Replacement Research Reactor Project

SAR CHAPTER 6
REACTOR COOLING SYSTEM AND CONNECTED SYSTEMS

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6 REACTOR COOLING SYSTEM AND CONNECTED SYSTEMS

6.1 INTRODUCTION

The reactor cooling systems remove the heat generated in the reactor core, irradiation facilities and spent fuel through direct cooling of the core and reflector and cooling of the reactor and service pools. The heat is transferred ultimately to the atmosphere.

The objectives of this chapter are:

1. To identify the specific safety requirements and safety design bases applicable to the reactor cooling and connected systems.
2. To provide a summary description of the design and operation of the reactor cooling and connected systems.
3. To identify the safety features of the reactor cooling and connected systems that contribute to nuclear and personnel safety.
4. To evaluate the design and operation of the reactor cooling and connected systems so as to demonstrate that they meet the identified safety requirements and safety design bases.
5. To identify possible faults that are subject to detailed safety analysis in Chapter 16.

6.1.1 Codes and Standards

All cooling systems are designed according to:

a) ASME Rules for the Construction of Pressure Vessels, equivalent to:
    (i) Australian Standard AS 1210: Pressure Vessels.
b) ASME Process Piping Code, equivalent to:
    (i) Australian Standard AS 4041: Pressure Piping.

6.1.2 Summary Description of Cooling Systems

The cooling systems are designed for the nominal power of 20 MW at which the reactor will operate, in addition to the heat generated in irradiation facilities, with the safety margins described in Chapter 5, Section 5.8, corresponding to the reactor thermal-hydraulic design. Safety margins ensure that all systems will have the required heat transfer capacity in all postulated conditions, with the following heat loads being extracted by each system during reactor operation (see core energy balance in Chapter 5, Section 5.1):

a) Heat extracted from the core by the Primary Cooling System (PCS)
b) Heat extracted from the Reflector Vessel by the Reflector Cooling and Purification System (RCPS).
c) Heat extracted from the irradiation facilities by the Reactor and Service Pools Cooling System (RSPCS).
d) Heat extracted from the Service Pool with a full load of spent fuel.

The cooling systems are capable, with adequate safety margins, of maintaining the fuel and core temperatures within their operational limits during reactor operation and within their safety limits following all design basis fault sequences.

The instrumentation and control signals of the cooling systems are connected either to one of the Reactor Protection Systems (RPS) or to the Reactor Control and Monitoring System (RCMS). The signals connected to the RPS belong to the reactor Engineered Safety Features (ESF), and are always triplicated with two-out-of-three voting logic. These signals will trip the reactor before safety limits are reached.

RCMS signals related to cooling system parameters generate automatic control actions within the RCMS that maintain the reactor parameters within normal limits, and alarm signals that provide warning to the operator about particular reactor events.

Seven cooling and related systems are provided, as follows:

Primary Cooling System (PCS)

Reactor and Service Pools Cooling System (RSPCS)

Reactor Water Purification System (RWPS)

Hot Water Layer System (HWLS) and Hot Water Layer Purification System (HWLPS)

Reflector Cooling and Purification System (RCPS)

Emergency Make-up Water System (EMWS)

Secondary Cooling System (SCS)

In all cases the cooling media is water, whose quality complies with strict purity requirements described with each system. Except for the Reflector Cooling and Purification System that employs both demineralised heavy water and demineralised light water, and the Secondary Cooling System that employs normal treated water, all other systems run with demineralised light water.

In addition, the Hot Water Layer System provides heating to the upper layer of the Reactor Pool water. This hot water layer can also be extended over the Service Pool.

A Block Diagram of the Reactor Cooling System and Connected Systems is shown in Figure 6.1/1.

The ultimate heat sink for all heat sources is the atmosphere.

During normal reactor operation the heat is transferred to the atmosphere by the cooling towers via the Secondary Cooling System. The thermal load in the Power state includes core fission heat and irradiation targets fission heat. This is removed mainly by the Primary Cooling System and the Reactor and Service Pools Cooling System respectively.

During the Physics Test and Refuelling states, the heat load includes the core and the irradiation targets decay heat. This is removed by natural circulation in the sections of the Primary Cooling System and Reactor and Service Pools Cooling System that are inside the Reactor Pool. Either forced or natural circulation is possible in the Shutdown state.

6.1.2.1 Primary Cooling System

The function of the Primary Cooling System is to remove heat from the core in all operational and accident situations maintaining the core in a safe condition. Heat is extracted by the flow of cooling water through the core either by forced circulation when the Reactor is in the Power state, or by natural circulation when the Reactor is in the Physics Test, Shutdown or Refuelling states. The heat extracted from the core is transferred to the Secondary Cooling System, directly through the heat exchangers of the Primary Cooling System, or indirectly through the Reactor and Service Pools Cooling System. Under abnormal conditions, or if the RSPCS is not available, the heat is transferred to the water of the reactor and service pools.

The portion of the Primary Cooling System, inside the Reactor Pool, which participates in the core cooling during normal operation and performs the function of core cooling by natural circulation, is defined as a Safety Category 1 Engineered Safety Feature. The portion of the Primary Cooling System outside of the Reactor Pool is not required for core cooling by natural circulation and is classified as a Safety Category 2 system.

6.1.2.2 Reactor and Service Pools Cooling System

The Reactor and Service Pools Cooling System removes heat from the irradiation rigs in the Reactor Pool and from the spent fuel in the Service Pool during all reactor states.

The system removes heat from the irradiation rigs by forced circulation during the reactor Power state and by natural circulation during the Physics Test, Shutdown or Refuelling states.

The Reactor and Service Pools Cooling System also indirectly removes the core heat from the Reactor Pool during the Physics Test, Shutdown, and Refuelling states.

Heat from the Reactor and Service Pools Cooling System is transferred to the Secondary Cooling System.

The portion of the Reactor and Service Pools Cooling System inside the Reactor Pool that performs the function of rigs cooling by natural circulation is defined as a Safety Category 1 Engineered Safety Feature. The portion of the system that does not participate in rig cooling by natural circulation is classified as a Safety Category 2 system.

6.1.2.3 Reactor Water Purification System

The Reactor Water Purification System performs the function of keeping the Primary Cooling System and the Reactor and Service Pools Cooling System water within the required purity limits by removing corrosion, fission and radioactive impurity traces. The system uses filters and ion exchange purification resins to perform its functions.

The Reactor Water Purification System includes Safety Category 2 and Safety Category 3 components.

6.1.2.4 Hot Water Layer System

The Hot Water Layer System provides:

a) additional personnel protection against radiation emitted by impurities from pool water

b) a means for continuous skimming of water surface

A non-active stable water layer at a higher temperature than the pool water reduces mixing and hence reduces potential contamination of the layer by impurities dissolved in the pool water. The Hot Water Layer System establishes this non-active, stable hot water layer by purification and heating a layer of water at the top of the Reactor Pool. This hot water layer can be extended over the Service Pool.

The Hot Water Layer System includes Safety Category 2 and Safety Category 3 components.

6.1.2.5 Reflector Cooling and Purification System

The Reflector Cooling and Purification System serves to cool and maintain the purity of the heavy water contained in the Reflector Vessel surrounding the reactor core.

The Reflector Cooling and Purification System includes the Reflector Primary Cooling Circuit, the Reflector Purification System, the Additional Cooling Circuit and the Reflector Intermediate Cooling Circuit. In addition, the system interfaces with the Deuterium Recombination System.

Reflector heavy water is cooled by the Reflector Primary Cooling Circuit. The system transfers heat to the Reflector Intermediate Cooling Circuit, which in turn transfers heat to the Secondary Cooling System. The reflector heavy water is purified by the Reflector Purification System.

The Reflector Intermediate Cooling Circuit has been designed to provide an additional barrier between tritiated heavy water and the water of the Secondary Cooling System in order to minimise the possibility of the release of tritium to the atmosphere.

To prevent heavy water degradation, the Reflector Cooling System operates with a helium cover gas in equilibrium with the heavy water. An on-line Deuterium Recombination System (DRS) keeps the deuterium and oxygen concentrations in the cover gas well below the flammability level of the mixture. The Reflector Intermediate Cooling Circuit removes heat from the gas coolers and compressors of the DRS.

The Reflector Cooling and Purification System includes Safety Category 2 and Safety Category 3 components.

6.1.2.6 Emergency Make-up Water System

The Emergency Make-up Water System is a passive system provided to ensure that the core is covered with water in the event of a beyond design basis loss of coolant accident (LOCA). The Emergency Make-up Water System injects water by gravity into the two lines of the Primary Cooling System, thus keeping the reactor core flooded. The water injection starts by the automatic opening of two valves when Reactor Pool water level reaches the upper Chimney level. The Emergency Make-up Water System has the capacity to maintain the Chimney full of water for up to twenty-four hours, compensating for coolant losses due to evaporation caused by residual core decay heat.

The Emergency Make-up Water System is classified as a Safety Category 2 system.

6.1.2.7 Secondary Cooling System

During normal operation in the Power state, the Secondary Cooling System (SCS) transfers heat to the atmosphere.

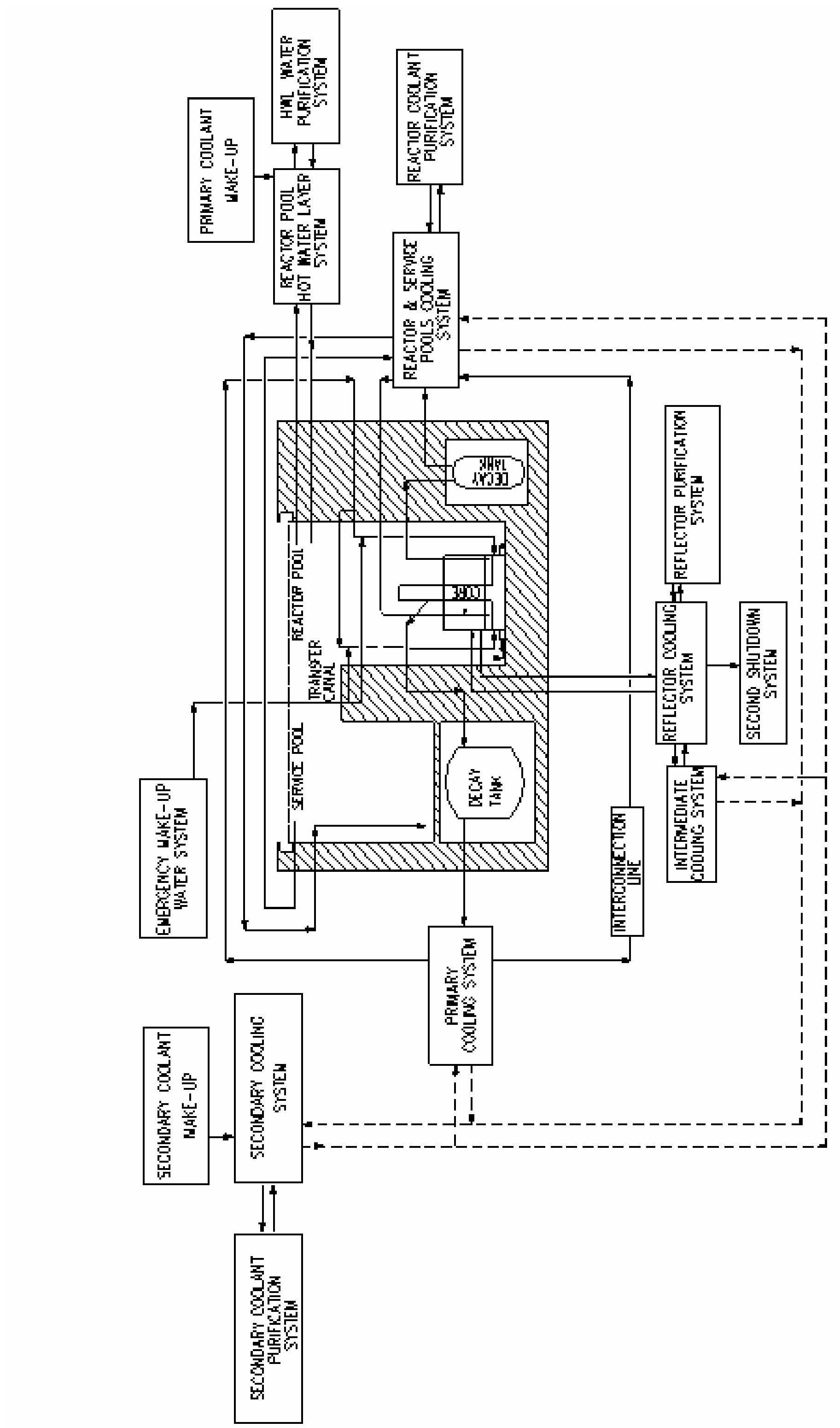
The SCS also cools the Cold Neutron Source helium compressors and Cold Box and the water from the Heating, Ventilation and Air Conditioning System and is designed to have spare capacity for future uses. Heat rejection to the atmosphere is done through a set of cooling towers.

The SCS is provided with a water treatment system. The SCS includes provisions for continuous radioactive monitoring.

The SCS includes Safety Category 2 and Safety Category 3 components.

End of Section

Figure 6.1/1 Block Diagram of Reactor Cooling System and Connected Systems



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6.2 PRIMARY COOLING SYSTEM

6.2.1 Introduction

The Primary Cooling System (PCS) removes core fission heat generated under full load by forced upward circulation of demineralised water and transfers the heat to the Secondary Cooling System (SCS). The portion of the PCS inside the Reactor Pool also removes core decay heat by natural upward circulation of the water, when the main pumps are shutdown or fail.

The PCS comprises the reactor and service pools, the main circuit piping, a decay tank, primary cooling pumps, heat exchangers, valves, and pipe fitting components. The pools are considered within the PCS because they are hydraulically connected. Part of the PCS circuit is outside the Reactor Pool and part of it is inside the Reactor Pool, which provides a large reservoir of coolant for PCS operation.

The primary cooling circuit outside the Reactor Pool is a Safety Category 2 system designed to provide core cooling in the reactor Power state. It can provide cooling in the reactor Shutdown state but its operation is not essential for maintaining core- cooling parameters within safety limits. The design is such that the reactor will be taken to a safe shutdown state following an abnormal condition and will remain in a safe shutdown condition without the participation of the PCS components outside the Reactor Pool.

The primary cooling circuit inside the Reactor Pool is a Safety Category 1 Engineered Safety Feature (ESF). It participates in the core cooling function when the Reactor is in the Power state and has the safety function to remove core decay heat by natural circulation when the reactor is in the Physics Test, Shutdown or Refuelling states.

In the reactor Shutdown state, the decay heat extracted from the core by natural circulation is deposited in the pool water. The Reactor Pool inventory has a large thermal inertia and, together with the Reactor and Service Pools Cooling System (RSPCS), maintains the Reactor Pool water temperature within a specified nominal range.

6.2.2 Safety Design Bases

The PCS has been designed to meet the following safety design bases:

a) To provide coolant flow to remove the fission heat from the core during the Power state. This coolant flow condition was established by the core thermal hydraulic design presented in Chapter 5, Section 5.8.

b) To maintain a steady core coolant inlet temperature over the range of normal operating conditions.

c) Removing core decay heat when the PCS pumps are not in operation by natural circulation, for thermal power ≤ 400 kW.

d) To ensure an adequate fuel cladding thermal margin during postulated transients.

e) To maintain its integrity during adverse combinations of loading and forces occurring in abnormal conditions (see section 6.2.10 and 6.2.11).

f) To prevent pool water level from dropping below the siphon breakers in the event of loss of coolant accidents, by means of different siphon breaking devices connected to PCS inlet and outlet pipelines.

6.2.3 Circuit Description

The PCS is a circuit open to the atmosphere. The pressure at the core exit is equal to atmospheric pressure plus the pressure of the water column above the core.

The circuit is completely within the containment. Some of the components are inside and other components outside the Reactor Pool.

After leaving the core in its upward flow, PCS water is collected in the Upper Chimney and is drawn at design flow rate through a pipe towards the Reactor Pool boundary. This pipeline leaves the pool and goes through the concrete of the reactor block, to the decay tank.

Inside the reactor pool, this pipe has a pipeline connection for venting. This acts as a siphon-breaker, preventing pool drainage in the event of LOCA occurrence in the primary circuit. The siphon breaker is a passive component with no valves in the line.

The decay tank provides a delay time to ensure that dissolved N-16 decays before the water exits the concrete shield.

The main coolant line leaves the decay tank and the concrete shielding, and enters the pump room area where it splits into three branches with a centrifugal pump and one plate-type heat exchanger in each branch. Two branches in operation will provide adequate cooling under full load. The third stand-by branch ensures reactor availability in case of loss of any of the other branches (e.g. due to maintenance or failure).

Each pump has sufficient inertia to maintain the coolant flow rate through the core in the event of a loss of normal power supply.

Each pump discharge pipeline directs the coolant to its corresponding heat exchanger where the heat is transferred to the Secondary Cooling System. There is a separate pump room for each of the three pumps and heat exchangers. Any one of the three branches can be isolated and maintained even when the Reactor is in the Power state, as adequate radiation protection is provided by the water flowing through the decay tank and by the concrete walls separating the PCS pump and heat exchanger branches.

The three branches of the primary side of the main heat exchangers merge into the main pump discharge line. This main line traverses the reactor concrete block and then splits into two branches, which enter the Reactor Pool, and discharge the cooling water in the core lower plenum. Water diffuses in the plenum before it flows into the fuel element inlet nozzles and enters the core cooling channels.

In order to allow the establishment of natural circulation when the PCS pumps are not in operation, Flap Valves are located in each of the lines returning to the pool.

The flap valves remain closed in the forced circulation mode due to the pressure provided by the PCS pumps. They open by gravity when the pumps stop due to failure or are shutdown. The open position of these valves establishes a path within the reactor pool, to remove the decay heat by natural circulation using the pool water after reactor shutdown.

The primary cooling loop inside the pool consists of the pool itself plus the portion of the circuit between the flap valves in the pump discharge lines and the siphon breaker in the pump suction line.

The pump discharge line of the PCS has a connection to the Reactor and Service Pool Cooling System (RSPCS) known as the interconnection branch. This bypass diverts a fraction of the core cooling flow into the RSPCS. This fraction of flow returns to the bottom of the Reactor Pool through the pump discharge line of the RSPCS. This arrangement causes a downward flow into the Upper Chimney, equal to that flow rate diverted from the PCS (by mass balance). This flow can be regulated by a control valve from the RCMS. The interconnection branch contributes to the preservation of the hot water layer. The control valve will be adjusted during commissioning to minimise the activity level at the top of the Reactor Pool during reactor full power operation.

The Reactor Pool, and hence the PCS, is open to the atmosphere in the Reactor Building and there is evaporation from the surface of the Reactor and Service Pools .

The PCS has provisions for early detection of fuel cladding failure, described in Chapter 12, Section 12.3.5.7.

Release of radioactive gases at the Reactor Pool surface is handled by the ventilation system, which draws air from over the Reactor Pool. Radioactive gases, including those arising from radiolysis, will flow to the decay tank, as a result of the downward water flow generated in the Chimney. These gases are allowed to decay in the tank and, after decaying, are vented through a pipeline that runs from the decay tank to the top of the Service Pool. The ventilation system is described in Chapter 10, Section 10.4 then takes these gases to the stack.

PCS operation parameters are monitored by the Reactor Control and Monitoring System (RCMS) and the Reactor Protection Systems (RPS). The RCMS commands power regulation actions to maintain parameters within their set safety range and administers interlock protection actions. The RPS commands shutdown actions if those parameters deviate beyond their safety system setting.

6.2.4 Primary Cooling System Operation Modes

There are two Operation Modes for core cooling by the PCS. They are:

Forced Circulation Mode.

Natural Circulation Mode.

The distinction between the two modes of operation lies in the operating condition of the PCS pumps. In forced circulation mode, the PCS pumps are in operation with participation of the circuit outside as well as that inside the Reactor Pool. In the core cooling by natural circulation mode, the pumps are shut down and only the circuit inside the Reactor Pool is used for core cooling.

Although not required for core cooling, the PCS pumps can be run when the reactor is in the Shutdown state.

The reactor Shutdown state includes the normal shutdown performed by the operator, and the shutdown reached after a reactor trip initiated by the RPS.

The main characteristics of the PCS Operation Modes are:

Reactor State	PCS Operation Mode	PCS Configuration	Flap Valve Position	Direction of Flow	PCS Function
Power	Forced Circulation Mode	2 PCS pumps in operation.	Fully Closed	Upward flow	Core fission heat removal
Physics Test	Natural Circulation Mode	PCS pumps are not in operation and prevented from start-up.	Fully Open	Upward flow	Core fission heat removal

Reactor State	PCS Operation Mode	PCS Configuration	Flap Valve Position	Direction of Flow	PCS Function
Shutdown	Forced Circulation Mode	1 or 2 PCS pumps are in operation	Fully Closed	Upward flow	Core decay heat removal
	Natural Circulation Mode	Circulation pumps are not in operation.	Fully Open	Upward flow	Core decay heat removal
Refuelling	Natural Circulation Mode	Circulation pumps are not in operation and prevented from start-up.	Fully Open	Upward flow	Core decay heat removal

The possible operation mode transitions are:

a) From forced circulation to natural circulation (Power state to Shutdown State).

b) From natural circulation to forced circulation (Shutdown state to Power state).

6.2.4.1 Core Cooling by Forced Circulation

When the reactor is in the Power state, the PCS forced circulation mode provides adequate cooling of the core with two pumps in operation.

The coolant flow through the core is in accordance with the safety margins defined in Chapter 5, Section 5.8, and allowing, at the same time, a flexible and efficient operation of the plant.

The core coolant inlet temperature is maintained steady over the range of operating conditions, regardless of variations in meteorological conditions prevailing at the site. This function is performed by the RCMS control loop that varies the speed of the cooling tower fans of the SCS.

