16.9 ANALYSIS OF LOSS OF FLOW EVENTS

16.9.1 Introduction

This Section provides a description of the analysis of events with loss of flow in the PCS. Incidents involving loss of flow to the irradiation facilities are considered in Section 16.15.

The analysis applies to the behaviour of the core and the PCS.

Loss of Flow Accidents (LOFAs) fall into two main groups, namely:

a) Those involving a flow decrease through the core or individual fuel assembly, referred to from now on as LOFA.

b) Those resulting from a power increase instead of a flow decrease, from now on referred to as power-flow mismatch events.

16.9.2 Loss of Flow Accident

A LOFA may arise through failures associated with the PCS pumps or events resulting in a decrease in the primary coolant flow with the PCS pumps functioning normally.

16.9.2.1 Primary Pump Failure

The following table summarises the effects on core cooling arising from failures of the PCS pumps.

Pump A	Pump B	Core cooling
Shaft seizure	Running	Forced circulation
Shaft seizure	Shaft seizure	Natural circulation
Motor failure	Running	Forced circulation
Motor failure	Motor failure	Fly-wheel controlled forced circulation/natural circulation

16.9.2.1.1 Pump Shaft Seizure

In this event the reduction in flow is sudden, with the shaft seizure impeding the flow coast down provided by the pump inertia. Until reactor shutdown is initiated by the FRPS, 50% of the nominal full power pumping capacity is available via the remaining pump to remove the core heat load. The FRPS triggers the FSS on low-pressure drop in the core and low-flow in the PCS. The reactor shuts down with the remaining pump removing decay heat.

The probability of occurrence of a pump shaft seizure is considered to be very low due to the high quality of manufacture. No pathway has been identified for the intrusion of a foreign object in the PCS piping that could lead to pump shaft seizure. A protective grid is placed on top of the chimney during operation. An object that had fallen into the pool during refuelling and been sucked into the PCS piping would remain in the decay tank located between the Reactor Pool and the PCS pumps.

The pumps are triple-redundant, with three pumps of 50% capacity. Two of the pumps are in operation and the third one is in standby. In accordance with international design codes, the manufacturers of the PCS pumps use very large safety margins in the design of pump shafts and rotating machinery.

Anticipatory signals would appear before shaft seizure. Vibration in the and high temperature in the pump motor would trigger alarms in the Main Control Room via the RCMS. In order to protect the integrity of the pump, very high vibration would cause automatic pump shutdown.

Even though shaft seizure is considered highly unlikely, the seizure of a shaft with full sudden stoppage of the pump is considered to be within the design basis and is simulated. However, the likelihood of shaft seizure together with failure of the FSS is considered so unlikely as to render it beyond the design basis.

16.9.2.1.1.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	Equipment purchased from qualified manufacturer
		Pumps designed and manufactured in accordance with international design codes and standards within a QA plan.
		Appropriate maintenance programme in place
2	Operation control and response to abnormal operation	Alarms on: a) Low flow of the PCS b) Low core pressure drop c) High core outlet temperature d) High core temperature difference e) High vibration f) High temperature on pump motor windings
		Pump trip (RCMS signal) on very high vibration
3	Control of accidents within the design basis	FRPS reactor trip signal on: a) Low flow of the PCS b) Low core pressure drop c) High core temperature difference SRPS reactor trip signal: a) Very low core pressure drop (setting is lower than setting for FRPS) together with no end-of-stroke signal from two or more CRs b) High core outlet temperature c) Failure of the FSS

16.9.2.1.2 Pump Motor Failure

This event deals with the failure of a pump motor due to, for example, malfunction or interruption of power supply (The failure is not due to loss of Normal Power. This is considered in Section 16.7.)

After failure of a pump motor, the reactor is automatically shut down by the FRPS on low core pressure drop, low PCS flow signals or high core temperature difference. The SRPS trips the SSS on very low core pressure drop coupled with no-end-of stroke signal from two or more CRs, high core outlet temperature or failure of the FSS. The undamaged pump removes decay power during the first minutes after shutdown. After this time, the undamaged pump is manually stopped by the operator and the flow coasts down according to the dynamics. As the flow coasts down, natural circulation is established.

In case both pumps experience a motor disconnection or failure, or if the power to the pump motors is lost (e.g., due to the simultaneous failure of the pumps' independent electrical switchboards), the pump inertia provides decreasing flow during shutdown. This flow is sufficient to remove decay power until natural circulation is established.

