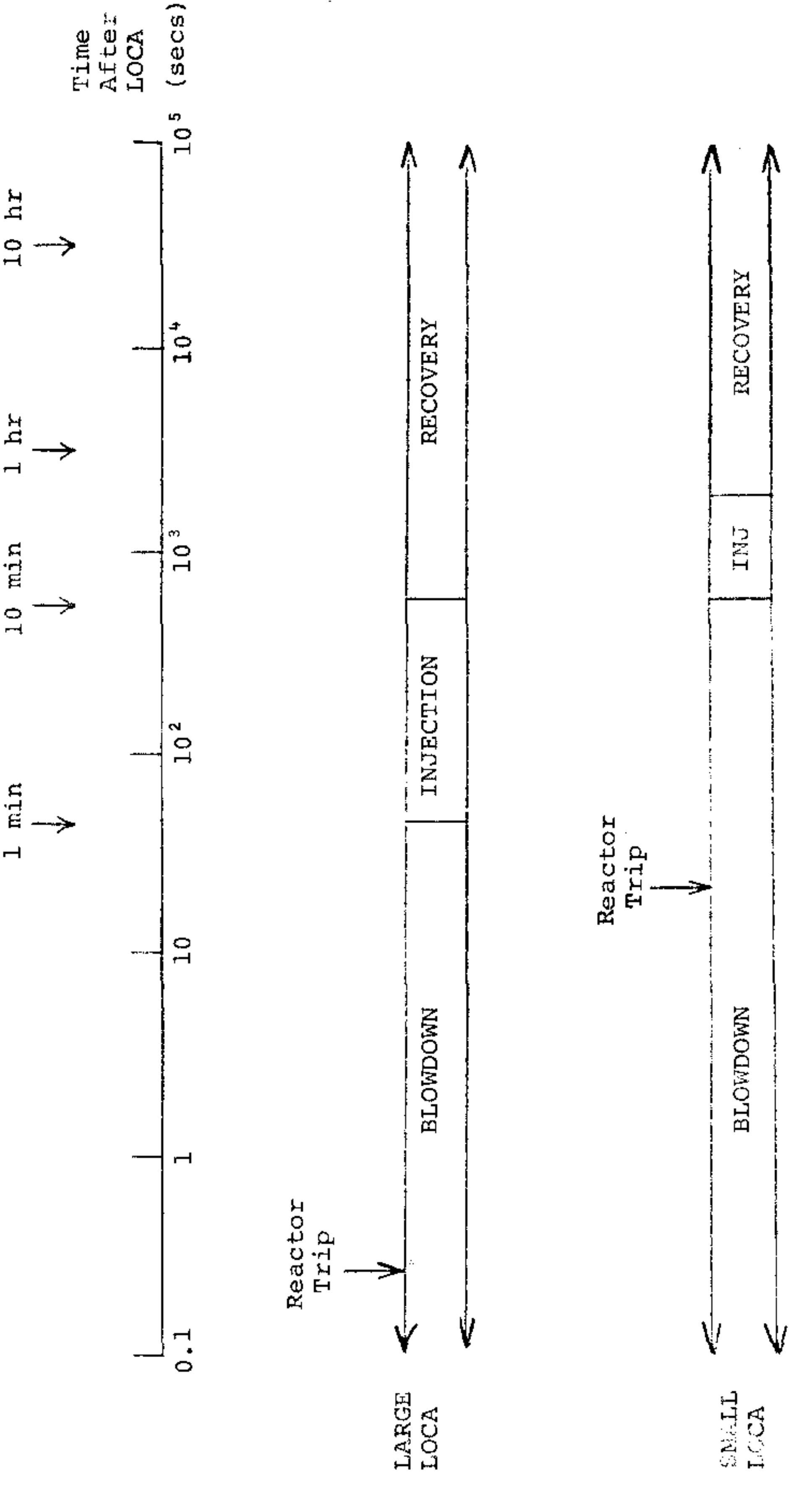

Figure 1: Phases of ECI Operation on a LOCA

Blowdown of the HT D_2O

This is defined as the period during which the HT D_2O system pressure is falling at a faster rate than the HT pressure control system can cope with. The leakage rate causing this is then of sufficient magnitude to say that a LOCA exists. In order to maintain adequate cooling for the fuel, ECI operation is required as the main heat transport system itself has no means of recovering the lost heat transport water in order to keep the system full of water for fuel cooling.

The blowdown phase ends when ECI injection pressure is reached and ECI water injects into the heat transport system. Notice here that it is possible for a small heat transport system break to result in a slow depressurization so that ECI injection pressure may not be reached before some fuel failures have occurred. This may happen because as soon as the heat transport pressure drops to saturation it will not fall any further, until the heat transport temperature is reduced. For instance, heat transport pressure cannot fall to the ECI injection pressure 700 kPa at Pickering NGS-A until the temperature has fallen to 170°C. Hence crash cooling of the heat transport system via boiler steam discharge is necessary to reduce coolant temperature below 170°C. Otherwise fuel overheating will occur due to the poor heat transfer now available inside the voiding fuel channels.