In PCS forced circulation cooling mode, the PCS Flap Valves are maintained in the closed position by the pressure of the coolant flow.

6.2.4.2 Core Cooling by Natural Circulation (Decay Heat Removal)

The natural circulation of Reactor Pool water is established to extract core decay heat as follows:

a) Hot water from the core flows upward through the Chimney.

b) Cold water enters the two PCS pump discharge lines through the four open Flap Valves and flows downward towards the core inlet plenum.

The core decay heat is transferred to the Reactor Pool. The available water for natural circulation amounts to the water volume in the Reactor Pool above the level of the lower Flap Valves. The heat from the core is transferred to the pool water. The large amount of water in the pool acts as a heat sink with heat being lost to the atmosphere by evaporation. There is sufficient water in the pools to remove core decay heat for at least 10 days in the absence of any other means of heat removal before the pool water reaches the actuation level for the EMWS.

Analysis of core cooling by natural circulation is presented with the thermal hydraulic design of the reactor in Chapter 5, Section 5.8.

The PCS core cooling by natural circulation takes place either with or without the simultaneous operation of Long Term Pool Cooling (LTPC) of the RSPCS.

6.2.4.2.1 Core Cooling with Long Term Pool Cooling of the Reactor and Service Pools Cooling System

The Long Term Pool Cooling (LTPC) Mode of the RSPCS provides an additional contribution to safety. It is designed to maintain Reactor Pool temperature within its nominal operating range. In the normal reactor Shutdown state, core cooling by natural circulation takes place while the RSPCS extracts heat from the Reactor Pool in its LTPC mode.

The LTPC mode of operation of the RSPCS is described in Section 6.3.3.

Chapter 16, Section 16.7 demonstrates that core cooling by natural circulation is capable of providing adequate core cooling without the operation of the RSPCS.

6.2.4.3 Transition from Forced Circulation to Natural Circulation Mode

Transition from forced circulation to natural circulation will take place under two situations:

a) Normal reactor shutdown by the operator followed by shutdown of the PCS pumps.

b) Abnormal conditions that remove PCS pumps from service.

The following events will take place after either of the above conditions:

i) Decrease of differential pressure between the inside of the Flap Valve (within the PCS piping) and the outside of the Flap Valve.

ii) Opening of PCS Flap Valves.

iii) Core cooling by natural circulation of Reactor Pool water through the Flap Valves and the PCS circuit inside the Reactor Pool.

Analysis of the transition from forced circulation to natural circulation cooling is provided in Chapter 5, Section 5.8 and in Chapter 16, Sections 16.7 and 16.9.

In the case of normal reactor shutdown by the operator two steps are recommended for pump shutdown to assist with a smooth transition of core parameters and to reduce the thermal demands on the core components:

Step one: One of the pumps is shut down soon after reactor shutdown with the core decay heat being extracted by the running pump.

Step two: Approximately half an hour after shutdown the reactor power reduces to well below 400 kW and the second pump can be shutdown to allow natural circulation cooling.

When the reactor and the PCS pumps are shutdown, and the PCS flow drops, the Flap Valves open and natural circulation of Reactor Pool water through the core is established.

6.2.4.4 Transition from Natural Circulation to Forced Circulation Mode

A direct change from the Physics Test to the Power state (natural circulation to forced circulation mode) is not possible.

In the Physics Test state (<400 kW) the core is cooled by natural convection. This cooling may or may not be assisted by the RSPCS.

Prior to being taken into the Power state, the reactor must be taken into the Shutdown state.

6.2.5 Operation of the Flap Valves and Siphon Breakers

The Flap Valves in each of the PCS pump discharge lines establish a natural circulation loop between the core (heat source) and the Reactor Pool water (heat sink). The reactor pool water provides a large thermal capacity.

The Flap Valves open and establish a path for natural circulation cooling when the PCS pumps are shut down, or are out of service due to abnormal conditions.

Sensors provide indication of the valve closed/open condition.

When operating with forced circulation the flap valves are kept closed by the pressure of the primary coolant flow. As this pressure decays away after the loss of forced circulation, the flap valves open. The valves are designed to open at a certain differential pressure, and this is nominally 125 seconds (±10 seconds) after the loss of both pumps.

6.2.6 Primary Cooling System Components

Components of the PCS are:

a) PCS circuit outside the Reactor Pool:
   - (i) PCS Pumps (three)
   - (ii) Heat Exchangers (three)
   - (iii) Decay Tank (one)
   - (iv) Piping external to the pool, valves, and minor piping components

b) PCS circuit inside the Reactor Pool:
   - (i) Core coolant channels; Chapter 5, Section 5.3, presents a detailed thermal hydraulic analysis of the fuel assembly.
   - (ii) Chimney, described in Chapter 5, Section 5.2.
   - (iii) Plenum, described in Chapter 5, Section 5.2.
   - (iv) PCS Piping inside the reactor pool
   - (v) Flap Valves
   - (vi) Siphon breaker.

The Reactor Pool is described in Chapter 4, Section 4.5.

6.2.6.1 Primary Cooling System Circuit Outside the Pool

6.2.6.1.1 PCS Pumps

Main parameters of the pump are:

Parameter	Value
Quantity	Three pumps, 50% capacity each
Type	Centrifugal, single stage horizontally split
Casing material	Stainless steel
Shaft seal	Mechanical seal

Parameter	Value
Accessories	Instrumentation: Temperature measurement in motor winding and bearings Vibration monitoring in bearings Instrumentation: Temperature measurement in motor winding and bearings

Check valves are provided at the pump outlet. Manual butterfly valves are used for isolation at pumps suction and discharge pipelines.

Pump operation is limited by RCMS interlocks described in the corresponding section.

6.2.6.1.2 Heat Exchangers

Main parameters of the heat exchangers are:

Parameter	Value
Quantity	Three, 50% capacity each
Type	Plate type
Fluids direction	Counter-current
Sealing material	EPDM (Ethylene propylene rubber)

The heat exchangers are designed so that failures of plate gaskets do not produce mixing of primary and secondary fluids.

6.2.6.1.3 Decay Tank

Main parameters of the decay tank are:

Parameter	Value
Quantity	One
Type	Vertical type, with internal baffle of cylindrical shape diffuser plate at inlet/ and piston type flow pattern

The decay tank is shielded by heavy concrete walls. Its design criterion is to delay the flow of cooling water in the tank for the time needed for the decay of nitrogen-16 before the water is allowed to exit the concrete shielding. The decay tank design is presented in Chapter 12, Section 12.3.2.5. The Design Standards listed in Section 6.1.1 apply.

6.2.6.1.4 Piping External to the Pool, Valves and other associated Components

All PCS piping is designed according to AS 4041. The material is stainless steel (Class B material).

Pipework embedded in concrete is covered with a layer of polyurethane rigid foam to allow for thermal expansion.

PCS materials resistant to severe operation and radiation environment used are:

a) EPDM (Ethylene propylene rubber), used for soft components such as O-rings, diaphragms, gaskets of plate heat exchangers, and valve seats.

b) UHMWPE (Ultra High Molecular Weight Polyethylene), used in special cases such as for ball valve seats.

Appropriate venting and drainage connections with suitable valves are provided. Water from all drainage points flows to the Radioactive Liquid Waste Management System.

6.2.6.2 Primary Cooling System Inside the Reactor Pool

The PCS pipelines inside the Reactor Pool are:

a) Two pipelines from the Reactor Pool penetration to PCS inlet plenum (pump discharge line).

b) One outlet pipe from the Chimney Riser up to the Reactor Pool penetration (pump suction line).

c) One siphon breaker pipeline from the pump suction line up to the Reactor Pool surface open to the atmosphere..

d) A pipeline connecting at the top of both the plenum inlet pipelines, ensures siphon break if any flap valve fails to open.

The piping inside the Reactor Pool is designed according to AS 4041 with stainless steel as the piping material.

The PCS circuit inside the Reactor Pool also includes the following core associated structures: Core Inlet Plenum, Diffuser, Core Coolant Channels and the Chimney. These are described in Chapter 5, Section 5.2.

6.2.7 Primary Cooling System Instrumentation

Instrumentation associated with the Reactor Protection Systems is triplicated.

The Reactor Protection Systems (RPS) consists of:

a) First Reactor Protection System (FRPS), and the

b) Second Reactor Protection System (SRPS)

The following are the parameters that are monitored by the RPS, the Reactor Controlling and Monitoring System (RCMS) and the Post Accident Monitoring System (PAM).

6.2.7.1 Temperature

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature sensor & transmitter	Core inlet	FRPS & RCMS	Indication High temperature alarm	Reactor trip 1 due to high core inlet temperature
Temperature sensor & transmitter	Core inlet – core outlet	FRPS & RCMS	Indication High core temperature difference alarm	Reactor trip 1 due to high core temperature difference.
Temperature sensors & transmitter	Core outlet	SRPS & RCMS	Indication High temperature alarm	Reactor trip 2 due to high core outlet temperature
Temperature sensor & transmitter	Decay tank inlet	RCMS	Indication High temperature	Alarm through RCMS to warn operator.

			alarm	
Temperature sensor & transmitter	Heat exchangers, inlet and outlet	RCMS	Indication	Alarm trough RCMS to warn operator
Temperature sensor & transmitter	Reactor pool (closed to the upper chimney edge)	RCMS	Indication	None
Temperature sensor & transmitter	Core mechanism flushing pipeline	RCMS	Indication	None

6.2.7.2 Flow

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Flow meter & transmitter	Core inlet	FRPS & RCMS	Indication Low flow rate to the reactor core inlet alarm	Reactor trip 1 due to low flow rate to the reactor core inlet
Flow meter & transmitter	Interconnection branch	RCMS	Indication Low flow rate alarm	None
Flow meter & transmitter	Core mechanism flushing	RCMS	Indication Low flow rate alarm	None
Flow Switch	Each pump outlet	RCMS	Low Flow Alarm	None

6.2.7.3 Pressure

Instrument	Location	System	Control Room indication/Alarm	Protection Functions
Differential pressure transmitter (DP Cell)	Reactor core	SRPS & RCMS	Indication Low differential pressure alarm	Reactor trip 2 due to low core differential pressure
Differential pressure transmitter (DP Cell)	Reactor core	FRPS & RCMS	Indication High and Low differential pressure alarm	Reactor trip 1 due to high or low core differential pressure

6.2.7.4 Reactor Pool Level

Instrument	Location	System	Control Room indication/Alarm	Protection Functions
Level switch	Reactor Pool water level (minimum operating level)	RCMS	Low level alarm	Power reduction due to low pool water level

Instrument	Location	System	Control Room indication/Alarm	Protection Functions
Level switch	Reactor Pool water level	FRPS	Very low level Alarm	Reactor trip 1 due to low level
		RCMS	Very low level Alarm	Pump trip due to very low pool water level
Level switch	Reactor Pool water level	SRPS & RCMS	Evacuation level alarm	Reactor trip 2 due to very low level
		PAM	Evacuation Low level Alarm	None
Level switch	Reactor pool water level (top of chimney, triggering of EMWS)	PAM & RCMS	Low level Alarm	None
Level switch	Reactor pool water level (top of core)	PAM & RCMS	Low level Alarm	None

6.2.7.5 Flap Valve Position

Instrument	Location	System	Control Room indication/Alarm	Protection Functions
Position switches	On each lower flap valve	PAM & RCMS	Full open position indication	None
Position switches	On all flap valves	RCMS	Full open/closed position indication Alarm when any flap valve is not fully open and core flow is lower than pre-set value Alarm when pumps are start-up and any flap valve is not fully closed with primary flow is higher than pre-set value.	Power state not allowed due to flap valve open

6.2.7.6 PCS Pump Temperature Instrumentation

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature sensors	Pump motor windings	RCMS	Temperature indication High temperature alarm	Pump trip due to very high motor winding temperature (hardwired logic)

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature sensors	Pump bearings	RCMS	Temperature indication High temperature alarm	None
Temperature sensors	Pump motor bearings	RCMS	Temperature indication High temperature alarm	None
Temperature sensors	Bearings	RCMS	Temperature indication High temperature alarm	None

6.2.7.7 PCS Pump Vibration Instrumentation

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Vibration sensors	Pump motor bearings	RCMS	High vibration alarm Very high vibration alarm	None

6.2.7.8 Leak Detection

Instrument	Location	System	Control Room indication/Alarm	Protection Functions
High water level switch	Pump seal leak reservoir	RCMS	Alarm	None
Level switch	Below DPcell instruments	RCMS	High level alarm	None

6.2.7.9 Failed Fuel Detection

Instrument	Location	System	Control Room indication/Alarm	Protection Functions
Fission product monitor	Core outlet pipeline	RCMS	Alarm	None

The Failed Fuel monitor is described in Chapter 8, Section 8.6.3.2.2.3.

6.2.7.10 Water Activity Monitor

Instrument	Location	System	Control Room indication/Alarm	Protection Functions
Gamma activity monitor (Active Liquid Monitoring System, ALMO)	Decay tank outlet pipeline	RCMS	Alarm	None

The monitor is described in Chapter 8, Section 8.6.3.2.2.1.

6.2.8 Actions on RPS and RCMS due to PCS Signals

The instrumentation and control system is fully described in Chapter 8, Section 8.8. This section reproduces the main actions of the RPS and RCMS associated with the PCS.

6.2.8.1 Trip Signals

Reactor trip signals generated by the FRPS
Low reactor pool water level
Low core primary coolant flow
Low core differential pressure
High core differential pressure
High core temperature difference
High core inlet temperature

Reactor trip signals generated by the SRPS
Low core differential pressure
Very low pool water level (evacuation level)
High core outlet temperature

A pump trip by the signal initiated by the RCMS or a hardwired interlock will produce a decrease of the flow rate. The low core flow rate signal will result in a reactor trip by the FRPS.

PCS pump trip signals
Very High motor winding temperature (generated by a hardwired logic)
Reactor Pool very low water level (generated by the RCMS)

6.2.8.2 Operator Actions

Condition	Operator Action
High bearing temperature alarm	The operator will evaluate the situation and take the appropriate action.
High motor winding temperature alarm	
High and very high motor bearings vibration alarm	
High motor bearings temperature alarm	
High pump bearings temperature alarm	
High pump seal leak reservoir level alarm	
Low pump flow alarm	
Low pool level alarm	
Pool leaks detection alarm	
Activity monitor alarms	

6.2.8.3 Interlocks

6.2.8.3.1 Primary Cooling System Pump

Condition	Interlocks
Two pumps in operation	Start-up of the third pump is not allowed due to electrical network limitation.
Failure of one of the two operating pumps	Automatic start-up of the stand-by pump is not allowed.
Failure of one of the two operating pumps.	The pump is not allowed to start-up again until a manual reset of the control logic has been performed.
Reactor in the Physics Test state	Pump start-up is not allowed.
Reactor in the Refuelling State	Pump start-up is not allowed.
Pump shutdown and pump start-up signals are transmitted simultaneously by mistake	The shutdown signal has priority.
Two of the pumps are not in operation	Reactor start-up in the Power state is not allowed.
PCS flow has not reached the pre-set value	Reactor start-up in the Power state is not allowed

6.2.8.4 Reactor and Service Pools

Condition	Interlock
Not all Flap Valves are closed	Reactor start-up in the Power state is not allowed

6.2.8.5 Loss of Coolant Accident

Analysis of LOCA is presented in Chapter 16, Section 16.11.

The provisions of the PCS to detect LOCA incidents are:

Possible consequences on the PCS as a result of LOCA	Means of detection
Decrease in reactor pool water level	Reactor pool level switches
Reactor pool automatic water make-up system flow is too high	Reactor pool automatic water makeup system flow transmitter
Water drainage	Leak detectors in LOCA drainage system

6.2.9 Inspection and Testing

The inspection and testing program for fabrication, assembly, pre-operation and in-service operation was developed during detailed engineering in accordance with the Construction Inspection and Test Plan (CITP).

6.2.10 Primary Cooling System Design Evaluation

The PCS meets the safety design bases:

a) The design is able to provide coolant flow to remove the core fission heat when the reactor is in the Power state. This function is performed by the PCS circuit inside and outside the Reactor Pool.

b) Together with the SCS (section 6.8), it is designed to maintain a steady core coolant inlet temperature over a range of normal operating conditions.

c) The removal of core decay heat, when the PCS pumps are not in operation, is performed by the Safety Category 1 function of the PCS, cooling the core by natural circulation, using the PCS circuit inside the Reactor Pool.

d) Ensuring that there is adequate fuel cladding thermal margin during postulated transients.

e) The PCS integrity is maintained during adverse combination of loading and forces occurring during postulated occurrences and abnormal conditions

For safety design bases (a), (b), (c) and (d) above, the requirements for core heat removal during the various reactor states are verified through the thermal hydraulic design performed with validated codes presented in Chapter 5, Section 5.10. The design establishes the coolant flow rate, core inlet coolant temperature, core temperature differential and core pressure differential required for maintaining the core within specified safety conditions. As a result of this analysis the required coolant flow rate indicated in the design basis conditions is established for the Power state.

The core thermal hydraulic parameters and other circuit characteristics are used as input for the calculation of the PCS mass and energy balance, to obtain the process flow diagram and the circuit hydraulic behaviour, with CHEMCAD 5.0.01 Chemstations Inc. software.

Engineers Aide SINET-XLT 5.3, Epcon International is used to perform head loss calculations for pipe networks and CRANE Companion 2.50 ABZ Inc. is used for single pipeline calculations.

Flow rate, available head loss and SCS data are inputs for a preliminary design of the heat exchangers. The final design of the heat exchangers to suit the needs of the circuit is then carried out by the manufacturer.

Selection of the appropriate pump is carried out on the basis of the analysis with the aid of the pump characteristic curves provided by the manufacturer. An adequate safety margin is assigned to ensure that the system capability will exceed the requirement of the design bases for the reactor at the Power state, and to fulfil the PCS Category 2 Safety function.

The PCS transient that takes place when the reactor and the PCS pumps are shutdown is analysed by means of the RETRAN code, to determine the core flow rate during pump coast down, and the optimum opening time for the PCS flap valves. Opening time is determined by the maximum power that can be removed under natural circulation conditions, in order to avoid the onset of nucleate boiling.

The fail-safe characteristics of the flap valves together with the high level of redundancy provided ensures a high reliability in the establishment of natural circulation of the reactor core following any condition that results in the shutdown of the PCS pumps.

The core pressure drop corresponding to the maximum core power level to be cooled by natural circulation is established and used as input for the mechanical design of the flap valves, ensuring that decay heat is extracted according to the design basis.

The failure of a PCS pump with abrupt shutdown is covered by the remaining pump that keeps running, as explained in Chapter 16, Section 16.9, where this and other incidents are analysed.

An appropriate safety margin has been assigned to the thermal capacity of the system to ensure its adequate performance in any postulated condition (Chapter 5, Section 5.8).

Appropriate safety margins have been employed in the capacities of the components and piping and fixing devices to ensure the integrity of the PCS boundary regarding internal pressure, corrosion, water quality (Section 6.4.4 Chemistry of Reactor Coolant) and seismic hazard (Section 6.2.11).

The pumps of the PCS are constructed of materials with good ductility.

All major valves in the PCS are butterfly valves. As the valves are part of the PCS pipework which is rigidly fixed to the reactor building walls and ceiling, the effect of a seismic event would be to cause the system to move as one item and to impose only minimal bending moments on the valve bodies. It should also be noted that the loads on the valve bodies are imparted by through-bolts that go right through the valve body from the flanges on each of the pipe ends. This ensures that only compressive loads are applied to the valve bodies. The structural evaluation of these components, including FEA, to determine the effects of the various loading cases, thermal, structural, seismic etc, has shown that the valves are appropriately selected. The use of cast iron for valve bodies is well accepted and is shown by analysis to meet required standards.

To maintain its structural integrity (safety design basis (e) above), the PCS is designed in accordance with the requirements of its safety categorisation. It is further protected from internal and external hazards by the Reactor Building. A Failure Mode and Effects Analysis of the PCS has been carried out. The analysis provided a list of PCS related initiating events which have been evaluated in Chapter 16, namely: Loss of Normal Power (Section 16.7), reactivity insertion events (Section 16.8), Loss Of Flow Accidents (LOFA) (Section 16.9), Loss of heat sink event (Section 16.10) and LOCA (Section 16.11). The sequence of events triggered by each postulated initiating event was analysed and modelled. The end-state for each sequence was a reactor in a safe shutdown condition with a non-exposed core and core cooling by natural circulation.

A stress analysis for nine relevant static load cases was performed for the primary circuit. The analysis also included the dynamic cases for the seismic event, presented in the subsection 6.2.11.

The applicable codes, calculation hypotheses, input data and models used are presented in Section 6.2.11. The circuit was modelled with six interconnected parts (see subsection 6.2.11.3).

The list of static cases analysed are:

Static Case Nr.	System Condition
ST1	Normal operation
ST2	Design
ST3	Accident case at 100ºC
ST4	Operation combination
ST5	Design combination
ST6	Hydrostatic test
ST7	Operation combination
ST8	Design combination

ST9	Combination for accident case at 100ºC

6.2.10.1 Reactor Pool to Decay Tank Model -Static case

All cases were within allowable limits.

For this pipeline section, case ST4 considers self-weight, operating pressure on the piping and operating pressure for the Decay Tank while case ST5 considers self-weight and the design pressure on the piping without the pressure on the Decay Tank .

6.2.10.2 Decay Tank to connecting node model - Static case

All cases were within allowable limits.

For this pipeline section, case ST4 considers self-weight, operating pressure on the piping and operating pressure for the Decay Tank, while case ST5 considers self-weight and the design pressure on the piping without the pressure on the Decay Tank.

6.2.10.3 Connecting node to Primary Pump model - Static case

All cases were within allowable limits.

6.2.10.4 Primary Pump to Heat Exchanger model - Static case

All cases were within allowable limits.

6.2.10.5 Heat Exchanger to Reactor Pool model - Static case

All cases were within allowable limits.