The failure of two pump motors is considered to be within the design basis and is simulated. The event bounds failure of a single pump motor. The response of the plant to this initiating event is analysed with actuation of the FSS and with failure of the FSS and actuation of the SSS. This scenario, which assumes that the pump motors fail as opposed to occurring as a result of the loss of electric power, is conservative, as it results in reactor trip being delayed until the low flow setting is reached instead of as soon as the power is lost.

16.9.2.1.2.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	High quality pump motor and electric switchboards
		Appropriate electrical maintenance programme
2	Operation control and response to abnormal operation	Alarm on high and very high temperature in motor windings
		Magnetic and electric protection in electric switchboards
		Pump trip on high motor winding temperature together with very high motor winding temperature.
		Alarms on: a) low PCS flow b) low core pressure drop c) high core temperature difference
3	Control of accidents within the design basis	FRPS reactor trip signal on: a) low flow of the PCS b) low core pressure drop c) high core temperature difference

Level	Main Characteristics	Safety Feature
		SRPS reactor trip signal on: a) Very low core pressure drop (setting is lower than setting for FRPS) together with no end-of-stroke signal from two or more CRs b) High core outlet temperature c) Failure of the FSS

16.9.2.2 Primary Coolant Flow Reduction

16.9.2.2.1 Coolant Flow Reduction Due to Failure or Blockage in Primary Cooling System Piping or Component

This initiator refers to a valve failure, or pipe blockage in the PCS piping, or to a heat exchanger blockage (see Chapter 6 for a description of the PCS).

In the case of a large PCS flow reduction, the FRPS shuts down the reactor by means of the FSS on low core pressure drop, low PCS flow signals or high core temperature difference. The SRPS trips the SSS on very low core pressure drop coupled with no-end-of stroke signal from two or more CRs, high core outlet temperature or failure of the FSS.

If flow reduction arises as a result of human error, e.g. valve position failure after maintenance, it would be detected by the RCMS as part of checking that the flow is correct before allowing the operator to increase the reactor power. The PCS has no remotely operated valves that could be closed spuriously. Manual valves require deliberate operator action to be closed. QA and careful inspection accounting for tools, cloths, and packaging after commissioning and maintenance minimises the likelihood of an obstruction due to foreign objects inside the piping.

A foreign object inside the PCS could cause the obstruction of a pipe or heat exchanger. During Stage A (cold) commissioning, the pumps are run extensively with a filter located at the pumps suction lines to collect any debris remaining from construction activities. The presence of a foreign object downstream of the pump would cause an obstruction in the heat exchanger. The heat exchanger is of plate type with over a hundred plates in the primary side. Thus, the presence of a foreign object would only lead to the obstruction of a very small percentage of the channels in the primary side of the heat exchanger. This would not significantly affect its performance or the flow (see Chapter 6 for a detailed description of the heat exchanger and its design evaluation).

Sizeable foreign objects introduced into the Reactor Pool during operation cannot enter the PCS. The flow coming from the core flows inside the chimney and the exit PCS line is connected to it, unconnected to the pool. A grille that acts as a filter for objects that could fall from the pool top covers the chimney top. Thus, any object falling into the pool has no pathway to enter the core during operation. The size of the openings in the protection grille is small enough to stop tools and small objects handled at the pool top during normal operation, and the grille would withstand the impact of the heaviest silicon ingot. Objects smaller than the openings in the grille would be light enough to be dragged by the PCS flow into the hot leg and would not fall into the core or the control rod guide box. Such objects would then be retained in the heat exchanger where they would result in a minor reduction in heat exchanger performance. Objects of a size sufficiently small to pass through the heat exchanger have the potential to be carried around the PCS and cause a blockage of the FA channels. The size of such objects, however, would preclude complete blockage of a FA channel. (Core flow blockage events are considered below.)

The grille is removed for refuelling operations. Operational procedures are in place during refuelling to reduce the likelihood of a foreign object falling into the core.

Downstream from the heat exchanger, there is only the gasket from the flange that joins the heat exchanger to the primary cooling system piping. This gasket is of high quality material and it is subject to mild operating conditions (e.g., low temperature, low radiation, demineralised water). Loss of integrity of the gasket is considered very unlikely.