For large heat transport system breaks, the rapid rate of heat transport D_2O steam leakage depressurizes the system to the ECI injection pressure rapidly enough to prevent fuel failures, without crash cooling. Typically this would take about a minute for a large break, compared to about 10 minutes for a small break where boiler crash cooling is utilized.

Initial Injection of ECI Water onto the Fuel

At the end of blowdown, ECI water is ready to inject into the heat transport system via the ECI injection valves (see Figures 2 and 3). The heat transport system will now have lost a lot of coolant and the fuel will be heating up, due to the poor heat transport properties of the high quality steam in the channels. The higher the injection pressure, the quicker the ECI water can rewet the fuel and establish adequate cooling. Current station injection pressures are typically 700 kPa (Pickering NGS-A). As the water is injected from the ECI storage location into the main HT system, the water will initially flash into steam as it contacts the hot fuel sheaths. This steam will eventually leave the main HT system via the break.

Recovery and Recirculation of ECI Water

As the ECI storage inventory of water is depleted, the water escaping from the HT system must be recovered and recirculated over the fuel. This stage would be reached typically about 10 minutes after injection began for a large LOCA.

Any interruption in ECI recirculation flow will result in the fuel sheath heating up, leading to sheath rupture if water cooling is absent for long enough. At this stage, preventing ECI pump cavitation/gas locking is very important. These problems are perhaps more likely to occur at this stage because of the increased suction temperature of the recovered ECI water and the entrapment of air during the recovery stage. In addition ECI flow could be reduced by pump suction line blockages due to debris from inside containment being swept into the recovery lines. (Hence good housekeeping and cleanliness within containment is very important during normal operation.)

3. Typical ECI System Design

At Bruce and Pickering there are currently two types of ECI system using:

- low pressure H_2O from the vacuum building, Bruce NGS-A
- low pressure D_2O from the moderator system, Pickering NGS-A.

(a) Pickering NGS-A (Figure 2)

Emergency Coolant Injection Line

Moderator D_2O from the main moderator system is taken and used for ECI. The injection take off point is from the outlet of the moderator HX's. This location is chosen as it is at the lowest temperature in the moderator system. The ECI system injection line ties into the main heat transport system via the shutdown cooling system loops associated with each heat transport system quadrant as shown in Figure 2.

The types of valves in the ECI injection line are typical of those of other ECI sytems, and in this case consist of a flow control valve, a motorized isolating valve and check valves. The flow control valve is tested periodically to demonstrate the system reliability.