6.2.10.6 Reactor Pool To Pump Room model - Static case

All cases were within allowable limits.

The results for the 6 static cases show that the maximum stress values of piping and components, for the different load cases (9) analyzed do not exceed the limits set by the applicable codes and manufacturers.

6.2.11 Seismic Evaluation

The PCS is classified Seismic Category 1. That means that the components of the system must maintain their structural or safety function during and after the SL-2 earthquake.

The seismic stress evaluation performed followed the recommendations of IAEA and USNRC about design criteria for the resistance against seismic hazard (see Chapter 2, section 2.6.1). It was applied to the PCS design resulting from the detailed engineering stage, and considered:

a) the acceleration spectra for the building positions where systems are fixed
b) consideration of the fixing characteristics
c) consideration of the mass of water contained within the system
d) stress evaluation in piping, components and fixing points

This seismic analysis is part of the stress analysis performed for the system. The purpose of this analysis is:

- To verify that the design of the pipelines corresponding to the Primary Cooling System meets the requirements of the ASME Code as regards stress including seismic loads.

- To verify that the loads imposed on the equipment including those to the seismic event are within allowable limits.

The applicable codes are:

a) ASME to be used in the analysis of the pipelines

b) Allowable loads of the pumps provided by the manufacturer

c) Allowable loads of the heat exchangers provided by the manufacturer

The seismic evaluation involved the pipelines of the primary cooling system outside the reactor pool including main components interactions (pipes, valves, pumps, vessels, heat exchangers, fittings).

The analysis was performed using the following codes:

CAESAR II 4.30

ANSYS 5.7

6.2.11.1 Hypotheses of the Analysis

The main hypotheses used in this analysis are:

a) Friction on the sliding supports is not considered.

b) Pipeline reducers are modelled as pipeline sections of a length equal to that of a standard reducer. The diameter and thickness adopted are the average of both diameters.

c) Assembly temperature is assumed as 21ºC

d) Decay tank is modelled as to represent realistic boundary conditions on the piping.

e) The amplification effect of the seismic event on the pipelines by the decay tank is considered.

6.2.11.2 Input Data

The basic input data used in this analysis consists of:

a) Dimensions, geometry and design characteristics of piping and equipment corresponding to the detailed engineering stage and when appropriate/available provided by the manufacturer.

b) Process data, including:

   (i) Operating and design states of Decay Tank

   (ii) States of the lines of the Reactor Pool to Decay Tank to Primary Pump Circuit

   (iii) States of the lines of the Primary Pump to Reactor Pool

c) Materials characteristic extracted from ASME Boiler & Pressure Vessel Code.

d) Seismic Spectra for seismic class SL-2 for the relevant levels,obtained from the Seismic Design Floor Response Spectra defined for the Reactor Building, which corresponds to 0.37 PGA.

6.2.11.3 Model Description

The PCS was divided into the following six parts, to produce the finite element models:

a) Reactor Pool to Decay Tank
b) Decay Tank to Connecting Node
c) Connecting Node to Primary Pump
d) Primary Pump to Heat Exchanger
e) Heat Exchanger to Reactor Pool
f) Reactor Pool to Pump Room

6.2.11.4 Definition of dynamic cases

The following list includes the dynamic cases analysed and their definitions:

DY1	Seismic event combination
DY2	Seismic event combination verified by ASME

6.2.11.5 Summary of Results

The results corresponding to the six sectors into which the analysis has been divided are presented for the dynamic case corresponding to the seismic event.

6.2.11.5.1 Reactor Pool to Decay Tank Model

All cases were within allowable limits.

6.2.11.5.2 Decay Tank to connecting node model - Dynamic case

All cases were within allowable limits.

6.2.11.5.3 Connecting node to Primary Pump model - Dynamic case

All cases were within allowable limits.

6.2.11.5.4 Primary Pump to Heat Exchanger model - Dynamic case

All cases were within allowable limits.

6.2.11.5.5 Heat Exchanger to Reactor Pool model - Dynamic case

All cases were within allowable limits.

6.2.11.5.6 Reactor Pool To Pump Room model - Dynamic case

All cases were within allowable limits.

6.2.11.6 PCS Pumps

Regardless of size, pumps are very robust components that are capable of resisting earthquakes in excess of SL-2. EPRI NP-6041 “A Methodology for Assessment of Nuclear Power Plant Seismic Margin” (October 1988) states that:

“For horizontal Pumps, where the failure mode is assumed to be failure of the drive shaft, the HCLPF capacities calculated in SPRAs have been less than 0.5g pga.

However the Panel believes that this failure mode is conservative and shaft bending and pump failure will not occur during or immediately after an earthquake…Experience data indicate that many pumps have survived earthquakes without damage for 0.5g pga."

Therefore, no special qualification will be required to the PCS pump or motor themselves. They are qualified based on earthquake experience both for Seismic Categories 1 and 2. This qualification by experience covers both electrical motor and the pump itself.

An analysis was performed to design the pump anchorage and bolts under seismic load. The analysis was carried out with Strand 7 (Finite Element Analysis Package). The analysis showed that the foundations and anchorage design withstand the SL-2 earthquake.

6.2.11.7 Heat Exchangers

The behaviour of the heat exchangers under seismic load was analysed with a FEM programmed in the Strand 7 code.

All stresses cases were within allowable limits.

6.2.11.8 Decay Tank

The behaviour of the decay tank under seismic load was analysed with a FEM model using NASTRAN. The input includes the geometric and material data of the tank. A combination of dynamic and static load (pressure plus weight) is applied.

The acceptance criterion is established by ASME. The analysis shows that the maximum stress is within acceptable values as established by the applicable code.

6.2.11.9 Conclusions

From the summary of results given above it concludes that the stress on the pipelines for the different load cases do not exceed the limits set by the applicable codes.

Stress on the exchangers does not exceed the maximum allowable values set by the manufacturer for the operation and seismic event states.

The anchorage of the PCS pumps can withstand the action of an SL-2 event.

The decay tank can withstand the action of an SL-2 event.

End of Section

6.3 REACTOR AND SERVICE POOLS COOLING SYSTEM

6.3.1 Introduction

The Reactor and Service Pool Cooling System (RSPCS) has been designed to meet the following requirements:

a) To provide coolant flow to remove the heat from the rigs during reactor operation in the Power state.

b) To maintain steady coolant inlet temperature to the rigs over the range of normal operating conditions.

2. To remove decay heat from the rigs when none of the PCS pumps is in operation.
3. To ensure an adequate temperature margin in the rigs during postulated transients.
4. To circulate water from the Reactor and Service Pools to the Reactor Water Purification System (RWPS) in order to maintain the purity of the demineralised water within the specified levels.

To achieve these functions, the flow through the rig channels is downward during forced circulation and upward during natural circulation operation and there is a flow reversal during the transition between the two.

The RSPCS removes heat from the irradiation rigs and residual core heat from the Reactor Pool, and spent fuel decay heat from the Service Pool by forced circulation of demineralised water. The RSPCS transfers heat to the Secondary Cooling System (SCS) through the RSPCS Heat Exchanger. The portion of the RSPCS inside the Reactor Pool is also capable of removing the decay heat from the rigs by natural upward circulation of the water using the large thermal capacity of the pool as the heat sink.

The RSPCS comprises the circuit piping, a decay tank, two main pumps, two Long Term Pool Cooling pumps, a heat exchanger, associated instrumentation and pipe fitting components, valves in general, flap valves within the Reactor Pool, a toroidal distributor, siphon breakers in all suction and discharge lines and a three-way valve to allow transition from Rigs Cooling Mode (RCM) to Long Term Pool Cooling Mode (LTPCM).

The alignment of the three-way valve determines which pipeline branch is selected: the Rigs Cooling branch or the LTPC branch. Each of these branches is associated with separate operational modes of the system.

During normal operation, the three-way valve is aligned open to the Rigs Cooling branch. During a reactor shutdown, it is possible to switch the water intake to the suction placed at the side of the upper chimney, immediately above the core. This, with the opening of the PCS flap valves, provides an additional means to remove the decay heat from the core. This would normally be done following removal of heat generating rigs from the Reflector Vessel irradiation facilities.

6.3.2 Safety Design Bases

The RSPCS has been designed to meet the following safety design bases:

5. To provide sufficient coolant flow during postulated transients for rigs cooling by natural circulation to avoid critical heat flux in the coolant channels of irradiation rigs when the circulation pumps are not in operation.

6. To remove decay heat from the Reactor Pool in the long term to maintain its temperature within the specified operational range in the Shutdown state.
7. To remove fission heat by forced circulation from the irradiation rigs when the reactor is in the Power State. This thermal load was established in the thermal hydraulic design of irradiation rigs, described in Chapter 5, Section 5.8.
8. To remove decay heat from spent fuel stored in the Service Pool during all Reactor States. This thermal load was established based on the maximum number of fuel assemblies to be stored in the Service Pool and the spent fuel decay curve.

- To maintain its integrity during adverse combinations of loading and forces occurring in abnormal conditions.

6.3.3 Reactor and Service Pools Cooling System Circuit Description

The RSPCS pumps and associated equipment are located inside the containment. The decay tank is located inside a room shielded by heavy concrete walls.

The RSPCS has three suction lines: two suction lines are in the Reactor Pool and one in the Service Pool and two discharge lines, one in each pool.

6.3.3.1 Main Cooling Circuit

Demineralised water is the coolant used in the RSPCS.

The RSCPS is open to the Reactor Hall atmosphere through the Reactor and Service Pools. The pressure at the rigs inlet is equal to the atmospheric pressure plus the water column above the rigs.

The Service Pool is connected to the Reactor Pool by a transfer canal. This canal provides a transport route for irradiated rigs and spent fuel from the Reactor Pool to the Service Pool and also ensures hydraulic equilibrium between the pools. An isolation gate may be positioned in order to isolate the pools for maintenance purposes.

RSPCS water flows downward through the rigs into the Rigs Plenum and is drawn into a pipe which runs upwards to where it exits the Reactor Pool boundary. A siphon breaker is provided at this section of pipe. The pipe then goes to the three-way valve and then to the RSPCS Decay Tank.

The main coolant line exits the RSPCS Decay Tank and the concrete shielding and meets the flow coming from the Service Pool.

The main pipeline splits into two branches and joins the flow coming from the RWPS. Each branch has a RSPCS main pump. One pump in service will provide adequate cooling capacity for reactor full load operation, while the other pump is on standby.

The coolant flows from the pump discharge to the RSPCS heat exchanger, transferring heat to the SCS.

The main pipeline splits into two branches after passing through the heat exchanger. One of these lines joins the flow coming from the Interconnection Line, from the PCS, and enters the Reactor Pool where there is a siphon breaker. The cooling water is discharged through a toroidal distributor device at the bottom of the Reactor Pool.

A small fraction of the flow returning to the Reactor Pool is directed through four pipelines to the bottom of the heavy water pipelines jackets in order to refresh and prevent stagnant water in jackets.

After the heat exchanger, the other pipeline enters the Service Pool. This pipe has a siphon breaker. The cooling water is discharged through a distribution device located at the bottom of the pool.

A small fraction of the flow returning to the Service Pool is diverted through a pipeline to the Service Pool Elevator duct to the Transfer Hot Cell. This is to prevent accumulation of stagnant water at the Elevator duct.

6.3.3.1.1 Rigs Cooling

The Rigs Cooling circuit is designated Safety Category 1, an Engineered Safety Feature (ESF) for rigs cooling by natural circulation during abnormal conditions when the main pumps are not in service.

The Rigs Cooling circuit has a pipe that extends from the Irradiation Rig Plenum below the Reflector Vessel and passes through the Reactor Pool boundary. Beyond the reactor pool boundary, it is connected to the three way valve and then to the RSPCS Decay Tank.

The pipe has flap valves and a siphon breaker.

The Rigs Cooling circuit also performs the Safety Category 2 function of rigs cooling when the reactor is in the Power state and a pump is in service.

6.3.3.1.2 Long Term Pool Cooling and Remaining Safety Category 2 RSPCS Circuit

The RSPCS has an additional pumping group known as the LTPC pumps. These two smaller-capacity pumps may be used when it is required to remove the core decay heat for a long period of time.

These pumps are also provided with a connection to the Standby Power Supply. When these pumps are in operation, the three-way valve is aligned with the flow coming from the LTPC branch in the Reactor Pool, and the water inlet to the pipe is taken from the side of the upper chimney, immediately above the core. This branch has a siphon breaker before leaving the pool. It passes through the concrete of the reactor block to join the other suction branch at the three-way valve.

The circuit leaves the RSPCS Decay Tank via a single pipe, which is connected, to the suction lines of the main and LTPC pumps. Upstream of the pump suction is a pipe connection from the Service Pool.

The system has two alternative pumping groups: the main pump group has two 100% capacity pumps in a parallel array. The LTPC pump group has two 100% lower power pumps, also arranged in a parallel configuration.

After the pumping stage, the circuit is directed to a Plate Type Heat Exchanger the secondary side of which is connected to the SCS. From the Heat Exchanger one pipe returns to the Service Pool and one pipe returns to the Reactor Pool. The Reactor Pool branch meets the interconnection line from the PCS before entering the pool.

A connection at the pump outlet diverts a fraction of the flow to the Reactor Water Purification System (RWPS), which maintains the required water quality for both the PCS and the RSPCS.

6.3.3.2 RSPCS Flap Valves and Siphon Breaker

The purpose of the valves is to guarantee natural circulation flow through the irradiation facilities when the RSPCS main pump is stopped.

The flap valves are located on the rigs cooling branch).

The valves are closed when the RSPCS is in Rigs Cooling Mode due to the differential pressure between the RSPCS and the Reactor Pool. Once the pump is stopped, this differential pressure decreases gradually according to the dynamics of the inertia, and the flap valves open.

Opening of one Flap Valve is enough to guarantee enough water flow for adequate cooling of the rigs.

The valves flanges can be assembled from the top of the pool.

The valve is provided with position sensors located on the fixed part of the valve, activated by a permanent electromagnet, which give indication of the closed status. The signal is triplicated and goes to the RPS.

Functional tests during valve manufacturing have tested the following:

a) Mock-up to determine operation and working reliability

b) Tests to determine possible flow leaks when the valve is in the closed state

Calibration during pre-operational tests will be carried out for:

a) Instruments to measure the closed state of the valve

b) Counterweights for proper opening and closing action

Possible faults of the valve were analysed with the following results:

a) The maximum gap between the disc and the seat valve falls within admissible flow leak levels.

b) The valve is coupled to the pipeline by means of operation nuts that allow mounting or dismounting the valve from the pool to carry out required maintenance tasks.

c) A special seal between the valve and the connection to the pipeline prevents water leaks. The seal design allows its inspection or removal. The seal is not airtight.

d) There are no loose elements that could fall inside the RSPCS pipeline, since all hazardous elements are outside the pipeline or else duly welded and bound.

In the event of a LOCA of the RSPCS, the Reactor Pool is protected from draining completely by siphon breakers in the suction and discharge lines of the RSPCS. The water above the siphon breakers can be contained in a LOCA drainage system.

6.3.3.3 Pump Inertia

The inertia of each of the RSPCS main pumps prevents a sudden drop of the coolant flow through the rigs in the event of loss of Normal Power or failure of the pump motor. This flow rate is sufficient to remove decay heat during the transient that goes from pump stop to natural circulation cooling.

6.3.3.4 Interconnection Line

The PCS pump discharge line has an Interconnection Line that diverts a fraction of the PCS cooling flow to the RSPCS. This flow joins the flow coming from the RSPCS pumps before it enters the Reactor Pool.

The Interconnection Line fulfils a radiological protection function by contributing to preventing activated water from reaching the upper part of the Reactor Pool.

6.3.3.5 Waste Management

Water from all the drainage points in the RSPCS flows into the Radioactive Liquid Waste Management System (RLWMS).

Release of radioactive gases from the Reactor Pool Surface is handled by the ventilation system, which extracts air from the pool top.

Radioactive gases, including those arising from water radiolysis, flow to the RSPCS Decay Tank as a result of the downward water flow forced into the rigs plenum. These gases are allowed to decay in the tank and, after decaying, can be vented through a venting pipe that runs from the decay tank to the top of the Service Pool. The ventilation system described in Chapter10, Section 10.4, takes these gases to the stack.

6.3.3.6 RSPCS Modes

The RSPCS can operate in three System Modes:

a) Rigs Cooling Mode (RCM)

b) Long Term Pool Cooling Mode (LTPCM)

c) Shutdown Mode (SDM)

The distinction between these System Modes lies basically in the position of the three-way valve and which RSPCS pumps are in operation.

When the reactor is in the Power State, the RSCPS can operate only in the Rigs Cooling Mode.

During reactor operation in the Physics Test state, the RSPCS can operate in the Rigs Cooling Mode or Shutdown Mode.

When the reactor is in the Shutdown state, the RSCPS can operate in the Rigs Cooling Mode, the Long Term Pool Cooling Mode or the Shutdown Mode.

When the reactor is in the Refuelling state, the RSPCS can operate in the Shutdown Mode only.

The following table summarises which system mode corresponds to each reactor state:

Reactor State	System Mode		
	RCM	LTPCM	SDM
Power	Required	Not Allowed	Not Allowed
Physics Test	Allowed	Not Allowed	Allowed
Shutdown	Allowed	Allowed	Allowed
Refuelling	Not Allowed	Not Allowed	Required

The main characteristics of the RSPCS operating modes are:

Reactor State	RSPCS System Mode	Three-way valve position	RSPCS Configuration	RSPCS Flap Valves Position	RSPCS Function

Reactor State	RSPCS System Mode	Three-way valve position	RSPCS Configuration	RSPCS Flap Valves Position	RSPCS Function
Power	RCM	Rigs cooling branch	1 RSPCS Main Pump in operation	Fully closed	Heat removal from rigs
Physics Test	RCM	Rigs cooling branch	1 RSPCS Main Pump in operation	Fully closed	Heat removal from rigs
	SDM	Either Rigs Cooling Branch or LTPC branch	No RSPCS Pumps in operation	Fully open	Heat removal from rigs
Shutdown	RCM	Rigs cooling branch	1 RSPCS Main Pump in operation	Fully closed	Rigs decay heat removal
	LTPCM	LTPC branch	1 RSPCS Main Pump or 1 RSPCS LTPC Pump or 2 RSPCS LTPC Pumps in operation	Fully open	Core decay heat removal
	SDM	Either Rigs Cooling branch or LTPC branch	No RSPCS Pumps in operation	Fully open	Rigs decay heat removal
Refuelling	SDM	Either Rig Cooling branch or LTPC branch	No RSPCS Pumps in operation	Fully open	Rigs decay heat removal

6.3.3.6.1 Rigs Cooling Mode

In the RCM, the three-way valve is aligned to the Rigs Cooling branch and one RSCPS main pump is in operation to guarantee the required coolant flow through the rigs, involving both circuits outside and inside the Reactor and Service Pools.

The RSPCS flap valves are maintained in their closed position by the suction action of the pump causing the pressure differential between the circuit and the Reactor Pool. The rigs cooling branch delivers water to the RSPCS Decay Tank, which has a large enough volume for decay of the dissolved activated nitrogen-16.

6.3.3.6.2 Transition from RCM to LTPCM

The transition from the Rigs Cooling Mode (including cooling of the service pool) to LTPC Mode is carried out manually by the operator after the reactor is in the Shutdown state. This is brought about by switching the position of the three-way valve and switching over the operation of the main pump to that of the LTPC pump.

This transition does not affect nuclear safety, but is advisable as it makes optimum use of the reactor and supporting equipment. The Operation Manual includes specific instructions on how to make this transition.

6.3.3.6.3 Configuration for Long Term Pool Cooling Mode

6.3.3.6.3.1 Long Term Pool Cooling for Reactor and Service Pools Pumps

When the RSPCS is in the LTPCM, the three-way valve is aligned to the LTPC branch and the RSPCS can operate with any of the following combination of RSPCS pumps:

1 Main Pump

1 LTPC pump

2 LTPC pumps

In the LTPC Mode of the RSPCS, the pump takes water from the Chimney just above the core. This position of the suction point for the RSPCS has the advantage that it reduces the flow that, having gone through the core as a result of natural circulation, will reach the upper level of the pool; hence preventing the flow from disturbing the hot water layer.

Moreover, due to its location above the core, the suction line of the LTPC mode will receive a large portion of the core decay heat removed by natural circulation.

The highest thermal load due to core decay heat that could be required to be removed corresponds to core power 80 seconds after shutdown. For the reactor at full power of 20 MW, 80 seconds after shutdown the power will be approximately 800 kW.

It should be noted that after the reactor shutdown, with the core cooled by PCS natural circulation, the decay heat of the core is removed by the water inventory of the reactor pool and the capacity of the pump in service is not important in respect of core cooling. The RSPCS may, in fact, not operate at all, without representing a hazard to the reactor.

6.3.3.6.4 Shutdown Mode

In the SDM, all RSPCS pumps are stopped and the three-way valve can be configured in either position: open to the Rigs Cooling or the LTPC branches. It may take place either as a result of normal reactor shutdown, or reactor shutdown under abnormal conditions such as after the loss of the RSPCS main pump.

The event of a reactor shutdown under abnormal conditions with the loss of the RSPCS main pump is analysed in Chapter 16, Sections 16.15 and 16.7. In these cases the flap valves of the RSPCS open and natural circulation is established through the Rigs Cooling branch to ensure cooling of the rigs.

6.3.3.7 Cooling for the Service Pool

Spent fuel elements will constitute the main heat source in the Service Pool. Heat will be removed from spent fuel by the natural circulation of the Service Pool water.

The RSPCS branch in the Service Pool has the function of removing heat from the pool and maintaining the pool temperature within nominal operational values. A thermal load equivalent to the total number of spent fuel stored after 10 years of reactor operation is considered. This heat load can be removed either by the main pump or by the LTPC pump in operation.

The Service Pool branch of the RSPCS is in operation during all system modes of the RSPCS.

6.3.4 Reactor and Service Pools Cooling System Components

6.3.4.1 Flap valves

Parameter	Value
Quantity	2
Type	Mechanical flap valve
Construction Material	Austenitic Stainless Steel

6.3.4.2 Siphon breakers

Type	Position
Orifice Protection: mesh cover	Rigs cooling branch
Orifice diameter: 25 mm Protection: mesh cover	LTPC branch
Orifice Protection: mesh cover	Reactor pool, inlet pipe
Orifice Protection: mesh cover	Service Pool branch

6.3.4.3 Main Pumps

Parameter	Value
Quantity	Two
Type	Centrifugal
Capacity	100 %
Accessories	Instrumentation: Temperature measurement in motor winding and bearings Vibration monitoring in bearings, mild steel
Moment of inertia of all pump set	11 kg m^2

6.3.4.4 Long Term Pool Cooling Pumps

Parameter	Value
Quantity	Two
Type	Centrifugal
Capacity	100%

6.3.4.5 Heat Exchanger

Parameter	Value
Quantity	One
Type	Plate type

Fluids direction	Countercurrent
Sealing material	EPDM

6.3.4.6 Decay Tank

Parameter	Value
Quantity	One

6.3.5 Reactor and Service Pools Cooling System Instrumentation

The RCMS and the RPS monitor the RSPCS operational parameters.

The RCMS initiates actions to maintain parameters within the pre-set range and administers Defence in Depth Level 2 protective actions.

The RPS commands trip actions if any of those parameters reach the trip set point.

The RSPCS main pumps can be started and stopped from the RCMS in the Main Control Room as well as in the field.

Hardwired Control Logic stops an individual pump when there is:

a) Very high temperature in any motor winding

b) Very high vibration in bearings

Hardwired Control Logic also prevents the start of the stand-by pump when the other pump is operating.

Stopping of an operating pump will cause a reactor trip due to low flow rate in the RSPCS signal.

Instruments associated with the RPS are triplicated.

6.3.5.1 Flow

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Flow meter & transmitter	Rigs cooling branch, inlet to decay tank	FRPS & RCMS	Indication Low Flow Alarm	Reactor trip 1 due to rigs low cooling flow in the Power state Reactor trip 1 due to high flow in the Physics Test state
Flow meter & transmitter	Service Pool outlet	RCMS	Indication	None
Flow transmitter	Outlet Heat exchanger	RCMS	Indication	None
Flow transmitter	Return pipeline to Service Pool	RCMS	Indication	None
Flow switch	Inlet Heat Exchanger	RCMS	Low flow alarm	None

6.3.5.2 Pressure

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions

Differential Pressure Transmitter	Reactor Pool and Rigs discharge plenum	RCMS	Indication High and low pressure difference alarm	None

6.3.5.3 Temperature

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature sensor & transmitter	Heat Exchanger inlet	RCMS	Indication High temperature Alarm	None
Temperature sensor & transmitter	Heat Exchanger outlet	RCMS	Indication High temperature Alarm	None
Temperature switch	Main pump motor windings	Field	None	Protection relay stop pump when high temperature is detected
Temperature sensor	Main pump set bearings	RCMS	Indication High temperature alarm	None

6.3.5.4 Valve Position

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Position switch	Flap Valves	FRPS & RCMS	Indication	Signal of “not fully closed valve” triggers reactor trip 1.
Position switch	Three way valve	RCMS	Indication	None

6.3.5.5 Conductivity

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Conductivity transmitter	Reactor Pool outlet	RCMS	Indication High conductivity alarm	None
Conductivity transmitter	Service Pool outlet	RCMS	Indication High conductivity alarm	None

6.3.5.6 Vibration

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Vibration Switch	Main pump set bearings	RCMS	High vibration alarm	None

Vibration Switch	Main pump set bearings	RCMS	Very high vibration alarm	Pump trip.

6.3.5.7 Fission Product Detection

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Fission Product Monitor	Rigs cooling branch outlet pipeline, before decay tank	RCMS	Alarm	None

6.3.5.8 Reactor and Service Pools Level

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Level switch	Service pool	RCMS	Low level alarm	None
Level switch	Service pool (upper spent fuel level)	PAM & RCMS	Low level alarm	None
Level switch	Reactor pool (chimney edge level)	PAM & RCMS	Low level alarm	None
Level switch	Reactor pool (core level)	PAM & RCMS	Low level alarm	None

6.3.6 Actions on RPS and RCMS due to Reactor and Service Pools Cooling System Signals

The Instrumentation and Control System is described in Chapter 8. This Section reproduces the main actions of the RPS and RCMS associated with the RSPCS.

6.3.6.1 Reactor Trip Signals

In the Power state a Trip 1 signal is generated on low rigs cooling flow. In addition, one or more flap valves not fully closed generates a Trip 1 signal. In the Physics Test state a Trip 1 signal is generated if rigs cooling flow is low and the flap valves are close. In addition, a Trip 1 signal is also generated if rigs cooling flow is high and the flap valves are open.

6.3.6.2 Manual Shutdown

Condition	Operator Action
High vibration alarm on main pump set bearing	The operator will evaluate the situation and take appropriate corrective actions.
High temperature alarm on main pump set bearing	
High or low pressure drop in rigs plenum	

6.3.6.3 Interlocks

Condition	Interlock
One main RSPCS pump in operation	Start-up of the stand by pump is not allowed.
Failure of the main operating pump	No automatic start-up of the stand-by pump

Condition	Interlock
Failure of the main operating pump	The pump is not allowed to start-up again until a manual reset of the control logic has been performed.
Low flow is detected in the system shortly after pump start up	Shutdown of the pump. Reactor start-up not allowed
Main pump shut-down and start-up signal are transmitted simultaneously by mistake	The shut-down signal has priority
Flow transmitter connected to FRPS detects low flow.	Reactor start-up not allowed
Three-way valve is not in the Rigs Cooling position	Reactor start-up not allowed
Switching of three-way valve to LTPC position	Not allowed during the Power state
Switching of three-way valve to LTPC position	Not allowed if flow or pressure drop is detected in the Primary Cooling System
Flap Valve is not fully closed	Reactor start up not allowed

6.3.7 Inspection and Testing

The inspection and testing program for fabrication, assembly, pre-operation and in-service operation was developed during detailed engineering in accordance with the Construction Inspection and Test Plan (CITP).

6.3.8 Reactor and Service Pools Cooling System Design Evaluation

The RSPCS meets the safety design bases:

a) It is able to provide sufficient coolant flow during postulated transients for rigs cooling by natural circulation to avoid the critical heat flux in the coolant channels of irradiation rigs when the circulation pumps are not in operation.

b) The Safety Category 1 function of the RSPCS extracts heat from the irradiation rigs after any postulated fault sequence and during the reactor Shutdown State by means of rigs cooling by natural circulation.

c) It is capable of removing decay heat from the Reactor Pool in the long term to maintain its temperature within the specified operational range during reactor operation or during the Shutdown State.

d) It is capable to remove heat by forced circulation from the irradiation rigs when the reactor is operating in the Power State.

e) The RSPCS extracts heat from irradiation rigs during reactor operation in the Power and Physics Test states and maintains the Reactor Pool temperature within the range of normal operational conditions.

f) The design of the RSPCS was performed on the basis of the maximum expected power to be dissipated at the irradiation targets. This was established by means of validated calculation codes and conservative assumptions that, together with appropriate safety margins for the thermal capacity of the system ensure its adequate performance in any postulated condition. Conservative assumptions, safety margins and calculation codes for thermal-hydraulic design are presented in Chapter 5, Section 5.8.

g) It is capable of removing decay heat from spent fuel stored in the Service Pool during all reactor States, with the maximum number of fuel assemblies stored in the Service Pool.

h) It maintains its integrity during adverse combinations of loading and forces occurring in abnormal conditions.

For all the above safety design basis, the inlet-outlet temperature difference across the rigs was established to have a similar temperature in all circuits to be cooled by the SCS. Rigs Cooling requirements and RSPCS circuit characteristics are used as input for the calculation of the RSPCS mass and energy balance to obtain the process flow diagram and the circuit hydraulic behaviour, with CHEMCAD 5.0.01 Chemstations Inc. software. The optimisation of electricity consumption and equipment capacities are also taken into consideration.

Engineers Aide SINET-XLT 5.3, Epcon International is used to perform head loss calculations for pipe networks and CRANE Companion 2.50 ABZ Inc. is used for single pipeline calculations.

Flow rate, available head loss and SCS data are inputs for a preliminary design of the heat exchangers. The final design of the heat exchangers to suit the needs of the circuit is then carried out by the manufacturer.

Selection of the appropriate main pumps and LTPC pumps is carried out on the basis of the analysis, based on pump characteristic curves provided by the manufacturer, with the assignment of an adequate safety margin, ensuring the system capability to meet the design bases.

The main pumps of the RSPCS have stainless steel casings, a material with good ductility.

All major valves in the RSPCS are butterfly valves and have cast iron bodies and stainless steel discs and stems. The use of cast iron for these valves is common practice in research and power reactors and the valves are required to be qualified for use to their specified seismic class and safety category.

As the valves are part of the RSPCS pipework, which is rigidly fixed to the reactor building walls and ceiling, the effect of a seismic event would be to cause the system to move as one item and to impose only minimal bending moments on the valve bodies. It should also be noted that the loads on the valve bodies are absorbed by the through-bolts that go right through the valve body from the flanges on each of the pipe ends. This ensures that only compressive loads are applied to the valve bodies. The structural evaluation of these components, including FEA, to determine the effects of the various loading cases, thermal, structural, seismic etc, has shown that the valves are appropriately selected. The use of cast iron for valve bodies is well accepted and is shown by analysis to meet required standards.

The RSPCS pumps have sufficient inertia to ensure adequate rigs cooling during the transition from forced to natural circulation cooling. The RSPCS transient that takes place when the RSPCS pumps are shutdown is analysed by means of the RETRAN code. This is to determine the decrease in the rigs cooling flow rate and flow inversion during pump coast down, and the minimum opening time for the RSPCS flap valve. The opening time is determined by the maximum power that can be removed under natural circulation conditions, in order to avoid the onset of nucleate boiling.

The pressure drop along the rigs corresponding to the maximum power level to be cooled by natural circulation is established and used as input for the mechanical design of the flap valves, ensuring that decay heat after any postulated fault condition is extracted according to the design bases. Redundancy of the flap valves provides the system with the required Category 1 reliability.

The components, piping and fixing devices have been designed with appropriate safety margins in accordance with relevant standards to ensure the system integrity.

Dependent failure analysis of the simultaneous failure of the RSPCS main pump, or the LTPC pump, indicate that there are no consequences of safety significance, due to the fact that these systems do not fulfil any Safety Category 1 function.

The RSPCS is further protected from external hazards by the Reactor Building.

A FMEA analysis of the RSPCS was carried out. This yielded the list of initiating events that were analysed in Chapter 16 (Section 16.7, 16.10, 16.11, 16.15.2.2). Each postulated initiating event concluded that in each case the irradiation rigs will remain adequately cooled and the reactor will remain in a safe condition.

The three-way valve is fail-open to the rigs cooling branch, ensuring rigs integrity.

6.3.9 Seismic Evaluation

The RSPCS is classified as Seismic Category 1 system, i.e. the components of the system must maintain their structural or safety function during and after the SL-2 earthquake

This seismic analysis is part of the stress analysis performed for the system. The purpose of this analysis is:

a) To verify that the design of the pipelines corresponding to the RSPCS meets the requirements of the ASME Code as regards stress including seismic loads.

b) To verify that the loads imposed on the equipment including those of the seismic event are below the allowable ones.

The applicable codes are:

a) ASME to be used in the analysis of the pipelines.

b) Allowable loads of the heat exchangers provided by the manufacturer.

c) Allowable loads of the pumps provided by the manufacturer.

The seismic evaluation involved the pipelines of Reactor & Service Pool Cooling System

The analysis was performed using the code CAESAR II 4.30 program for the analysis of stress on pipelines. The dynamic analysis made corresponds to the response spectrum method - total response (displacement, stress, etc).

The analysis was restricted to the load states indicated in Section 6.3.9.4.

6.3.9.1 Hypotheses of the Analysis

The main hypotheses used in this analysis are:

a) Friction on the sliding supports is not considered.

b) The calculation model simulates the pipeline design configuration with the positions of adequate supports to meet the stability conditions in static and dynamic rates.

c) Pipeline reducers are modelled as pipeline sections of a length equal to that of a standard reducer. The diameter and thickness adopted shall be the average of both diameters.

d) Assembly temperature: 21ºC

6.3.9.2 Input Data

The basic input data used in the analysis consist of:

a) Dimensions, geometry and design characteristics of piping and equipment corresponding to the detailed engineering stage and when appropriate/available provided by the manufacturer.

b) Process data, including operation and design data for all the pipelines and components of the RSPCS, including the Decay Tank.

c) Characteristics of materials as obtained from the ASME Boiler & Pressure Vessel Code Section II – Part D.

d) Seismic Spectra for SL-2 for the relevant levels, obtained from the Seismic Design Floor Response Spectra defined for the Reactor Building, which corresponds to 0.37 PGA.

6.3.9.3 Model Description

The RSPCS was divided into 4 parts to produce the finite element models:

a) Heat exchanger to reactor pool and service pool

b) Reactor pool to decay tank

c) Decay tank to pump

d) Pump to heat exchanger

6.3.9.4 Definition of Dynamic Cases

DY1	Seismic event combination
DY2	Seismic event combination verified by B31.1

6.3.9.5 Summary of Results

This section presents the results for each of the four sections into which the RSPCS has been divided for the analysis.

6.3.9.5.1 Heat Exchanger to Reactor Pool And Service Pool

All cases were within allowable limits.

6.3.9.5.2 Reactor Pool to Decay Tank

All cases were within allowable limits.

6.3.9.5.3 Decay Tank to Pump

All cases were within allowable limits.

6.3.9.5.4 Pump to Heat Exchanger

All cases were within allowable limits.

6.3.9.6 RSPCS Pumps

The same principles stated in 6.2.11.6 for the PCS pumps apply for the RSPCS pumps.

6.3.9.7 Heat Exchanger

The analysis was performed using a FEM and the Strand 7 code.

6.3.9.8 Decay Tank

The Decay Tank FEM model was built using ANSYS 5.7 for Windows code. The input includes the geometric and material data of the tank. The applicable acceleration corresponds to Beam Hall Level (conservative), for the frequency corresponding to the first global oscillation mode. An equivalent static method was applied. The above accelerations are applied in the Decay Tank whole mass. A linear combination of the seismic accelerations was applied. An internal design pressure was also considered.

The calculations show that the maximum stresses are due to internal design pressure and not to the seismic event.

6.3.9.9 Conclusions

From the summary of results given above it is concluded that the stress on the pipelines for the different load cases do not exceed the limits set by the applicable codes.

Stress on the exchangers does not exceed the maximum allowable values set by the manufacturer for the operation and seismic event states.

The anchorage of the RSPCS pumps can withstand the action of an SL-2 event.

Stress on the decay tank does not exceed allowable limits.

6.4 REACTOR WATER PURIFICATION SYSTEM

6.4.1 Introduction

Water purification is achieved by diverting a fraction of the RSPCS flow to the purification system. Simultaneous purification of the two pools or individual purification of either one of them is possible.

The system includes two independent groups, each consisting of:

a) filter

b) resin exchange column

c) resin trap

One of the groups is in operation and the other, on standby.

Figure 6.4/1 shows a diagram of the system.

6.4.2 Safety Design Bases

The RWPS has been designed to meet the following design requirements:

a) To maintain the Reactor Pool and Service Pool water within purity grade by eliminating corrosion, fission and impurity traces.

b) To prevent build up of radioactivity in reactor coolant by removal of solids and dissolved fission products.

c) To maintain a high optical quality of Reactor Pool and Service Pool water by removal of non-soluble particles.

d) To provide protection for fuel cladding and core structure integrity by providing corrosion inhibition through keeping water conductivity below 1 μScm^{-1}.

6.4.3 Circuit Description

The equipment associated with the system is located inside the containment. The ion exchange columns and filters are located inside individual shielded rooms, with heavy concrete walls.

The operation of the valves is done manually from a remote location outside the shielded rooms. The system is operated continuously regardless of whether or not the reactor is in operation. It relies only on the operation of an RSPCS pump to provide the motive force for the system.

Water is pumped through a primary filter where non-soluble particles are retained. The filtered stream is then sent to a mixed bed ion exchange column where soluble and colloidal-type particles are eliminated. A resin trap placed at the column outlet prevents entrained resins from leaving the system.

The filters have a back-washing facility for cleaning by means of pressurisation with compressed air and a drain line. Valves are provided for sampling the quality of water at the inlet and outlet of the resin column.

Replacement of the resin column is required when:

a) water conductivity reading exceeds a pre-determined value

b) activity outside the biological shielding exceeds pre-set value

c) the column pressure drop exceeds a pre-set value

6.4.4 Chemistry of Reactor Coolant

6.4.4.1 Water Characteristics

The reactor coolant is demineralised water with the following characteristics:

Conductivity < 1 μScm^{-1}

pH: neutral

Non dissolved solids: < 0.5 ppm

6.4.4.2 Sources of Impurities

The impurities, non-dissolved particles and traces of corrosion, fission or radioactive impurities come from:

a) Fuel: erosion and corrosion of the cladding.

b) Reactor water surface: soluble and insoluble particles from the air in the reactor hall, and impurities resulting from operation activities including tools and rigs.

c) Corrosion of structural components: piping, equipment, pools and their internals.

6.4.5 Main Components

6.4.5.1 Ion Exchange Columns

Parameter	Value
Quantity	Two (one on stand-by)
Ionic exchange resins type	Nuclear quality mixed bed 1:1

6.4.5.2 Filter

Parameter	Value
Quantity	Two (one on stand-by)
Type	Cartridge

6.4.5.3 Resin Trap

Parameter	Value
Quantity	Two (one on stand-by)

6.4.5.4 Fresh Resins Transportation Facility

Parameter	Value
Quantity	one

6.4.6 Instrumentation

6.4.6.1 Conductivity

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Conductivity transmitter	Resins trap outlet	RCMS	Indication High conductivity alarm	None

6.4.6.1.1 Flow

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Flow transmitter	Inlet pipeline	RCMS	Indication	None

6.4.7 Actions on RCMS due to Reactor Water Purification System Signals

Condition	Operator Action
High conductivity alarm	The operator will evaluate the situation and take appropriate action.

6.4.8 Inspection and Testing

6.4.8.1 Fabrication and Assembly

The inspection and testing program for fabrication, assembly, pre-operation and in-service operation has been developed during detailed engineering in accordance with the Construction Inspection and Test Plan (CITP).

6.4.9 Design Evaluation

The RWPS meets the following safety design bases:

a) It is designed to keep Reactor Pool and Service Pool water within purity grade by eliminating corrosion, fission and impurity traces to maintain water conductivity below 1 μScm^{-1}.

b) It prevents build up of radioactivity in reactor coolant by removal of solids and dissolved fission products.

c) It will maintain a high optical quality of Reactor Pool and Service Pool water by removal of non-soluble particles.

d) It provides protection for fuel cladding and core structure integrity by providing corrosion inhibition through keeping water conductivity below 1 μS/cm.

The main requirement on the RWPS is to maintain the appropriate water quality to minimise corrosion of fuel element cladding, core and other pool internal structures and to avoid activity build up in reactor coolant.

The hydraulic design of the RWPS was performed with the aid of CHEMCAD 5.0.01 Chemstations Inc. software. Engineers Aide SINET-XLT 5.3, Epcon International is used to perform head loss calculations for pipe networks and CRANE Companion 2.50 ABZ Inc. is used for single pipeline calculations.

The appropriate performance of the system is determined by the choice of the resin beds and the polishing flow pattern that ensures one change of the water inventory in 21 hours or less.

The use of validated calculation codes and conservative assumptions ensure that the system will perform according to the design basis conditions.

6.4.10 Seismic Evaluation

The RWPS is classified under Seismic Category 1. Its seismic evaluation was performed at the detailed engineering stage and involved the same considerations as for the PCS given in Section 6.2.10.

6.4.10.1 Resins Storage Tank

The seismic load corresponds to the floor spectra of the level where the tank is located,.

The tank itself will not fail due seismic action. The response of the support legs and bolts has been analysed. The force and overturning moment caused by the seismic action on the tank was calculated and was within allowable limits for all cases.

6.4.10.2 Ion exchange columns

The seismic load corresponds to the floor spectra of the level where the tank is located,.

The column itself will not fail due to seismic action. The response of the support legs and bolts has been analysed. The force and overturning moment caused by the seismic action on the tank was calculated and was within allowable limits for all cases.