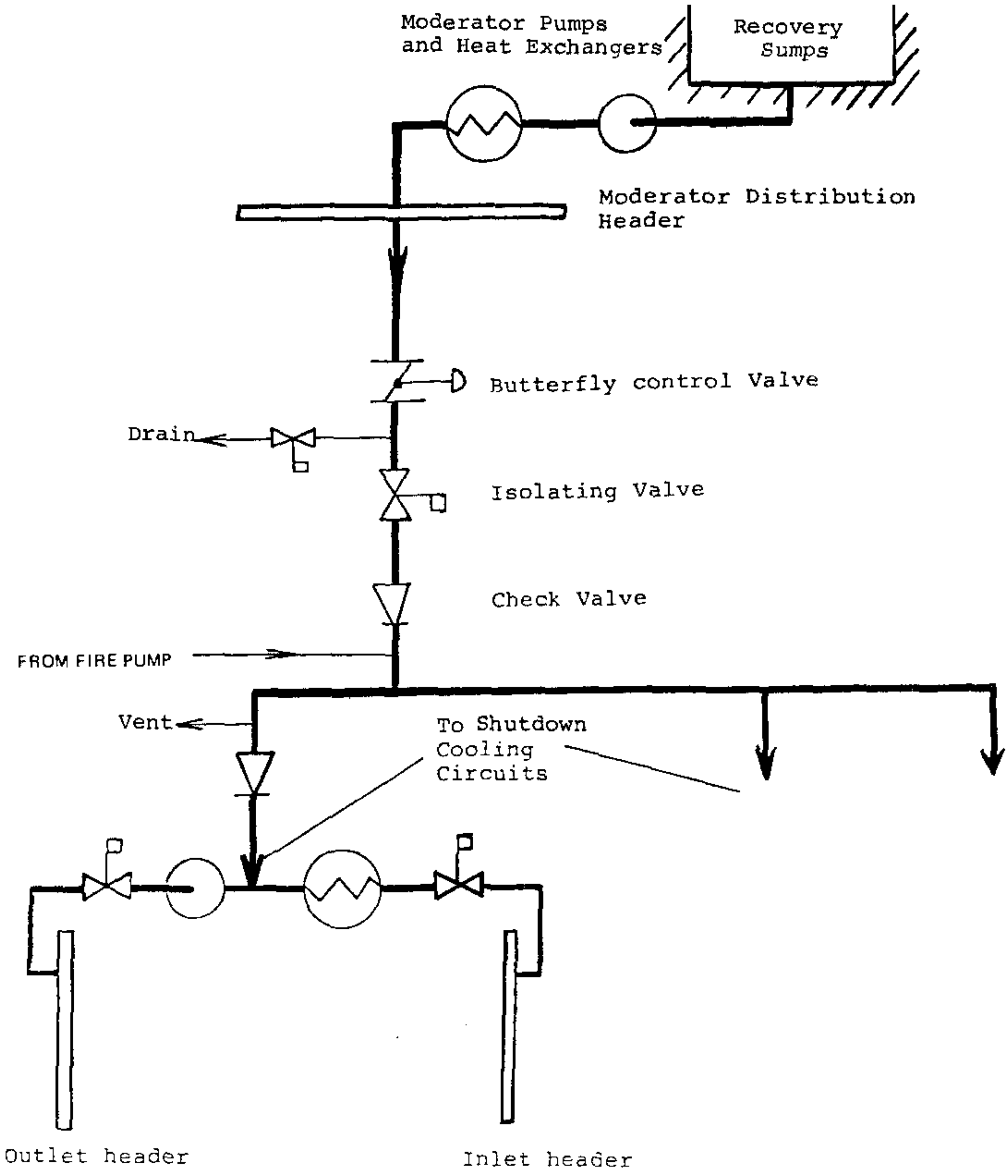

Figure 2: Emergency Coolant Injection System, Pickering NGS-A

For this testing a drain line is provided to collect moderator D_2O trapped past the valve following the test. Notice that the space between the check valves is usually empty and provided with a vent to release entrapped air when injection begins.

ECI Injection Phase

On a 700 kPa pressure signal from the heat transport main system outlet headers the flow control valve and shutdown cooling system isolating valves will open. The motorized isolating valve in the ECI injection line will already be open as it is closed to provide isolation only during the testing of the control valve. ECI water will then flow into the main heat transport system via the injection pipework when the main system pressure drops below injection pressure at the injection check valves. The ECI system injects into all main system headers regardless of the location of a heat transport system break. Flow through the core will then be established for fuel rewetting, with ECI water spilling out via the heat transport system break, ready for the recovery phase. Automatic interconnect valve closure will have isolated the two heat transport system loops to restrict blowdown to 50% of the core. Of great importance at this stage is to keep the ECI pumps operating without cavitation or gas locking, so that ECI flow can be maintained.

Recovery and Recirculation Phase

Recovery of ECI water, and spilt heat transport D_2O from the LOCA, is via recovery sumps in the fuelling machine vaults, calandria vault, and boiler room. Recovery pipework provides for gravity drainage from these sumps to the moderator pump suction headers. This recovered water can be recirculated indefinitely, via the HX's, which provide the major heat sink for the decay heat. If the recovered D_2O supply is inadequate to maintain recirculation, as indicated by low level in the recovery sumps, then it is possible to valve in fire water to the ECI injection line, see Figure 2.

(b) Bruce A (Figure 3)

The emergency injection system at Bruce employs a different philosophy from previous stations in the following respects:

(a) a light water H_2O system is used.

(b) emergency coolant supply is common for all four units.