6.4.10.3 Pumps

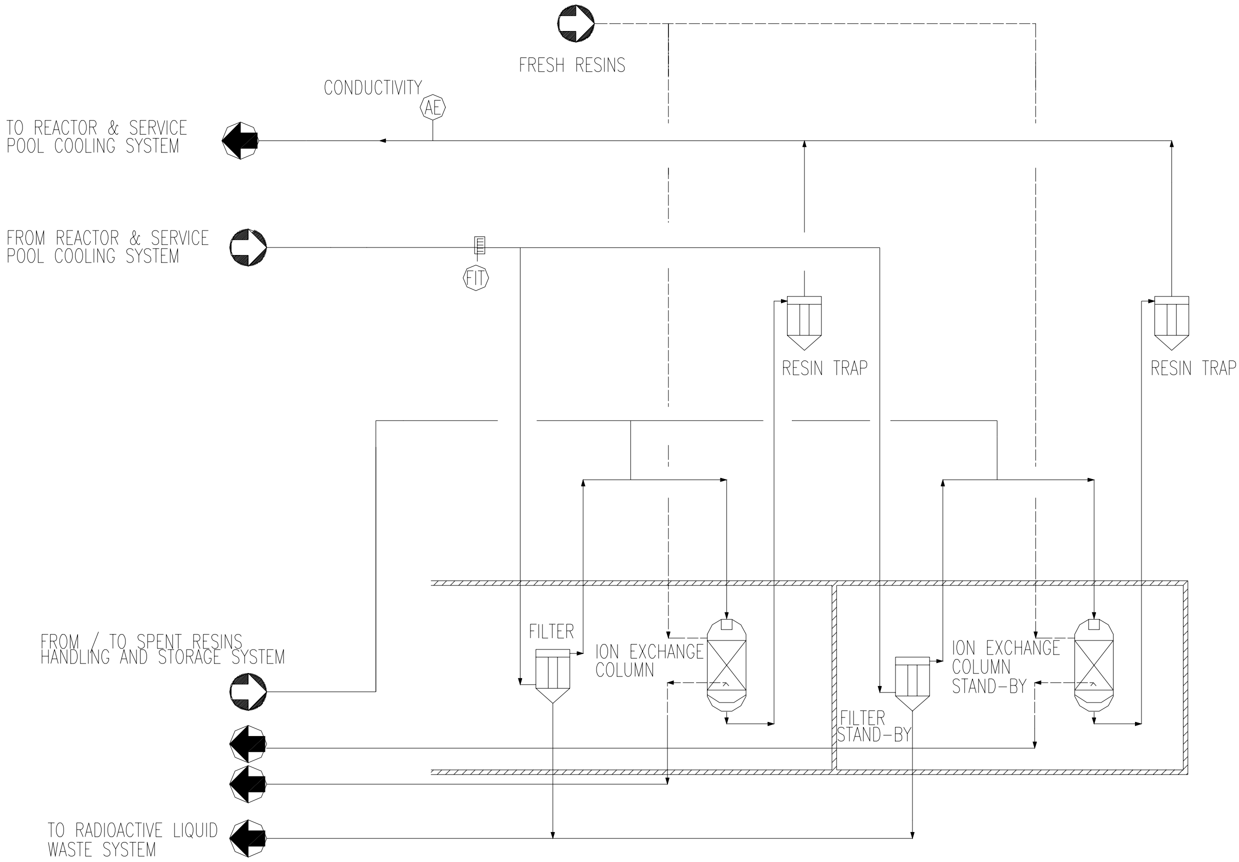
The same principles applied to the PCS and RSPCS pumps apply to the RWPS fresh resin loading pump.

6.4.10.4 Conclusions

The RPWS can withstand the effect of an SL-2 event.

End of Section

Figure 6.4/1 Diagram of the Reactor Water Purification System



End of Figures

6.5 HOT WATER LAYER SYSTEM AND PURIFICATION SYSTEM

6.5.1 Introduction

The Hot Water Layer System (HWLS) provides:

a) protection against radiation emitted by impurities in the pool water

b) a means for continuous water-surface skimming

The system fulfils its function by means of a non-activated stable water layer over the Reactor Pool and Service Pool water volume. This is obtained by purification and heating of a layer of water at the top of the reactor and service pools. The hot water layer reduces mixing and thus prevents any impurities dissolved in the remaining pool water from reaching the pool surface.

The purification is performed by the reactor Hot Water Layer Purification System (HWLPS), which removes traces of corrosion, fission or radioactive impurities.

Skimming is performed by raising the level of the pools water and creating an overflow of pool water into the collection channel in the ventilation, instrumentation and overflow canal (VIO canal) at the top of the pools. Floating debris are carried by the flow and captured in the HWLS and HWLPS.

Figure 6.5/1 shows a diagram of the HWLS.

6.5.2 Design Bases

The HWLS has been designed to meet the following safety design bases:

a) To provide protection for personnel from radiation emitted by impurities in the water, by providing a stable water layer at the surface of the pool.

b) To maintain HWLS water quality with conductivity below 1 μScm^{-1} and solids content less than 0.5 ppm.

6.5.3 Circuit Description

6.5.3.1 Hot Water Layer System

The equipment associated with HWLS is located inside the containment, in the basement.

The material for piping and equipment is low carbon austenitic stainless steel.

The HWLS takes water from the hot water layer at the top of the Reactor Pool. The hot water layer suction pipe is submerged below the pool surface. There is another suction line located in the Service Pool.

The suction line leads the coolant to the two pumps (100% capacity each, one on standby) where water is pumped to the HWLPS.

Once purified, the water is returned to the HWLS and passes through two electrical heaters (100% capacity each) that provide the pre-set temperature rise before the water enters the Reactor Pool through a diffuser at the end of the line.

In the skimming process, a control loop increases the pool water level allowing the water to overflow into the canal surrounding the pools. This process removes foreign particles floating on the water surface and improves water clarity. Water from the overflow canal is collected in a water storage tank and then pumped, using the skimming pump, to the HWLPS. The water is recycled to minimise water wastage.

6.5.3.2 Hot Water Layer Purification System

The material for piping and equipment is low carbon austenitic Stainless Steel.

Ion exchange columns and filters are located inside the containment, in a shielded room with thick heavy concrete walls.

Water coming from the HWLS flows through a primary filter and then is sent to the mixed bed ion exchange column. The filtered stream continues on to a resin trap placed at the column outlet and finally joins to the HWLS.

The ion exchange column is connected to lines from the Reactor Water Purification System (RWPS) for fresh resin loading and the Spent Resins Handling and Storage System (SRHSS) for resin disposal.

6.5.4 System Modes

The HWLS and the HWLPS have two modes of operation: Operational and Shutdown.

Reactor State	System Modes		Function
	Operational	Shutdown	
Power	required	not allowed	Radiation Protection
Physics Test	required	not allowed	
Shutdown	not required	allowed	
Refuelling	not required	allowed	

The HWLS is designed to establish a hot water layer:

- for the Reactor Pool only, or
- simultaneously for both the Reactor and Service Pools

Reactor operation in the Power and Physics Test states requires the HWLS operation to provide additional protection against radiation. For the Shutdown and Refuelling states, operation of the HWLS is recommended to provide radiation protection but is not required.

During the start up of the system, the two electrical heaters will be used until the desired temperature is reached in the upper section of the pool. Temperature sensors, placed in the heater outlet and also inside the pool, monitor the coolant temperature. The power supply to the heaters is regulated by the sensors inside the pool.

Once a steady state is reached, the power consumption is decreased and simultaneous operation of both heaters is no longer required.

During the steady state, the system fulfils its function by keeping a non-activated stable water layer over the Reactor Pool water volume.

Large floating debris is deposited on a screen mounted around the pool at the surface level. Small particles that pass through the screen are collected in strainers before the pump suction.

The HWLPS primary filter retains remaining insoluble particles while the ion exchange column maintains the dissolved ions within limits. The resin trap prevents resins from entering the HWLS.

A conductivity meter monitors the resin condition. The resins can be replaced through a connection to the fresh resin transportation facility. Spent resins are managed by the Spent Resins Handling and Storage System.

6.5.5 Hot Water Layer System and Purification System Components

6.5.5.1 Hot Water Layer System Components

6.5.5.1.1 Pumps

Parameter	Value
Quantity	Two (one on stand-by)
Type	Centrifugal
Capacity	100%

6.5.5.1.2 Skimming Pump

Parameter	Value
Quantity	One
Type	Centrifugal

6.5.5.1.3 Water Heater

Parameter	Value
Quantity	Two (In steady state: one in normal operation and one on stand-by; during heating transients: both in operation))
Type	Vertical cylindrical tank, electrical heaters cladding SS

6.5.5.1.4 Skimming Tank

Parameter	Value
Quantity	One
Volume	0.7 m^3

6.5.5.2 Hot Water Layer Purification System Components

6.5.5.2.1 Ion Exchange Columns

Parameter	Value
Quantity	One
Ion exchange resins type	Nuclear quality mixed bed 1:1

6.5.5.2.2 Filter

Parameter	Value
Quantity	One
Type	Cartridge
Filtering material	Mesh, backing in both faces

6.5.5.2.3 Resins Trap

6.5.5.2.4

Parameter	Value
Quantity	One
Filtering material	Screen

6.5.6 Hot Water Layer System and Hot Water Layer Purification System Instrumentation

6.5.6.1 Hot Water Layer System

6.5.6.1.1 Flow

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Flow transmitter	Pumps outlet	RCMS	Indication	None
Flow totaliser	Water make-up pipeline	RCMS	Indication	None
Flow switch	Heaters outlet	RCMS	Low flow alarm	Heater and pump trip due to low water flow

6.5.6.1.2 Temperature

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature transmitter	Heaters outlet	RCMS	High temperature alarm	None
Temperature transmitter	Reactor Pool, Hot water layer bulk	RCMS	High temperature alarm	None
Temperature switch	Heaters	RCMS	High temperature Alarm	Heater trip due to high water temperature

6.5.6.2 Hot Water Layer Purification System

6.5.6.2.1 Conductivity

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Conductivity transmitter	Resins trap outlet	RCMS	Indication / High conductivity alarm	None

6.5.7 Actions on RCMS due to Hot Water Layer System Signals

The Instrumentation and Control System is fully described in Chapter 8, Section 8.13.

6.5.7.1 Interlocks

Condition	Interlock
High temperature in heater	The heater is turned off.

Failure of the main operating pump	The heater is turned off.
Low flow rate	The heater is turned off.

6.5.8 Inspection and Testing

The inspection and testing program for fabrication, assembly, pre-operation and in-service operation was developed during detailed engineering in accordance with the Construction Inspection and Test Plan (CITP).

6.5.9 Design Evaluation

The HWLS and HWLPS meet the safety design bases:

a) To provide protection for personnel from radiation emitted by impurities in the water.

b) To maintain HWLS water quality with conductivity below 1 μScm^{-1} and solids content less than 0.5 ppm.

The safety design basis (a) is achieved by providing a stable hot water layer in the reactor and service pool surface. The skimming process and the purification system maintains the water quality and clarity.

Water high purity is ensured by means of the resin bed design with polishing flow pattern that retains anionic and cationic impurities and by the short renewal time of the purification cycle.

Appropriate safety margin has been assigned to the thermal capacity of the system to ensure its adequate performance in any abnormal condition.

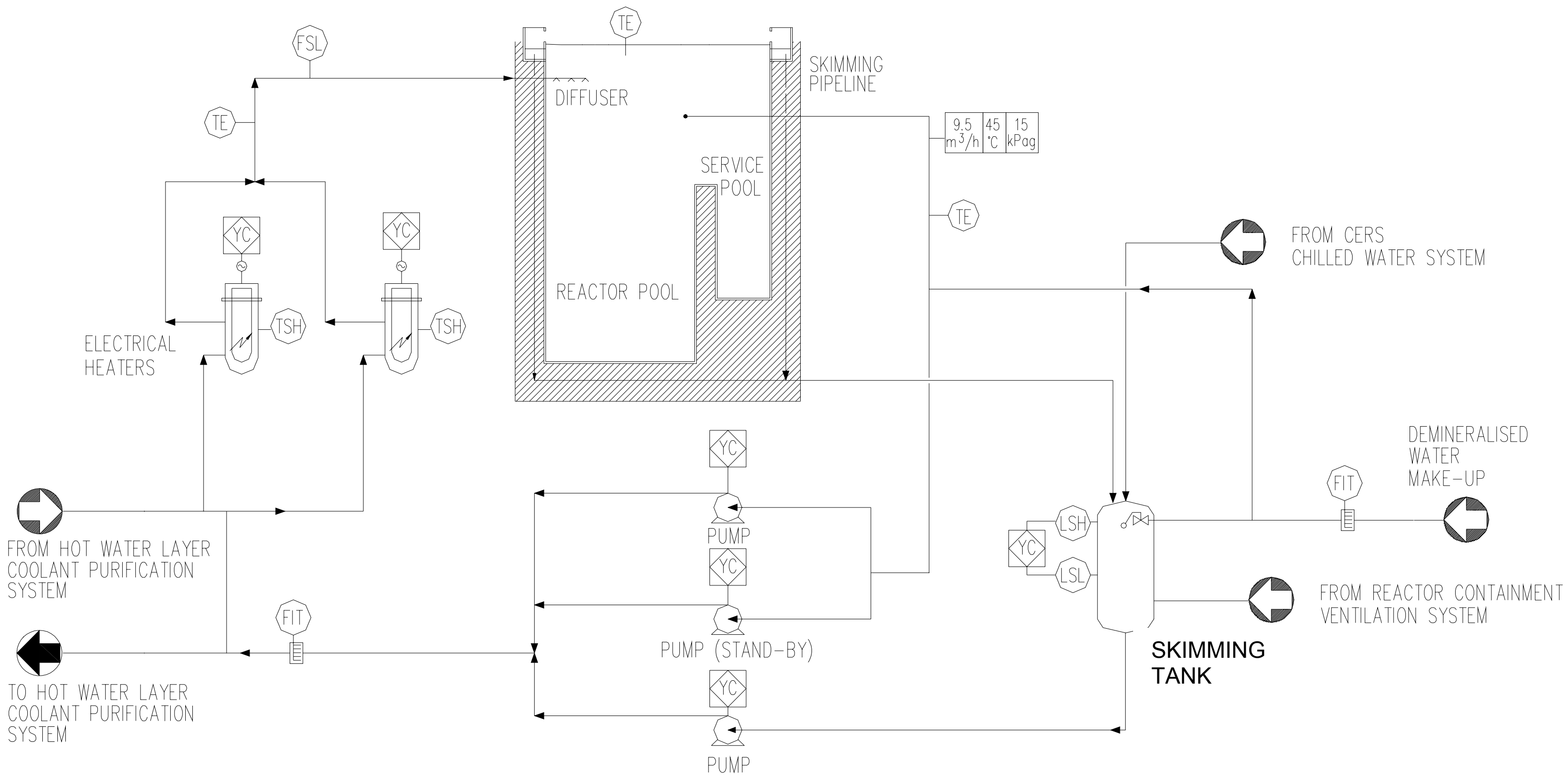
The Failure Modes and Effects Analysis (FMEA) for the HWLPS indicated that failures of this system do not represent a significant safety hazard to the reactor. No initiating events are needed to be further evaluated in Chapter 16 in relation to failures of the HWLS.

6.5.10 Seismic Evaluation

The HWLS is classified Seismic Category 2 systems, some components are classified under Seismic Category 3. Shielding and ion exchange resins are classified as Seismic Category 1 due to radiation protection requirements. The seismic evaluation for the shielding of the ion exchange resins was performed at the detailed engineering stage and involved the same considerations as for the PCS given in Section 6.2.11. An FEM method was used.

End of Section

Figure 6.5/1 Diagram of Hot Water Layer



End of Figures

6.6 REFLECTOR COOLING AND PURIFICATION SYSTEM

6.6.1 Introduction

This Reflector Cooling and Purification System (RCPS) removes heat from the heavy water of the Reflector Vessel in order to maintain its temperature within the design range, maintain the purity of the heavy water, and keep the concentrations of deuterium and oxygen in the cover gas within the normal operating range.

The RCPS also circulates heavy water through the Cold Neutron Source Reflector Plug (CNS RP) and the future Hot Neutron Source (HNS), during normal operation of the reactor, and cools the CNS RP, the CNS Vacuum Containment and the future HNS once the Second Shutdown System (SSS) is triggered.

The system consists of:

a) Reflector Primary Cooling Circuit that circulates the heavy water, transferring the moderation heat received in the Reflector Vessel to the Reflector Intermediate Cooling Circuit.

b) Additional Cooling Circuit that circulates heavy water to cool CNS RP and future HNS during normal operation of the reactor and to cool CNS RP, CNS vacuum containment and future HNS, in case of SSS trip.

c) Reflector Intermediate Cooling Circuit that circulates demineralised water to transfer the heat removed from the Reflector Primary Cooling Circuit to the Secondary Cooling System (SCS). This circuit provides an additional barrier against tritium migration towards the SCS.

d) Reflector Purification System that maintains the heavy water quality within the admissible values.

e) Deuterium Recombination System that maintains deuterium and oxygen levels within acceptable levels for safe operation, and recombines the deuterium and oxygen gases produced by heavy water decomposition due to radiolysis.

Figure 6.6/1 shows a diagram of the Reflector Cooling and Purification System.

Figure 6.6/2 shows a diagram of the Deuterium Recombination System.

The Reflector Vessel itself is part of the core-associated structures and is described in Chapter 5, Section 5.2.

The heavy water storage tank is also part of the Second Shutdown System (SSS). It collects and stores the heavy water after a SSS trip. The SSS is described in Chapter 5, Section 5.5.

6.6.2 Safety Design Bases

The RCPS has been designed to meet the following safety design bases:

a) Capacity to remove reflector heat.

b) To prevent any leakage of heavy water outside the containment through a leak in the heat exchanger.

c) To keep D2O conductivity level below 1 μScm-1.

d) To maintain the deuterium/oxygen concentration at a safe level.

e) To maintain its integrity during adverse combinations of loading and forces occurring during abnormal conditions (see Sections 6.6.9 and 6.6.10).

6.6.3 Circuit Description

6.6.3.1 Reflector Primary Cooling Circuit

The Reflector Primary Cooling Circuit (RPCC) is located inside the containment. The pumps, heat exchanger, heavy water storage tank and expansion tank are located in a dedicated sealed area known as the Heavy Water Room.

The Heavy Water Room is air-tight, with a dedicated ventilation system provided with molecular-sieve filter for heavy water vapour retention, airlock entrance, tritium monitoring, and liquid collection network.

The Heavy Water Room is also watertight. The floor has an epoxy coating and is capable of collecting the whole water volume in the event of any accidental leakage (heavy water coming from the Reflector Primary Cooling Circuit and the Reflector Purification Circuit or demineralised water coming from the Reflector Intermediate Cooling Circuit).

The design allows maintenance activities to be performed with minimum tritium risk. Vacuum and helium connections are available for purging of isolated sections during equipment disassembly.

The water tightness of the system minimises tritium risks and reflector degradation by light water. It ensures that the reflector maintains the heavy water isotopic purity within the desired range (>99.75%) for more than 10 years.

The fresh heavy water isotopic concentration is 〈99.9%).

6.6.3.1.1 Reflector Primary Cooling Circuit

The Reflector Primary Cooling Circuit takes heavy water from the upper part of the Reflector Vessel via a distributor and through a pipeline that feeds the pumps. One of two 100% canned centrifugal type pumps circulates heavy water through a welded plate type heat exchanger. After the heat exchanger, heavy water is discharged through a distributor into the lower part of the Reflector Vessel. Downstream of the pumps, and prior to the heat exchanger, part of the main circulating flow rate is diverted to the purification system and then returns to the Reflector Vessel.

Downstream of the heat exchanger part of the main circulating flow rate is diverted to cool the Hot Neutron Source during normal operation of the reactor, and then returns to the Reflector Vessel.

The system includes two tanks, a heavy water storage tank and an expansion tank.

The heavy water storage tank is connected to the discharge pipe of the SSS, the discharge pipe of the active drainage network, the fresh heavy water inlet pipe, the overflow line from the expansion tank, the Deuterium Recombination System outlet pipe, the helium supply pipe, the vacuum network, the Reflector Vessel drainage pipe and the suction pipe of the heavy water loading pumps.

A pipeline connects the gas chambers of the expansion and heavy water storage tanks and a pipeline connects the reflector and expansion tanks, ensuring equalisation of cover gas pressure throughout the system.

Two parallel centrifugal pumps, fed by a pipeline, extract heavy water from the bottom of the heavy water storage tank, to be used for re-filling the system after a SSS trip, or to maintain the water level in the expansion tank during reactor operation. The expansion tank is connected to the make up heavy water pipe from the storage tank. At the bottom of the expansion tank, a pipeline is connected to the Reflector Vessel. The expansion tank also has an overflow pipe discharging into the heavy water storage tank. The expansion tank gas space is also connected to the Cold Neutron Source support systems (to be used for deuterium recombination during major reactor shutdown), to the oxygen supply network and to the inlet pipe of the Deuterium Recombination System.

Ball valves are located at the suction and discharge of the main pumps, inlet of the heat exchanger and inlet and outlet of the Reflector Vessel.

Pump suction and discharge pipes are provided with drainage lines; similarly, drainage lines are located at the inlet and outlet of the heat exchanger. Diaphragm valves are provided for isolation purposes. Fluid Sampling Manifolds allow the taking of periodic samples of heavy water and cover gas during reactor shutdown. The samples are analysed in the laboratory.

Leakage view finders, connected to leakage testing chambers of ball valves and special flanged joints, make possible the detection of heavy water leakage through the first seals barrier.

In the event of a reactor trip, part of the core and rigs decay heat will be released in the Reflector Vessel. If the RPCC is not operating, this heat will be transferred by conduction to the Reactor Pool via the walls of the Reflector Vessel.

6.6.3.1.2 Additional cooling circuit

The function of the Additional Cooling Circuit is to circulate heavy water in order to cool the CNS during normal operation of the reactor and to cool the CNS and future Hot Neutron Source in case the SSS is actuated and heavy water is drained from the reflector vessel.

This system does not perform any safety function, but it protects the CNS structure from a potential temperature rise due to decay heat from the core, which might limit the availability of the CNS.

The system is continuously in operation and does not depend on any trigger signals for its actuation.

Two 100 % capacity canned centrifugal-type pumps (one on standby) circulate heavy water from the Reflector Vessel bottom, fed by a pipeline. The pumps are backed by standby power.

A pipeline leads the heavy water from the pumps discharge to a distributor header. The distributor header diverts the heavy water flow to three different pipelines as follows:

a) Heavy water flows through a pipeline from the distributor header to the CNS RP returning to the line downstream of the purification system.

b) A pipeline leads heavy water from the distributor header, to the inlet connection of the CNS lower flange. Heavy water flows and wets the outer wall surface of CNS In-pile Thimble returning to the Reflector Vessel.

c) A pipeline leads heavy water from the distributor header to a pipeline of the Reflector Primary Cooling Circuit to permit cooling of the Hot Neutron Source by the ACC once the SSS is triggered.

6.6.3.2 Reflector Intermediate Cooling Circuit

The Reflector Intermediate Cooling Circuit is located inside the containment in the Heavy Water Room and the Piping Connection Room.

All system components are made of stainless steel.

This system transfers the heat removed from the Reflector Primary Cooling Circuit to the SCS. Two 100% capacity centrifugal pumps circulate, through a pipeline, a flow rate of demineralised light water to the intermediate plate-type heat exchanger, where the heat is removed by the SCS. Downstream of this heat exchanger the flow is diverted through a pipeline to cool the gas coolers and compressors of the Deuterium Recombination System. The remaining flow circulates through the primary heat exchanger, taking the heat from the Reflector Primary Cooling Circuit

A by-pass pipe connects the outlet with the inlet of the pumps.

The system has an expansion tank connected to the pump suction line through a pipeline. The expansion tank is connected to the Demineralised Water Supply System.

To maintain the required purity level in the circulating water, a part of the total flow is diverted through a cartridge-type filter and then returned to the expansion tank.

Isolation valves are available on the suction and discharge sides of the pumps and inlet and outlet of the heat exchangers. Check valves are installed at pump outlets.

6.6.3.3 Reflector Purification System

This system is located inside the Heavy Water Room.

The Reflector Purification System has the function of keeping the reflector chemistry within the specified values for safe operation (conductivity $<1\ \mu Scm^{-1}$).

The Reflector Purification System takes heavy water from the Reflector Primary Cooling Circuit via a pipeline connected downstream of the primary pumps. The pipe feeds two purification circuits, one in service and the other on stand-by. The purification circuit outlet stream discharges into the outlet pipe from the expansion tank which discharges into the Reflector Vessel.

The stream to be purified flows through one of two ion exchange resin columns. Each ion exchange resin column includes a pre-filter, two resin strainers and a resin trap as internal components. The pre-filter is designed to retain suspended solids prior to entering the ion exchange resin bed. Once filtered, the flow undergoes ion exchange in a mixed-type resin bed that also acts as filter for minor particles. The resin strainers are designed to retain the resin within the resin bed chamber. The resin trap is designed to trap eventual resin leaks into the circuit.

Diaphragm valves are installed upstream and downstream of each purification circuit. Remote actuated valves located on the inlet and outlet pipes of each of the two circuits allow the selection of the operating circuit from control room via the RCMS.

When heavy water conductivity is above the admissible level or high differential pressure is verified across the operating train, the standby is started. This operation is performed from the Main Control Room by means of remotely actuated valves.

The resin column is replaced following a specific procedure. No resin regeneration is required.

The system is also connected to the cover gas spaces of the Heavy Water Storage Tank and Expansion tank for heavy water drainage purpose when a resin column replacement is required.

6.6.3.4 Deuterium Recombination System

The Deuterium Recombination System is located inside the Heavy Water Room.

During reactor operation, a decomposition reaction (radiolysis) takes place in the Reflector Vessel due to the irradiation of heavy water. As a consequence, deuterium and oxygen gases are produced and accumulated inside the expansion tank, mixing with the He cover gas. The Deuterium Recombination System (DRS) keeps the concentration of these gases below explosive levels by recombining deuterium and oxygen in a catalyst bed, producing heavy water. Heavy water thus generated is returned to the heavy water storage tank

During reactor shutdown, the DRS is also able to treat the tritiated deuterium coming from the Cold Neutron Source.

The DRS comprises two compressors, two dampening vessels, two recombiners and two gas coolers, providing a 100% redundant circuit for the circulation of the cover gas from Expansion Tank to Heavy Water Storage Tank.

Under normal operating conditions, only one of the recombining circuits operates, while the other remains on stand-by.

A pipeline directs the cover gas from the heavy water Expansion Tank to the compressors' inlet.

Two compressors, (one on standby) impel the cover gas through a pipeline towards recombining units (one on standby).

The gas coolers and the head of the compressors are cooled with demineralised water coming from the Reflector Intermediate Cooling Circuit.

Bi-directional flame arresters are installed upstream and downstream the recombiners.

The gas mixture enters the recombination unit where the recombining reaction takes place. These recombiners are designed to operate at high temperatures.

The stream exiting the recombiner flows through a pipeline towards the gas cooler where the gas mixture is cooled and flows through a pipeline returning to the Heavy Water Storage tank.

Helium and vacuum service connections are available for maintenance purposes.

6.6.4 Reflector Cooling and Purification System - Operation Modes

The RCPS has four operation modes:

a) Reflector Cooling Mode
b) CNS RP and HNS Cooling Mode
c) After SSS Triggering Mode
d) Halt Mode

Main Characteristics of the operation modes are described below.

Reactor State	RCPS System Mode	RCPS Configuration	RCPS Function
Power	Reflector Cooling Mode	Reflector Primary Cooling Circuit, Additional Circuit, Reflector Intermediate Cooling Circuit, Reflector Purification System and Deuterium Recombination System are in service.	Reflector Cooling, CNS RP cooling and HNS cooling D_2 and O_2 recombining
Physics Test	CNS RP and HNS Cooling Mode	Reflector Primary Cooling Circuit shutdown (HW Main Pump stopped by the operator). Additional Circuit, Reflector Intermediate Cooling Circuit and Deuterium Recombination System in service.	CNS RP cooling and HNS cooling D_2 and O_2 recombining
Shutdown without SSS actuation	CNS RP and HNS Cooling Mode	Reflector Primary Cooling Circuit shutdown (HW Main Pump stopped by the operator). Additional Circuit, Reflector Intermediate Cooling Circuit and Deuterium Recombination System in service.	CNS RP cooling and HNS cooling D_2 and O_2 recombining
	Halt Mode (After 24 hs)	Reflector Primary Cooling Circuit, Additional Circuit, Reflector Intermediate Cooling Circuit, Reflector Purification System and Deuterium Recombination System are in shutdown.	None
Shutdown after a reactor trip by SSS actuation	After SSS triggering Mode	Reflector Primary Cooling Circuit shutdown (HW Main Pump and HW Make-up Pump automatically stops). Additional Circuit, Reflector Intermediate Cooling Circuit and Deuterium Recombination System in service.	CNS RP cooling, CNS Vacuum Containment cooling and HNS cooling D_2 and O_2 recombining
Refuelling	Halt Mode	Reflector Primary Cooling Circuit, Additional Circuit, Reflector Intermediate Cooling Circuit, Reflector Purification System and Deuterium Recombination System are in shutdown.	None

6.6.4.1 Reflector Cooling Mode

In Reflector Cooling Mode, the Reflector Primary Cooling Circuit (RPCC), Additional Cooling Circuit, Reflector Intermediate Cooling Circuit, Reflector Purification System and the Deuterium Recombination System are in service.

The RPCC circulates the heavy water, transferring the heat to the Reflector Intermediate Cooling Circuit, which in turn transfers heat to the SCS.

Only one of the primary pumps is necessary to circulate the heavy water through the Main cooling circuit while the other one is on stand by.

The Additional Cooling Circuit circulates heavy water to cool the CNS Reflector Plug vessel and the HNS.

Only one of the Additional Cooling Circuit pumps is necessary to circulate the heavy water while the other one is on stand by.

The reflector operates with a cover gas of helium in equilibrium with heavy water at a pressure slightly over the atmospheric pressure so as to prevent ingress of air into the system, hence preventing degradation of the heavy water.

The pressure at any point inside the Reflector Vessel is less than that of the surrounding light water in the Reactor Pool. In this way, there will be no tritium transfers to the reactor PCS should there be a leak in the reflector cooling system.

One of the reflector purification circuits operates whilst the other remains on stand by. The stand-by train will be started if the conductivity of the heavy water rises above the permissible level or if there is a high differential pressure across the operating train. This operation can be performed from the control room by operating the actuated valves located at the inlet and outlet pipes of each train.

One circuit of the Deuterium Recombination System is in operation whilst the other remains on stand by. The heavy water vapour generated after the recombining action is returned to the heavy water storage tank.

The inlet and outlet streams of the Deuterium Recombination System are constantly analysed using on-line instruments to monitor deuterium concentration in the cover gas and also to determine the performance of the recombination units.

Heavy water and cover gas quality is monitored by sampling when the reactor is shutdown. The samples are analysed in the laboratory.

6.6.4.2 CNS and HNS Cooling Mode

In CNS and HNS Cooling Mode, the Reflector Primary Cooling Circuit is shutdown (HW Main Pump is stopped by the operator). The Additional Cooling Circuit, Reflector Intermediate Cooling Circuit and the Deuterium Recombination System are in service.

6.6.4.3 SSS triggered mode

In the event that the SSS is triggered, the operating reflector primary cooling pump is automatically stopped. The operating heavy water make-up pump from the reflector storage tank is stopped and its start-up inhibited. The operating pump of the Additional Cooling Circuit continues in service.

After resetting the trip, heavy water can be transferred from the heavy water storage tank to the Reflector Vessel via the Expansion Tank by manually starting one or both heavy water loading pumps.

6.6.4.4 Halt Mode

In Halt Mode, Reflector Primary Cooling Circuit, Additional Cooling Circuit, Reflector Intermediate Cooling Circuit, Reflector Purification System and Deuterium Recombination System are shutdown.

6.6.5 Reflector Cooling and Purification System - Components

6.6.5.1 Reflector Primary Cooling Circuit

6.6.5.1.1 Reflector Vessel

Parameter	Value
Quantity	One

Further details are given in Chapter 5, Section 5.2 and Section 5.5.

6.6.5.1.2 Reflector Primary Cooling Pumps

Parameter	Value
Quantity	Two (one on stand-by)
Type	Centrifugal Canned
Capacity	100% each
Fluid	Heavy Water

6.6.5.1.3 Heavy Water Make-up Pumps

Parameter	Value
Quantity	Two (one on stand-by)
Type	Centrifugal, Magnetic Coupling
Capacity	100% each
Fluid	Heavy Water

6.6.5.1.4 Heavy Water Heat Exchanger

Parameter	Value
Quantity	One
Type	Welded plate
Capacity	100%

6.6.5.1.5 Heavy Water Expansion Tank

Parameter	Value
Quantity	One
Type	Vertical tank

6.6.5.1.6 Heavy Water Storage Tank

Parameter	Value
Quantity	One
Type	Horizontal tank

6.6.5.1.7 Safety Related Valves

Type	Location	Function

Type	Location	Function
Pressure Control Valve	Helium supply line	Maintains pressure of cover gas
Pressure Safety Valve	Helium supply Line	Opens if operating pressure exceeded
Pressure Control Valve	Oxygen supply line	Control of pressure in oxygen supply line
Pressure Safety Valve	Oxygen supply line	Opens if operating pressure exceeded
Pressure safety valve	Expansion tank	Redundancy of Pressure Safety Valves of helium and oxygen supply line

6.6.5.1.8 Additional Cooling Circuit Pump

Parameter	Value
Quantity	Two (one on stand-by)
Type	Centrifugal Canned
Capacity	100% each
Fluid	Heavy Water

6.6.5.2 Purification System

6.6.5.2.1 Ion Exchange Columns

Parameter	Value
Quantity	Two (one on stand-by)
Ion exchange resins type	Nuclear quality mixed bed
Internals:	One Pre-filter Two Resin Strainers One Resin trap

6.6.5.3 Reflector Intermediate Cooling Circuit

6.6.5.3.1 Reflector Intermediate Circuit Pumps

Parameter	Value
Quantity	Two (one on stand-by)
Type	Centrifugal
Capacity	100% each
Fluid	Demineralised water

6.6.5.3.2 Reflector Intermediate Circuit Heat Exchanger

Parameter	Value
Quantity	One
Type	Plate

Capacity	100%

6.6.5.3.3 Reflector Intermediate Circuit Expansion Tank

Parameter	Value
Quantity	One
Type	Horizontal tank

6.6.5.3.4 Reflector Intermediate Circuit Filter

Parameter	Value
Quantity	One
Type	Cartridge
Filtering element	Mesh

6.6.5.4 Deuterium Recombination System

6.6.5.4.1 Compressors

Quantity	Two (one on stand-by)
Type	Triple Metal Diaphragm

6.6.5.4.2 Recombiners

Quantity	Two (one on stand-by)
Type	Fixed bed reactor with external electrical heaters

6.6.5.4.3 Heat Exchangers (Gas Coolers)

Quantity	Two (one on stand-by)
Type	Double tube

6.6.5.4.4 Flame Arresters

Parameter	Value
Quantity	Recombiner inlet: Two (one on stand-by) Recombiner outlet: Two (one on stand-by)
Type	Bi-directional, crimped metal

6.6.5.4.5 Dampening Vessels

Parameter	Value
Quantity	Two (one on stand-by)
Type	Vertical tank

6.6.6 Reflector Cooling and Purification System Instrumentation

This section lists the instrumentation associated with the second and third levels of Defence in Depth. Instrumentation associated with the RPS is triplicated.

6.6.6.1 Reflector Primary Cooling Circuit and Additional Cooling Circuit

6.6.6.1.1 Temperature

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature sensor & transmitter	Reflector Vessel	RCMS SRPS	Indication High and very high temperature alarms	High temperature: power reduction Very high temperature: Reactor Trip (SSS)
Temperature sensor & transmitter	Reflector primary cooling pump inlet	RCMS	Indication	None
Temperature sensor & transmitter	Heavy water Heat Exchanger outlet	RCMS	Indication	None
Temperature sensors	Reflector primary pumps rotor chamber	RCMS	High temperature alarm	The Operator decides pump changeover
Temperature sensors	Reflector primary pumps motor winding	Local	Indication of Pump stopped	Pump trip due to very high motor winding temperature (hardwired logic)

6.6.6.1.2 Flow

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Flow meter & transmitter	Heavy Water Heat Exchanger outlet	FRPS	Indication Low Flow Alarm	Reactor trip due to low water flow
Flow meter	Main cooling circuit, HNS branch.	RCMS	Local indication Low Flow Alarm	None
Flow meter	Additional cooling circuit, CNS RP branch	RCMS	Local indication Low Flow Alarm	None
Flow meter	Additional cooling circuit, for CNS In-pile Thimble branch	RCMS	Local indication Low Flow Alarm	None
Flow meter	Additional cooling circuit, HNS branch.	RCMS	Local indication Low Flow Alarm	None
Flow meter	Flow rate diverted to purification train	RCMS	Local indication Low Flow Alarm	None

6.6.6.1.3 Level

Instrument	Location	System	Control Room	Protection Functions

			indication/Alarm	
Level Switches	Heavy Water Expansion Tank	FRPS	Very Low Level Alarm	Reactor trip due to low water level
Level transmitter	Heavy Water Expansion Tank	RCMS	Indication Low Level Alarm	The Operator starts heavy water make up pump.
Level Transmitter	Heavy Water Storage Tank	PAM RCMS	Indication Low, High and very High level Alarms	None
Level switch	Floor sump	RCMS	High level Alarm	None
Level switch	Reflector primary pumps outlet connections	RCMS	Low level Alarm	Start up of the pumps is inhibited by low level (dry running protection)

6.6.6.1.4 Pressure

Instrument	Location	System	Control Room indication/Alarm	Protection Functions
Pressure transmitter	Heavy water expansion tank	RCMS	Indication Low and High Pressure alarms	None
			Very high pressure alarm	Very High pressure opens the venting valve and closes the He, O_2 & D_2 feed block valves.
Pressure transmitter	Heavy water storage tank	Local (in field)	Indication	None
Pressure transmitter	Before Helium supply Line Control Valve	RCMS	Indication High and Low pressure alarm	None
Pressure transmitter	Before Oxygen supply line Control Valve	RCMS	Indication High and Low pressure alarm	None
Pressure switch	SSS - compressed air tank	RCMS	Low pressure alarm	Reactor start up not allowed
Pressure transmitter	SSS- compressed air tank	RCMS	Indication High pressure alarm	None
Pressure switch	SSS- compressed air supply pipeline.	RCMS	Low pressure alarm	None

6.6.6.1.5 Gas Detection

Instrument	Location	System	Control Room indication/Alarm	Protection Functions
Oxygen analyser	Heavy water expansion tank	RCMS	Oxygen concentration indication High and very high oxygen concentration alarm	Regulates oxygen inlet valve Very high oxygen concentration shuts the oxygen feed block valve
Nitrogen analyser	Heavy water expansion tank	RCMS	Nitrogen concentration indication High and very high nitrogen concentration alarm	None
Deuterium analyser	Heavy water expansion tank	RCMS	Deuterium concentration indication High and very high Deuterium concentration alarm	Regulates deuterium inlet valve Very high deuterium concentration shuts the deuterium feed block valve

6.6.6.1.6 Valves Position

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Position switch	SSS manual blocking valve	FRPS	Indication	Valve not fully open , reactor start up not allowed
Position switch	Each one of the six SSS trigger valves	RCMS	Indication	None
Position switch	Venting, Expansion Tank	RCMS	Indication	None

6.6.6.1.7 Conductivity

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Conductivity sensor	Reflector primary pumps outlet pipeline	RCMS	Indication High conductivity alarm	None

6.6.6.2 Purification System

6.6.6.2.1 Pressure

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Differential pressure transmitter	Between inlet and outlet of the purification system	RCMS	Indication High differential pressure alarm	None

6.6.6.3 Reflector Intermediate Cooling Circuit

6.6.6.3.1 Pressure

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Differential pressure switch	Between inlet and outlet of the filter	RCMS	High differential pressure alarm and local indication	None

6.6.6.3.2 Temperature

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature sensor	Intermediate Circuit Heat Exchanger inlet	RCMS	Indication High Temperature Alarm	None
Temperature sensor	Intermediate Circuit Heat Exchanger outlet	RCMS	Indication High Temperature Alarm	None
Temperature sensor, thermistor type	Intermediate Circuit pump motor windings	RCMS	High Temperature Alarm	High temperature in pump motor winding stops the running pump (hardwired control logic)

6.6.6.3.3 Flow

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Flow meter	Intermediate Circuit Heat Exchanger outlet	RCMS	Indication Low Flow Alarm	Low flow, reactor start up not allowed
Flow meter	Intermediate Circuit Filter inlet	RCMS	Local Indication Low Flow Alarm	None

6.6.6.3.4 Level

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Level transmitter	Intermediate circuit expansion tank	RCMS	Indication High, low, very high and very low level alarm	Very low level stops the operating pump

6.6.6.4 Deuterium Recombination System

6.6.6.4.1 Temperature

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature transmitters	Recombiners wall	RCMS	Indication Low temperature alarm	Control the electric power to heaters
Temperature transmitters	Recombiners catalyst bed.	RCMS	Indication High, Very high and Low temperature alarm	Compressor trip due to very high temperature
Temperature transmitter	Each Recombiner outlet	RCMS	Indication High and very high temperature alarm	Compressor trip due to high temperature
Temperature transmitter	Coolers outlet.	RCMS	Indication High temperature alarm	Compressor trip due to high temperature
Temperature transmitter	Recombiners common inlet pipeline	RCMS	Indication High temperature alarm	Compressor trip due to high temperature
Temperature sensors	Inlet pipeline of each compressor	RCMS	Low temperature on the pipeline wall alarm.	None
Temperature sensors	Inlet pipeline of each recombiner	RCMS	Low temperature on the pipeline wall alarm	None
Temperature sensors	Each Recombiner, catalyst bed.	Local	Local Indication (in field)	None
Temperature switches	Each Recombiner compressor outlet	Hardwired logic	High temperature alarm	Compressor trip due to high temperature

6.6.6.4.2 Pressure

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions

Pressure transmitter	Compressors outlet	RCMS	Indication High pressure alarm	None

6.6.6.4.3 Flow

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Flow transmitter	Compressor’s common outlet	RCMS	Indication Low flow alarm	None
Flow meter & switch	Coolers, coolant inlet pipeline	RCMS	Local indication Low flow alarm	Compressor trip due to low flow of coolant
Flow meter & switch	Compressors, coolant inlet pipeline	RCMS	Local indication Low flow alarm	Compressor trip due to low flow of coolant

6.6.6.4.4 Gas Detection

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Deuterium concentration sensor	Gas Coolers common outlet outlet	RCMS	Indication High concentration alarm	None

6.6.6.4.5 Valves Position

Instrument	Location	System	Control Room Indication/Alarm	Related Safety Actions
Position switch	Circuit blocking valves	RCMS	Indication	Valve closed, compressor start up not allowed
Position switch	Compressors blocking valve	RCMS	Indication	Valve closed, compressor start up not allowed
Position switch	Recombiner blocking valve	RCMS	Indication	Valve closed, compressor start up not allowed
Position switch	Recombiner blocking valve	RCMS	Indication	Valve closed, compressor start up not allowed
Position switch	Compressors coolant blocking valve	RCMS	Indication	Valve closed, compressor start up not allowed

6.6.7 Actions on RPS and RCMS due to RCPS Signals

The Instrumentation and Control System is fully described in Chapter 8. This section reproduces the main actions of the RPS and RCMS associated with the RCPS.

6.6.7.1 Reflector Primary Cooling Circuit

6.6.7.1.1 Trip Signals

Reactor Trip Signals generated by FRPS:
Low flow rate entering the Reflector Vessel
Very low level in the heavy water expansion tank

Reactor Trip Signals generated by SRPS:
Very High temperature at the Reflector Vessel

RPCC pump trip generated by RCMS:
Low flow in the system shortly after start up
Trigger of SSS
Very Low Level in heavy water expansion tank

Very high temperature in the motor winding will stop the pump automatically (through a hardwired control loop. The reactor will trip due to low flow rate entering the Reflector Vessel).