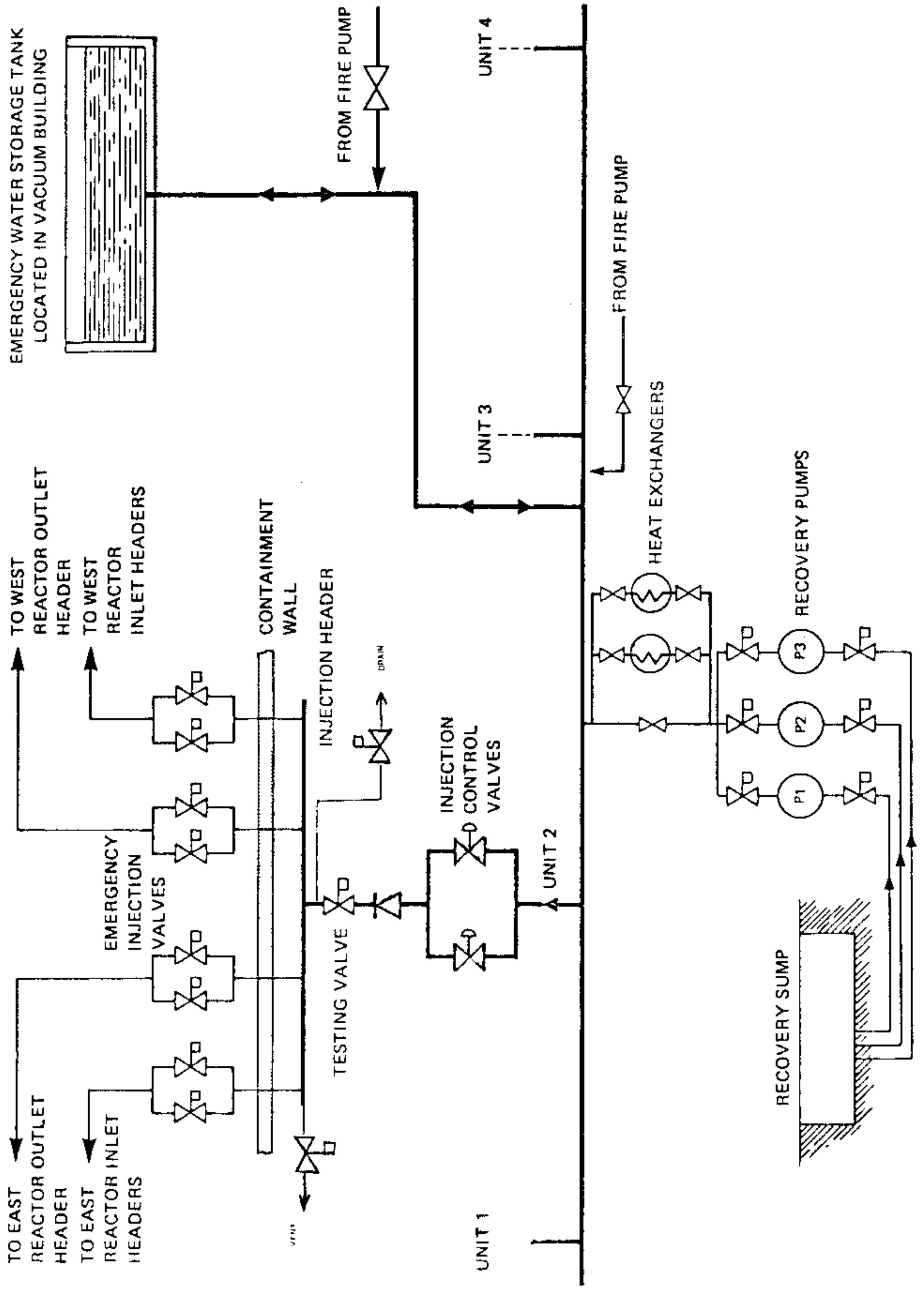

FIGURE 3: EMERGENCY CORE COOLING SYSTEM BRUCE G.S.A

The reasons for these changes were:

(i) a separation between process and safety systems is achieved,

(ii) no highly tritiated moderator water should be spilt within containment,

(iii) no downgrading of moderator water will result,

(iv) a heat sink is provided for the fuel by the moderator remaining in the calandria, via pressure tube/calandria tube heat transfer.

The system is shown in Figure 3. Operation is essentially as described above for Pickering except that initial injection on a LOCA is provided by the hydrostatic head of H_2O from the emergency H_2O storage tank, (or dousing tank, as it is sometimes called, as it also provides a dousing function) situated in the vacuum building.

Injection via the injection valves shown, is into all reactor headers directly (shutdown cooling circuits are of different design to Pickering).

After the water level in the storage tank falls, long term injection is maintained by (3 x 50%) recovery pumps which recirculate water accumulated in the fuelling machine duct recovery sump through the heat exchangers, back into the fuel channels.

As at Pickering NGS-A an additional water supply is available from the fire water system, if the recovery sump level falls too low.

ECI Unavailability

The ECI system is designed to meet an expected unavailability of typically 10^{-3} years/year, ie, ~ 8 hours/year. In order to meet this target the automatic opening of the ECI control valves and associated control logic are tested periodically.

When ECI is made unavailable for maintenance, it must always be possible to restore it to service within 8 hours. Notice that ECI may be deliberately blocked when the heat transport main system is being depressurized. In this case, blocking the injection by overriding the automatic opening of the injection control valve(s) will prevent a spurious injection, when heat transport pressure drops below ECI injection pressure. This deliberate blocking of ECI while the heat transport system is depressurized does not contribute to the unavailability.

ASSIGNMENT

1. (a) What is the overall purpose of the safety systems?

   (b) What is the specific purpose of the ECI system?

2. List and describe the three operational phases of emergency injection.

3. Draw a simplified schematic of the ECIS at your station.

4. (a) What is the target unavailability value for the ECIS at your station?

   (b) What actions are taken by station staff to meet this value?

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