Other pumps trip generated by RCMS:
Trigger of SSS stops heavy water make up pumps
Very low level in heavy water storage tank stops the make-up pumps
High level in heavy water expansion tank stops the operating make-up pump when automatic mode is selected

6.6.7.1.2 Manual Shutdown

Condition	Operator Action
High temperature in primary cooling pump rotor chamber before automatic stop takes place.	The operator will take the appropriate actions after assessing the situations.
Very high deuterium concentration in cover gas	
Low level in expansion tank, and failure of heavy water make up pump	
Low flow in CNS additional cooling circuit	
Low flow in CNS Vacuum containment cooling circuit	
Low flow in HNS cooling circuit	

6.6.7.1.3 Interlocks

Condition	Interlock
Very High Pressure alarm in the heavy water expansion tank	Helium, Deuterium and Oxygen feed block valves close and the venting valve opens. The venting valve of the relief valves close automatically when the pressure returns to normal.
Very high deuterium concentration in the heavy water expansion tank	Deuterium feed block valve closes
Very high oxygen concentration in the heavy water expansion tank	Oxygen feed block valve closes
Failure of the operating primary cooling pump	There is no automatic start-up of the stand-by pump The pump is not allowed to start-up again until a manual reset of the control logic has been performed
Very low level in the heavy water storage tank	Heavy water make-up pump start-up not allowed
Electrical failure of the operating Heavy Water make up Pump	Automatic start-up of the stand-by pump
Any of the heavy water make up pumps is automatically stopped by any alarm signal	The control logic must be manually reset prior to starting them again
Failure of the operating Additional Cooling Circuit Pump	Automatic start-up of the stand-by pump The pump is not allowed to start-up again until a manual reset of the control logic has been performed
Any of the Additional Cooling Circuit pumps is automatically stopped by any alarm signal	The control logic must be manually reset prior to starting them again
Off and Local modes set on Local Control Stations	None of the RPCC pumps are allowed to be started from control room
Very low level in the heavy water expansion tank	Primary cooling pump start-up not allowed Reactor start-up not allowed
Low level in the outlet connection of the primary cooling pump	Pump start-up not allowed (dry running protection)
SSS is triggered	Primary cooling pump trip
Primary cooling pump shut-down and start-up signals are transmitted simultaneously by mistake	The shutdown signal has priority
Very high temperature alarm on primary cooling pump motor windings	Pump trip (through a hardwired control logic)
Flow Transmitter connected to FRPS detects low flow.	Reactor start-up not allowed
Low flow is detected in the reflector primary cooling shortly after pump start up	Pump trip

Condition	Interlock
SSS is triggered and insertion of control rods is not verified	Heavy Water make up pumps start up not allowed

6.6.7.2 Reflector Cooling and Purification System - Purification System

6.6.7.2.1 Trip Signals

There are no reactor trip signals for this circuit.

6.6.7.2.2 Manual Shutdown

When the conductivity sensors indicate a high value in the main circuit the operating purification train is isolated and the stand-by one is put in operation.

Similarly, when a high differential pressure alarm of the operating train is triggered. That indicates clogging of the ion exchange column internals and the necessity to change the purification train.

In case of a low flow alarm in the purification circuit, the operator will take the appropriate actions after assessing the situation.

6.6.7.2.3 Interlocks

There are no interlocks for this circuit.

6.6.7.3 Reflector Cooling and Purification System - Intermediate Cooling Circuit

6.6.7.3.1 Trip Signals

There is no direct reactor trip signal from the Reflector Intermediate Cooling Circuit. A low flow rate in the intermediate cooling circuit may result in a high temperature in the reflector vessel. This will activate the SSS.

6.6.7.3.2 Manual Shutdown

Conditions	Operator Action
High temperature in primary cooling circuit caused by low flow in Reflector Intermediate Cooling Circuit.	The operator will assess the situation and take the appropriate actions.
Low level in the intermediate circuit expansion tank	

6.6.7.3.3 Interlocks

Condition	Interlock
Failure of the Reflector Intermediate Cooling Circuit operating pump	The stand-by pump starts up automatically The pump is not allowed to start up again until a manual reset of the control logic has been performed
Off and Local modes set on Local Control Stations	None of the intermediate cooling pumps are allowed to be started from control room
Intermediate cooling pump in operation	Start-up of the stand by pump is not allowed.
Low level in the Intermediate Circuit	Start-up of the pump is not allowed

Expansion Tank.	
Very low level in the Intermediate Circuit Expansion Tank.	Intermediate cooling pump trips
Very high temperature in the operating pump motor winding	Pump trip (through a hardwired control logic)
Low flow rate in intermediate circuit	Start-up of the reactor is not allowed

6.6.7.4 Reflector Cooling and Purification System – Deuterium Recombination System

6.6.7.4.1 Trip Signals

No reactor trip is associated with this system

6.6.7.4.2 Manual Shutdown

Conditions	Operator Action
High deuterium concentration alarm in the heavy water expansion tank caused by Deuterium Recombination System shutdown.	The operator will assess the situation and take the appropriate actions.

6.6.7.4.3 Interlocks

Condition	Interlock
High temperature at the recombiners inlet	Power supply to compressor is cut off
Very high temperature in the catalyst bed of the recombiner	Power supply to compressor is cut off
Very High temperature at the recombiner outlet	Power supply to compressor is cut off
High temperature at the gas coolers common outlet	Power supply to compressor is cut off
Off and Local modes set on Local Control Station	None of the compressors or heaters are allowed to be started from control room
The compressor is automatically (failure) or manually stopped	The compressor is not allowed to start-up again until a manual reset of the control logic has been performed
Compressor in operation	Start-up of the stand by compressor is not allowed.
Low temperature in the catalyst bed of recombiner	Start-up of the compressor is not allowed
Low temperature at the compressor inlet pipeline	Start-up of the compressor is not allowed
Low temperature at the recombiner inlet pipeline	Start-up of the compressor is not allowed
Low coolant flow in compressor	Start-up of the compressor is not allowed Power supply to compressor is cut off
Any valve (Inlet and/or outlet of compressor, or circuit blocking) is closed	Start-up of the compressor is not allowed

Condition	Interlock
Low coolant flow in gas coolers	Start-up of the compressor is not allowed Power supply to compressor is cut off.
High temperature in compressor outlet	Power supply to compressor is cut off (through a hardwired control logic)
High pressure in compressor outlet	Power supply to compressor is cut off (through a hardwired control logic)
High pressure in the compressor leak detector	Power supply to compressor is cut off (through a hardwired control logic)
Low pressure in the hydraulic circuit of compressor	Power supply to compressor is cut off (through a hardwired control logic)

6.6.8 Inspection and Testing

The inspection and testing program for fabrication, assembly, pre-operation and in-service operation was developed during detailed engineering in accordance with the Construction Inspection and Test Plan (CITP).

6.6.9 Reflector Cooling and Purification System – Design Evaluation

The RCPS meets the following safety design bases:

a) It has the capacity to remove reflector heat.

The design of the RCPS is based on the maximum heat to be removed from the reflector heavy water as a result of neutron reflection. This proportion of the core energy and other circuit characteristics are the input for the verification of the system mass and energy balance, by means of the CHEMCAD 5.0.01 Chemstations Inc. software.

The design also allows cooling of the Cold Neutron Source (CNS) Reflector Plug and the future Hot Neutron Source (HNS) during normal operation of the Reactor and the cooling of the CNS Reflector Plug, CNS Vacuum Containment and HNS, once the Second Shutdown System is triggered

Engineers Aide SINET-XLT 5.3, Epcon International was used to perform head loss calculations for pipe networks and CRANE Companion 2.50 ABZ Inc. is used for single pipeline calculations.

Flow rate, available head loss and SCS data were inputs to the design of the heat exchangers.

Selection of the appropriate pump was carried out on the basis of the analysis with the aid of the pump characteristic curves provided by the manufacturer, and the assignment of an adequate safety margin, ensuring the system capability to meet the design basis.

b) The design minimises the possibility of any leakage of heavy water beyond the containment due to a leak in the heat exchanger.

A welded plate heat exchanger is used as the interface between the heavy water and light water to increase the leaktightness of the system. Furthermore, the Reflector Intermediate Cooling Circuit provides an additional barrier to prevent the leakage of tritium to the SCS and to the atmosphere.

c) The purification system maintains the quality of the D_2O at an acceptable level.

d) The deuterium recombination system maintains the deuterium/oxygen concentration at a safe level.

The deuterium recombination system ensures that the content of deuterium gas will not exceed the safety limits specified to avoid hydrogen explosion hazard. Adequate instrumentation has been included in the design to ensure that automatic remedial action by the RCMS which displays operating parameters and provides operators with the alarms if operating limits are exceeded.

e) To maintain its integrity during adverse combinations of loading and forces occurring during abnormal conditions.

Appropriate safety characteristics have been adopted regarding the reflector vessel shape and diffusing rings to ensure its adequate performance (Chapter 5, Section 5.2). The decay heat removal by passive means through the Reflector Vessel structure to the Reactor Pool ensures its performance during any postulated conditions.

Appropriate safety margins in accordance to applicable standards (Section 6.1.1) have been employed in the capacity of the components and piping and fixing devices to ensure the integrity of the RCPS boundary regarding internal pressure, corrosion, water quality (Section 6.4.4 Chemistry of Reactor Coolant) and seismic hazard (Section 6.6.10).

Failure Modes and Effects Analysis (FMEA) was conducted for this system and the conclusions are summarised below:

a) Leaks from the reflector primary cooling circuit. This will result in a loss of reflection power. This event represents an insertion of negative reactivity for which the control rod will try to compensate. It is not a safety hazard. This event is analysed in Chapter 16.

b) Loss of reflector cooling. It includes events such as Loss of Heat Sink (LOHS) and loss of the Reflector Intermediate Cooling Circuit. The events are analysed in Chapter 16.

c) High concentration of deuterium in the system due to failure in the recombination process (for example, due to the failure of the Deuterium Recombination System or loss of oxygen supply).

This event will first initiate the deuterium concentration high alarm. If the condition persists, a deuterium concentration very high alarm will be indicated. In either case, the operator will assess the situation and take corrective actions.

In the improbable event that the two recombination trains fail, the deuterium concentration will keep increasing until the mixture becomes explosive and the pressure will be released by the relief valves to the tritium containment area. This event is analysed in Chapter 16.

6.6.10 Seismic Evaluation

The RCPS is classified Seismic Category 1. That means that the components of the system must maintain their structural and safety function during and after the SL-2 earthquake.

The seismic stress evaluation performed followed the recommendations of IAEA and USNRC about design criteria for the resistance against seismic hazard (see Chapter 2, section 2.6.1). It was applied to the RCPS design resulting of detailed engineering stage, and considered:

a) The acceleration spectra for the building positions where systems are fixed
b) consideration of the fixing characteristics
c) consideration of the mass of water contained within the system
d) stress evaluation in piping, components and fixing points

This seismic analysis is part of the stress analysis performed for the system. The purpose of this analysis was:

a) To verify that the design of the pipelines corresponding to the Reflector Cooling & Purification System meets the requirements of the ASME Code as regards stress.
c) To verify that the loads imposed on the equipment are below the allowable ones.

The applicable codes were:

a) ASME used in the analysis of the pipelines
b) Allowable loads of the heat exchangers provided by the manufacturer
c) Allowable loads of the pumps provided by the manufacturer

The seismic evaluation involved the pipelines of the RPCS outside the reactor pool including main components interactions (pipes, valves, pumps, vessels, heat exchangers, fittings).

The analysis was performed using CAESAR II 4.30 program for the analysis of stress on pipelines. The intermediate circuit heat exchanger was analysed with Strand 7.

The seismic analysis of the reflector vessel is presented in Chapter 5.

6.6.10.1 Hypotheses for the Analyses

The main hypotheses used in this analysis are:

a) Friction on the sliding supports is not considered
b) The calculation model simulates the pipeline design configuration with the positions of adequate supports to meet the stability conditions in static and dynamic rates.
c) Pipeline reducers are modelled as pipeline sections of a length equal to that of a standard reducer. The diameter and thickness adopted shall be the average of both diameters.
d) Assembly temperature: 21ºC

6.6.10.2 Input Data

The basic input data used in this analysis consists of:

a) Dimensions, geometry and design characteristics of piping and equipment corresponding to the detailed engineering stage and when appropriate/available provided by the manufacturer.
b) Process data.

c) Materials characteristic extracted from ASME Boiler & Pressure Vessel Code, Section II – Part D.

d) Seismic Spectra for seismic class SL-2 for the relevant obtained from the Seismic Design Floor Response Spectra defined for the Reactor Building, which corresponds to 0.37 PGA with the following considerations:

(i) When the support is bound to a slab, the spectra corresponding to that slab level was applied.

(ii) When the support is bound to a wall, the spectra corresponding to the level closest to the support was applied.

(iii) Supports with gap were modelled as restrictions acting during the earthquake. The gaps assigned to each support had a value well below the displacement during earthquake values should these restrictions not be present.

(iv) Seismic actions due to the three spatial directions were combined as the square root of the sum of each.

6.6.10.3 Model Description

The RCPS piping was divided into five parts to produce the finite element models. These parts result from dividing the system pipelines in the following way:

a) Storage Tank To Reactor Pool

b) Pump to Reactor Pool

c) Pump to Heat Exchanger

d) Heat Exchanger to Reactor Pool

e) Control Rod Room to Reactor Pool

6.6.10.4 Definition of dynamic cases

The table summarises the list of dynamic cases analysed:

DY1	Seismic event combination
DY2	Seismic event combination verified by ASME

6.6.10.5 Summary of Results

6.6.10.5.1 Storage Tank to Reactor Pool

All cases were within allowable limits.

6.6.10.5.2 Pump to Reactor Pool

All cases were within allowable limits.

6.6.10.5.3 Pump to Heat Exchanger model

All cases were within allowable limits.

6.6.10.5.4 Heat Exchanger to Reactor Pool

All cases were within allowable limits.

6.6.10.5.5 Control Rod Room to Reactor Pool

All cases were within allowable limits.

6.6.10.6 Expansion tanks

The response of the expansion tanks under a seismic event has been analysed using the PV Elite Version 4.1 and NASTRAN codes.

The appropriate seismic spectra for the item's location were used. The seismic load was applied in combination with operation (pressure) loads and weight.

The maximum stress on the tanks is below the allowable limit according to the applicable code.

6.6.10.7 Heavy Water Storage Tank

The response of the expansion tanks under a seismic event has been analysed using the PV Elite Version 4.1 and NASTRAN codes.

The appropriate seismic spectra for the item's location were used. The seismic load was applied in combination with operation (pressure) loads and weight.

The maximum stress on the tank is below the allowable limit according to the applicable code.

6.6.10.8 Ion Exchange Columns

The calculations are made with the PV Elite Version 4.1 code.

The appropriate seismic spectra for the item's location were used. The seismic load was applied in combination with operation (pressure) loads and weight.

The stress on the welds that connects the shell to the support lugs was calculated and it was demonstrated that it complies with the acceptance criterion in the applicable code.

6.6.10.9 Deuterium Recombination System

The behaviour of the piping and components of the Deuterium Recombination System under a seismic event was analysed.

The calculations were performed with the following codes:

c) PV Elite Version 4.1

d) NASTRAN2.1

e) ANSYS 5.7

The appropriate seismic spectra for the item's location were used.

6.6.10.9.1 Recombiner

Stresses were within the allowable limit.

6.6.10.9.2 Dampening Vessel

Stresses were within the allowable limit.

6.6.10.9.3 Piping

All cases were within allowable limits.

6.6.10.10 Conclusion

The summary of results show that the stress on the pipelines and components for the different load cases does not exceed the limits set by the applicable code.

End of Section

6.7 EMERGENCY MAKE-UP WATER SYSTEM

6.7.1 Introduction

The Emergency Make-up Water System (EMWS) is provided to ensure that the core is covered with water in the event of a beyond design basis LOCA, which involves a drop in the water level of the Reactor Pool to below the edge of the upper chimney.

EMWS injects water under gravity into the two legs of the PCS pool inlet pipelines. The water level is maintained in the reactor chimney, hence the reactor core is kept flooded.

EMWS is a passive system. The water flow is initiated by the automatic opening of at least one out of two valves when Reactor Pool water level reaches the level of the upper edge of the reactor chimney. If one of the valves fails to open, the system can still fulfil its function via the remaining valve.

EMWS is designed to keep the chimney full of water for twenty-four hours, compensating coolant evaporation losses caused by the core decay heat.

It is possible to maintain the system in operation for more that twenty-four hours by refilling the EMWS storage tanks with water from the Refilling Pool (Radioactive Liquid Waste Management System), from the Demineralised Water Supply System or from another external water source such as a tanker.

6.7.2 Safety Design Basis

The EMWS has been designed to keep the core covered with water in the event of a beyond design basis LOCA that could be expected to drop the Reactor Pool water level below the upper chimney edge.

6.7.3 Circuit Description

The material of all piping and equipment is stainless steel.

The system consists basically of two water storage tanks, piping, and two injection valves.

The EMWS Storage Tanks are located within the Reactor Hall in the EMWS room. The tanks are cylindrical and are placed horizontally. Each one is 50% capacity.

Each of the tanks has a discharge pipeline, with manual isolation valves, provided for tanks maintenance, then both lines are brought together into a single main pipeline.

Inside the Reactor Pool the pipeline splits into two parallel injection pipelines. Each one of them has an injection valve located in the upper part of the Reactor Pool.

Each pipeline is connected to one of the two inlet pipes, below the PCS Flap Valves, in such a way that the full flow is directed towards the core.

The internal valve arrangement prevents back-flow when the PCS is operating in forced circulation.

The tanks have the following auxiliary connections:

a) Demineralised water pipeline from the Demineralised Water Supply System, for filling and make-up through a float-type valve.

b) Pipeline from the RLWM Refilling Pool, for water make-up. This connection allows manual refilling when continuous emergency make-up water is to be provided twenty four hours after the EMWS has been triggered and when the DWSS is unavailable.

c) Overflow line pipe connected to the RLWM Refilling Pool

d) Vent pipe.

All auxiliary connections of the EMWS storage tanks are provided with in-line strainers to prevent foreign material from entering the tanks.

6.7.4 System Modes

The EMWS is available during reactor operation in both the Power and Physics Test states.

In the Refuelling and Shutdown States, the system is not required but it remains active.

When the reactor pool water drops to the upper chimney level, the two valves open. This allows water to flow under gravity into the two legs of the PCS pool inlet pipelines.

The total EMWS water inventory is capable of compensating for evaporation and keeping the chimney full of water for twenty four hours, without back up water supply.

6.7.5 Determination of EMWS Flow-Rate Requirement

The thermal-hydraulic aspects related with the time evolution of the water level inside the chimney due to the water injection were analysed. The following initial conditions are assumed:

a) The EMWS is triggered with the pool water level at the upper edge of the chimney.

b) The reactor has been tripped 475s earlier due to a major LOCA.

Assuming the reactor was operating at 20 MW at the moment of the reactor trip, the decay power at the time of the EMWS actuation is equal to 740 kW, as estimated using the ANSI/ANS - 5.1 – 1979 standard calculation procedures.

The mass balance equation was solved with three flow components: injection, evaporation and leakage.

The water level evolution was calculated according to the liquid mass inside the chimney and the flow area corresponding to the chimney and the two pump discharge lines of the PCS.

The Departure from Nucleate Boiling (DNB) Ratio was calculated (“Le calcul thermique des reacteurs de recherche refroidis par eau”, S. Fabrega, CEA-R-4114) and the results indicate that the fuel will be cooled by boiling off the water in the chimney, with no damage to the cladding.

It is concluded that a constant injection flow will keep the core covered with water and water evaporation will not cause any damage to the core.

During the transient, the minimum DNB Ratio is 2.3. This margin to the safety limit (DNBR = 1.5 for transients, see Chapter 16) ensures the integrity of the fuel assemblies.

6.7.6 EMWS Components

6.7.6.1 Water Storage tank

Parameter	Value

Parameter	Value
Quantity	2 (two)

6.7.7 EMWS Instrumentation

6.7.7.1 Flow

Instrument	Location	System	Control Room Indication/Alarm	Related Safety Actions
Flow switch (2)	Main pipeline	RCMS PAM	Downward flow alarm	None
Flow switch	Main pipeline	RCMS	Upward flow alarm	None

6.7.7.2 Level

Instrument	Location	System	Control Room Indication/Alarm	Related Safety Actions
Level switch (2)	Storage tank	RCMS PAM	Low level alarm	Reactor start-up not allowed
Level switch	Overflow level of the EMWS Storage Tank 1	RCMS	High level alarm (overflow)	None

6.7.7.3 Valves Position

Instrument	Location	System	Control Room Indication/Alarm	Related Safety Actions
Position switch (2 for each valve)	Isolation ball valves	RCMS	Indication (fully open/fully closed) Alarm (not fully open)	Valve not fully open, reactor start up not allowed.
Position switch (2 for each valve)	Injection valves	RCMS	Indication (fully open/fully closed)	None

6.7.8 Actions on RCMS due to EMWS Signals

The Instrumentation and Control System is fully described in Chapter 8, Section 8.12. This section reproduces the main actions of the RPS and RCMS associated with the EMWS.

6.7.8.1 Reactor trip signals

There are no trip signals for this system.

6.7.8.2 Manual shutdown

Condition	Operator action
Low level alarm	The operator will assess the situation and take

	corrective action.

6.7.8.3 Interlocks

Condition	Interlock
Low level in water storage tanks	Reactor start-up not allowed
Manual blocking valve is closed	Reactor start-up not allowed

6.7.8.4 Other Control Logics

An alarm signal is triggered in the RCMS if downward flow is detected on the main discharge line with system start-up signal (fully open position of any injection valves).

6.7.9 Inspection and Testing

The inspection and testing program for fabrication, assembly, pre-operation and in-service operation was developed during detailed engineering in accordance with the Construction Inspection and Test Plan (CITP).

6.7.10 Design Evaluation

The EMWS meets the safety design bases:
a) To keep the core covered with water in the event of a beyond design basis LOCA that could be expected to drop the Reactor Pool water level below the upper chimney edge

The minimum flow-rate to fulfil this requirement was calculated according to the description of Section 6.7.5. The flow-rate calculation was further confirmed by calculation of the mass and energy balance with CHEMCAD 5.0.01 Chemstations Inc. software, to establish the required flow to compensate for evaporation and leaks from reactor chimney.

The constant injection flow was able to compensate the maximum evaporation rate during the initial stages when water injection starts, and later exceeds the evaporation rate.

Engineers Aide SINET-XLT 5.3, Epcon International is used to perform head loss calculations for pipe networks and CRANE Companion 2.50 ABZ Inc. is used for single pipeline calculations and orifice plate sizing.

The duration of the constant injection is defined as a requirement and determines the water inventory in the storage tanks.

Appropriate safety margins have been adopted in the design of the components and piping and fixing devices to ensure the integrity of the EMWS boundary under all operating conditions.

The FMEA for the EMWS indicated that failures of this system do not represent a significant safety hazard to the reactor. No initiating events need to be evaluated in Chapter 16 in relation to failures of the EMWS.

6.7.11 Seismic Evaluation

The EMWS is classified under Seismic Category 1, with some of its components classified under Seismic Category 2. The Seismic Category 1 components must maintain their structural and safety function during and after the SL-2 earthquake, independent of whether they remain operational or out of service for the rest of their useful life. This last condition depends on the type of component under study.

The seismic stress evaluation performed followed the recommendations of IAEA and USNRC about design criteria for the resistance against seismic hazard (see Chapter 2, section 2.6.1). It was applied to the EMWS design resulting of detailed engineering stage, and considered:

a) The acceleration spectra for the building positions where systems are fixed
b) consideration of the fixing characteristics
c) consideration of the mass of water contained within the system
d) stress evaluation in piping, components and fixing points

This seismic analysis is part of the stress analysis performed for the system. The purpose of this analysis is:

a) To verify that the design of the pipelines corresponding to the Emergency Make Up Water System meets the requirements of the ASME Code as regards stress.
b) To verify that the loads imposed on the equipments are below the allowable values

The applicable code is ASME to be used in the analysis of the pipelines.

The seismic evaluation involves the pipelines of the EMWS outside the reactor pool and the discharge pipes.

The CAESAR II 4.30 program was used for the analysis of stress on pipelines

6.7.11.1 Hypotheses of the Analysis

The main hypotheses used in this analysis are:

a) Friction on the sliding supports is not considered.
b) Pipeline reducers are modelled as pipeline sections of a length equal to that of a standard reducer. The diameter and thickness adopted shall be be the average of both diameters.
c) Assembly temperature: 21ºC

6.7.11.2 Input Data

The basic input data used in this analysis consists of:

a) Dimensions, geometry and design characteristics of piping and equipment corresponding to the detailed engineering stage and when appropriate/available provided by the manufacturer.
b) Materials characteristic extracted from ASME Boiler & Pressure Vessel Code, Section II – Part D.
c) Seismic Spectra for seismic class SL-2 for the relevant levels, with the following considerations
    (i) When the support is bound to a slab, the spectra corresponding to that slab level shall be applied.
    (ii) When the support is bound to a wall, the spectra corresponding to the level closest to the support shall be applied.
    (iii) The damping applied to the pipelines is of 2%.

(iv) Supports with gap are modelled as restrictions acting during the earthquake. The gaps assigned to each support have a value well below the displacement during earthquake values should these restrictions not be present.

6.7.11.3 Model Description

The system has been modelled with finite elements to represent the piping under analysis.

6.7.11.4 Definition of dynamic cases

DY1	Seismic event combination
DY2	Seismic event combination verified by B31.1

6.7.11.5 Summary of Results

All cases were within allowable limits.

6.7.11.6 Conclusions

From the summary of results given above it concludes that the stress on the EMWS for the different load cases does not exceed the limits set by the applicable codes.

End of Section

6.8 SECONDARY COOLING SYSTEM

6.8.1 Introduction

The Secondary Cooling System (SCS) transfers to the atmosphere the heat from:

a) Primary Cooling System (PCS)
b) Reactor and Service Pool Cooling System (RSPCS)(includes rigs cooling and core decay heat)
c) Reflector Cooling and Purification System (RCPS)
d) Reactor facilities (includes specific cooling for irradiation targets and Cold Neutron Source)
e) Reactor auxiliaries (water chillers – Heating, Ventilation and Air Conditioning (HVAC) systems)

Heat is dissipated to the atmosphere by a set of cooling towers.

The system includes continuous monitoring for radioactivity.

6.8.2 Design Bases

The SCS has been designed to meet the following design bases:

a) To remove the whole heat load transferred from the PCS, RSPCS, RCPS, reactor facilities and reactor auxiliaries and discharge it to the atmosphere.

b) Together with the PCS and the control system, to maintain a steady core coolant inlet temperature over the range of operating conditions regardless of variations in meteorological conditions prevailing at the site.

c) To minimise the probability of a release of radioactivity from the Primary Cooling System to the environment.

d) To maintain its integrity during adverse combinations or loading and forces occurring during abnormal conditions (see Section 6.8.9 and 6.8.10)

6.8.3 Circuit Description

Every pipeline entering or exiting the Reactor Building is provided with isolating valves located as close as possible to the containment.

SCS blow-down and pump drains are connected to the ANSTO liquid wastes line C.

The cooling towers are placed at a safe distance from the bush existing at the site to allow for safe operation in the event of a bush fire.

The pumping groups are located outdoors, adjacent to the cooling towers and surrounded by a fence.

6.8.3.1 Cooling Towers

The system comprises a counter flow forced draft cooling tower, arranged into five equivalent modules or cells. During normal reactor operation, four of them operate while the remaining one is on stand-by.

A temperature control loop keeps the PCS coolant entering the reactor core at a constant temperature.

The cooling tower basin has an internal separation, which will divide the basin into two compartments when the water level is dropped to the maintenance level. This internal division allows water to be retained in either of the two compartments while the other is being completely drained for cleaning purpose. This arrangement will allow at least one cooling tower in operation to serve the HVAC systems.

A dedicated pump is provided for draining of the cooling tower basin.

The cooling towers are capable of operating without damage in case of a bush fire in close proximity to the site.

6.8.3.2 Cooling Circuit

Three main centrifugal pumps of 50% capacity are installed. Two are in operation and one is on stand-by. A fraction of this flow is diverted to the blow-down before reaching the Reactor Building. Part of this is directed to a side stream self-cleaning filter before being returned to the cooling tower basin. This is part of the water treatment system to keep the water quality within operating range.

Three pipelines take water from the cooling tower basin to the main pumps collecting into a header that runs under the ground to the Reactor Building. Inside the containment, the cooling line heads to the process area. An internal pipe network provides cooling water to heat exchangers of the following systems: PCS, RSPCS, targets irradiation facilities cooling and Reflector Intermediate Cooling Circuit.

Another pumping group, for long term pool cooling consists of two lower capacity centrifugal pumps (100 % capacity each, one on stand by) and is placed in parallel with the main pumps. These pumps are connected to both the Normal Power Supply and to the Standby Power Supply.

After the heat exchangers, the lines join the header that takes water back from the reactor building to the cooling tower where the coolant is distributed among the operating cooling tower modules by means of individual lines.

The SCS is continuously monitored by an activity detector placed on a dedicated line inside the Reactor Building. This line takes water from downstream of the primary heat exchangers, and returns it to the cooling tower basin after flowing through the secondary water activity monitor (SAMO).

There are two other pumping groups that are connected to the system. They are for the helium compressors and Cold Box of the CNS and the water chillers of the reactor building HVAC system.

6.8.3.3 Cold Neutron Source - Helium Compressors Circuit

Two centrifugal pumps of 100% capacity, one operating and one on stand-by, circulate water to the helium compressors and Cold Box of the CNS.

The pumps take water from the cooling tower basin by means of the header and discharge to a line leading to the auxiliary building where the He compressors are located. A branch is provided to serve the cold box located inside the Reactor Building. Water then flows back to the cooling towers.

6.8.3.4 Heating, Ventilation and Air Conditioning - Water Chillers

Two centrifugal pumps of 100% capacity, one operating and one on stand-by, circulate water to the water chillers of the HVAC system.

This pump takes water from the cooling tower basin by means of the header and discharge to a line heading to the auxiliary building where the chillers are placed. Water then flows back to the cooling towers.

6.8.4 Secondary Cooling System Operation Modes

The SCS has two possible operation modes: Power state heat removal mode and LTPC mode. Power state heat removal mode operates when the reactor is in the Power or Physics Test states. The LTPC mode operates when the reactor is in the Shutdown or Refuelling states.

<table>
<tr><th>Reactor State</th><th>SCS Operation Mode</th><th>SCS Configuration</th><th>SCS Function</th></tr>
<tr><td>Power</td><td rowspan="2">Power state heat removal mode</td><td rowspan="2">2 main pumps on
1 main pump on standby
LTPC pumps off
1 pump for the chillers on
1 pump for the chillers on standby
1 pump for He compressors on
1 pump for He compressors on standby
SCS Water treatment: on</td><td>Heat removal from:
PCS, RSPCS, RCPS, target irradiation facilities
HVAC water chillers
He compressors
CNS Cold box</td></tr>
<tr><td>Physics Test</td><td>Heat removal from:
RSPCS and RCPS
HVAC water chillers
He compressors
CNS Cold box</td></tr>
<tr><td>Shutdown
Refuelling</td><td>LTPC mode</td><td>3 main pumps off
1 LTPC pumps on
1 LTPC pumps off
1 pump for chillers on
1 pump for chillers on standby
2 pumps for He compressors on stand by
SCS Water treatment: on</td><td>Heat removal from:
RSPCS
HVAC water chillers</td></tr>
</table>

A flow meter placed in the water make-up stream monitors the volume of water consumption.

The water chemistry is controlled by the SCS Water treatment system described in the next section.

Main characteristics of the two operation modes are described below.

6.8.4.1 Long Term Pool Cooling Mode

After the reactor is shutdown, the operator will decide whether to continue running the main pumps or to change over to the lower capacity pump for the long term cooling of the pools.

The pumps for the long term cooling of the pools are connected to the stand-by power supply. In the event of a main power supply failure, the one long term cooling pump in operation will be able to provide adequate water circulation to maintain the pool temperature within the normal operating range.

6.8.5 Secondary Cooling System Components

6.8.5.1 Cooling Tower

Parameter	Value
Quantity	5 cells (one on stand-by)
Type	Forced draft- counter flow

6.8.5.2 Main Pumps

Parameter	Value
Quantity	Three (one on stand-by)
Type	Centrifugal split case
Capacity	50% each

6.8.5.3 LTPC Pumps

Parameter	Value
Quantity	Two (one on stand-by)
Type	Centrifugal

6.8.5.4 Cold Neutron Source Helium Compressors - Refrigeration Pump

Parameter	Value
Quantity	Two (one on stand-by)
Type	Centrifugal
Capacity	100% each
Casing Material	Cast iron

6.8.5.5 Cooling Tower Drainage Pump

Parameter	Value
Quantity	One
Type	Centrifugal
Capacity	100%
Casing Material	Cast iron

6.8.5.6 Heating, Ventilation and Air Conditioning - Water Chillers Cooling Pumps

Parameter	Value
Quantity	Two (one on stand-by)
Type	Centrifugal
Capacity	100% each
Casing Material	Cast iron

6.8.6 Secondary Cooling System Instrumentation

6.8.6.1 Pressure

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Pressure switch	Instrumentation chamber, reactor building pump discharge line.	RCMS	Low pressure alarm	None

6.8.6.2 Temperature

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature transmitter	Instrumentation chamber, reactor building pump discharge line.	RCMS	Indication	None
Temperature transmitter	Instrumentation chamber, reactor building pump discharge line.	RCMS	Indication	None
Temperature transmitter	CNS He compressors inlet	RCMS	Indication	None
Temperature transmitter	CNS. He compressors outlet	RCMS	Indication	None
Temperature transmitter	PCS Heat Exchangers inlet	RCMS	Indication	None
Temperature transmitter	PCS Heat Exchangers outlet	RCMS	Indication	None
Temperature transmitter	RSPCS Heat Exchanger inlet	RCMS	Indication	None
Temperature transmitter	RSPCS Heat Exchanger outlet	RCMS	Indication	None
Temperature transmitter	RCPS Heat Exchanger inlet	RCMS	Indication	None
Temperature transmitter	RCPS Heat Exchanger outlet	RCMS	Indication	None

6.8.6.3 Flow

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Flow meter	Instrumentation chamber, reactor building pump discharge line.	RCMS	Indication Low Flow Alarm	None

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Flow meter	Blow down stream	RCMS	Indication	None
Flow meter	Pumps discharge	RCMS	Indication	None

6.8.6.4 Level

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Level transmitter	Cooling tower basin	RCMS	Indication High level alarm Low level alarm	None

6.8.6.5 Position

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Position switch	Containment isolation valves	RCMS	Indication full closed position	None

6.8.6.6 Main Pump Temperature Instrumentation

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature switch	Pump motor winding	RCMS	High temperature alarm	None
Temperature switch	Pump motor winding	RCMS	Very high temperature alarm	Pump trip

6.8.6.7 Chillers Cooling Pump Temperature Instrumentation

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Temperature switch	Pump motor winding	RCMS	None	None

6.8.6.8 Circulation Pump Vibration Instrumentation

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Vibration switch	Motor bearings	RCMS	High vibration alarm	None
			Very high vibration Alarm	None

6.8.6.9 Cooling Tower Fans Vibration Instrumentation

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Vibration switch	Each fan	RCMS	High vibration alarm	None

6.8.6.10 Water Activity Monitor

Instrument	Location	System	Control Room indication/Alarm	Protection Functions
Gamma activity monitor (SAMO)	Reactor building. return pipeline to the cooling towers	RCMS	Alarm	None

6.8.6.11 Differential pressure

Instrument	Location	System	Control Room Indication/Alarm	Protection Functions
Differential pressure	Self cleaning filter	RCMS		None

6.8.7 Secondary Coolant System Water Treatment

6.8.7.1 Introduction

The SCS Water Treatment (SCSWT) controls the water chemistry so as to prevent corrosion, scale and microbiological growth in the system. The program includes the control of Legionallae bacteria.

The treatment includes:

a) SCS side-stream filtering to control solid levels.

b) Blow-down stream to control chloride level.

c) pH control, conductivity control, oxidant biocide control

d) Chemical dosing (corrosion inhibitor, dispersing and bio-dispersant agents, oxidant and non-oxidant biocide, sulphuric acid).

6.8.7.2 Circuit Description

The chemical control equipment is installed beside the cooling towers. It consists of a control and monitoring (C&M) unit, corrosion monitoring unit, dosing pumps and chemical storage tanks.

The system diverts flow from SCS return pipeline to the SCSWT on-line units (C&M unit, corrosion monitoring unit). The C&M unit regulates the different dosing units or blow-down stream.

Chemicals are dosed either to the cooling tower pool or to the water return line.

A pipe diverts water from the SCS main pump discharge line to blow-down and the self-cleaning filter. The blow down quantity is controlled by the C&M unit and the remaining of the water returns via a pipeline passing through the filter to the bottom of the control tower basin. The discharge is via a set of injectors that sweep the floor, preventing the undesirable build-up of sludge. The filter controls the size of solids in the system

Cleaning of the filter takes place automatically.

A flow meter is installed at the blow-down stream in order to monitor the volume of water released to the liquid waste line C.

6.8.7.3 Operation Mode

The system has only one operating mode in controlling SCS water quality.

The treatment involves a blow-down stream and the supply of chemicals such as sulphuric acid, corrosion inhibitor, dispersing and bio-dispersant agents, biocide to keep the coolant within correct chemical quality to control the rate of corrosion and biological growth in the system.

An on-line system is continuously monitoring the secondary coolant quality and will initiate chemical dosing or open the blow-down valve to correct the chemical properties if they exceed predetermined levels.

The self-cleaning filter controls the level of solids in the system.

6.8.7.4 Components

6.8.7.4.1 Filter

Parameter	Value
Quantity	One
Type	Self-cleaning

6.8.7.4.2 Dosing Units

Chemicals are stored in tanks provided with independent metering pumps to dose the chemicals into the system.

6.8.7.5 Instrumentation

The following instruments belong to the Reactor Control and Monitoring System:

Instrument	System	Control Room Indication/Alarm	Control action	Protection Functions
Conductivity meter & controller	RCMS	High & low level alarm	Control of blow-down rate	None
pH meter & controller	RCMS	High & low level alarm	Sulphuric acid dosing	None
Free halogen concentration/Oxidant Reduction Potential meter & controller	RCMS	High & low level alarm	Dosing of sodium hypochlorite	None
Multiple controller	RCMS	High & low level alarm	Dosing of corrosion inhibitor/corrosion inhibitor + dispersant /bio-dispersant	None

6.8.8 Actions on RPS and RCMS due to Secondary Cooling System Signals

The Instrumentation and Control System is fully described in Chapter 8, Section 8.9. This section reproduces the main actions of the RCMS associated with the SCS.

6.8.8.1 Trip Signals

There are no reactor trip or shutdown signals for this circuit. Low flow in the SCS will result in a reactor trip due to high temperature in PCS.

Very-High temperature in main pump motor winding will stop the pump (hardwired interlock). The stand-by pump starts automatically (by RCMS).

6.8.8.2 Manual Shutdown

Condition	Operator Action
High temperature in main pump motor winding	The operator will assess the situation and take appropriate corrective actions.
High temperature in main pump bearings	
High vibration in Cooling Tower fans.	
High temperature in pump discharge line to the reactor building	
Low level alarm in Cooling Tower basin	
Failure of make up water	

6.8.8.3 Interlocks

Condition	Interlock
Failure of one of the main operating pumps	Stand-by pump starts automatically
High and very high temperature in motor winding of any main pump	Main pump trip
High temperature in motor winding of chillers cooling pump	Chillers cooling pump trip
Main pump shut-down and start-up signals are transmitted simultaneously by mistake	The shut-down signal has priority
Water chemistry exceed operating range	Controller opens blow-down valve.

6.8.9 Inspection and Testing

The inspection and testing program for fabrication, assembly, pre-operation and in-service operation was developed during detailed engineering in accordance with the Construction Inspection and Test Plan (CITP).

6.8.10 Secondary Cooling System - Design Evaluation

The SCS meets the following design basis:

a) It is designed to transfer the heat load from the PCS, RSPCS, RCPS, reactor facilities and reactor auxiliaries and to discharge it to the atmosphere.

b) It is designed together with the PCS and the control system, to be able to maintain steady core coolant inlet temperature over the range of operating conditions and regardless of variations in meteorological conditions prevailing at the site.

c) It reduces the probability of the release of radioactivity from the primary cooling system to the environment.

d) To maintain its integrity during adverse combinations or loading and forces occurring during abnormal conditions.

The nominal heat load resulting from the thermal balance of these systems was used as input for the verification of the SCS design by means of the CHEMCAD 5.0.01 Chemstations Inc. software.

Engineers Aide SINET-XLT 5.3, Epcon International is used to perform head loss calculations for pipe networks and CRANE Companion 2.50 ABZ Inc. is used for single pipeline calculations.

Cooling tower specifications for the SCS were calculated for the wet bulb temperature on the basis of the SCS design. The cooling towers were designed and fabricated by the manufacturer to meet the required specifications to ensure the system capacity to remove the nominal heat from the cooling systems.

The steady temperature at the core inlet flow is ensured by the SCS control loop, which has a comfortable margin of operation given the large thermal inertia of the SCS water and the capacity of the cooling towers.

Appropriate safety margin has been assigned to the thermal capacity of the system to ensure its performance in all operating conditions.

Appropriate safety margins have been employed in the sizing of the components and piping and fixing devices to ensure the integrity of the SCS boundary. The design of the heat exchangers provides appropriate separation between the SCS and the PCS, to prevent the possibility of contaminating the SCS with PCS water.

The SCWTS design ensures that water quality will be maintained within acceptable limits for safe operation.

FMEA has been performed on the system to identify possible initiating events associated with the SCS that should be analysed as safety issues in Chapter 16. The analyses in Chapter 16 indicate that all postulated events will result in a safe reactor shutdown with the core safely covered and cooled.

Dependent failure analysis has been carried out to assess the impact of failures of redundant component such as main SCS pumps, long term pool cooling pumps or cooling towers. The conclusions of the assessment are as follows:

a) The analysis identifies electrical supply as a common cause of failure for main SCS pumps. This event is identified as a loss of heat sink event and its consequences are analysed in Chapter 16, section 16.10. The pumps associated with long term pool cooling are connected to the stand-by supply system. Failure of this is not considered as possible for any of the initiating events involving the loss of the Normal Power Supply. Justification is given in Chapter 16, section 16.9.

b) Failure of cooling towers due to extreme winds is considered as loss of heat sink event analysed in Chapter 16, section 16.10.

c) Cooling towers out of service due to extreme temperatures. Two cases are analysed:

   (i) Very low temperatures. Cooling tower fans can be regulated to diminish the effect of forced cooling and they can be stopped if it is required. Hence, this issue does not represent a safety hazard.

   (ii) Very high temperatures. This case can be considered as a loss of heat sink event, analysed in Chapter 16, section 16.10.

SCS design includes provisions for protection against hazards such as fires, missiles, and falling loads. A summary of the protections provided for the SCS are:

a) Fire: the cooling towers are located a safe distance from the bush existing at the site and will not be affected in the event of a bush fire. Moreover, the plastic packing of the cooling tower is of limited combustibility with flame spread rating lower than 25 in accordance with NFPA 255/ASTM 84 Standards.

b) Missiles: Aircraft crash on one or more of the cooling towers will result in loss of heat sink that is analysed in Chapter 16, section 16.10.

6.8.11 Seismic Evaluation

The equipment and piping of the SCS associated with the long term pool cooling is classified under Seismic Category 1. The rest of the equipment is classified under Seismic Category 2 and 3 (SCSWT)

End of Section