The valve seals of the valves in the PCS are a single part and experience has shown that damage to this type of seal does not produce small parts. Consequently, it is also considered very unlikely that valve seals could introduce foreign objects into the PCS.

The reduction in primary coolant flow arising from the failures identified above is considered to be within the design basis. Its consequences are bounded by the failure of both pump motors.

16.9.2.2.1.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	QA and careful inspection accounting for tools, cloth and packaging after commissioning and maintenance.
		Demineralised water minimises corrosion
		Appropriate maintenance programme: high reliability of pumps, valves, gaskets and seals.
		Start-up walk-through to verify appropriate configuration and check maintenance
		No remotely operated valves in PCS.
		Protection logic that checks if the flow is correct before allowing the operator to increase the reactor power
		Gasket material qualified for environment conditions
		Mild environment for gasket material: low temperature and pressure; low radiation due to existence of decay tank.
2	Operation control and response to abnormal operation	Power reduction
		Power limitation and bank insertion
		Alarms on: a) low PCS flow b) low core pressure drop c) high core temperature difference

Level	Main Characteristics	Safety Feature
3	Control of accidents within the design basis	FRPS reactor trip signal on: a) low flow of the PCS b) low core pressure drop c) high core temperature difference
		SRPS reactor trip signal on: a) Very low core pressure drop (setting is lower than setting for FRPS) together with no end-of-stroke signal from two or more CRs b) High core outlet temperature c) Failure of the FSS

16.9.2.2.2 Coolant Flow Reduction Due to Core Bypass

A core by-pass could take place due to:

a) a break or leak in the PCS piping inside the Reactor Pool

b) spurious opening of any of the flap valves located at the inlet pipes of the PCS while the reactor is operating at nominal power (see Chapter 6 for a detailed description of the flap valves).

A break or leak in the PCS piping is deemed unlikely. Large safety margins are present in the PCS piping specifications. The design pressure of the PCS pipes is well above the operating value. The thermal stresses of the PCS piping inside the pool has been verified and the values are below the allowable limit for stainless steel. . The mechanical design and stress analysis of the PCS piping ensures that it withstands the SL-2 seismic event. Furthermore, the piping is properly supported. Failure of seals is considered unlikely, given the quality of the materials selected and the relatively benign conditions of operation.

The flap valves are designed to provide natural circulation in the reactor core during low power operation and to remove the decay heat after reactor shutdown.

The design of the flap valves is such that the probability of occurrence of a flow by-pass during operation is very low. The flap valves remain closed while the flow inside the PCS is enough to maintain a pressure difference between the water inside the PCS pipes and the Reactor Pool. When the PCS pumps are stopped after reactor shutdown (due to maintenance shutdown or reactor transient), the flow in the PCS coasts down according to the dynamics of the pump, until the pressure difference is small enough to allow for the opening of the flap valve.

The pressure within the cold leg when the primary cooling pumps are operating is such that even if the air chamber is completely full of water, the weight of the piston assembly is insufficient to open the valve.

The pressure within the cold leg when the primary cooling pumps are operating is such that, if the flap becomes disconnected from the connecting stem (e.g. due to failure of the connecting stem), then the flap would remain in position.

The breakage or disintegration of components is also considered very unlikely due to the high quality of the design and the relatively benign operating conditions.

The flap valves are located in an area where the movement of heavy loads is strictly controlled. In addition, the flap valves are protected against possible impact by a mesh. Thus, the likelihood of a dropped load causing any damage is considered very remote.

Notwithstanding the low likelihood of a core bypass, a number of means of detecting a by-pass are provided:

a) The start-up strategy includes a RCMS interlock that inhibits power raise beyond the low power operation level if flap valve positions are not correct.

b) In case of opening of flap valve during operation, the operator is warned by a signal of low-pressure drop at the core.

c) The FSS is triggered by the FRPS on low core flow, low core pressure drop, or high core temperature difference.

d) The SSS is triggered by the SRPS on very low pressure drop in conjunction with no end-of-stroke signal from two or more CRs, high core outlet temperature or failure of the FSS.

Reactor start-up to Physics Test takes place with open flap valves as in this reactor state, cooling is by natural circulation. However, a RCMS interlock prevents increase of power above the Physics Test mode limit. If this were to fail, the FRPS would trip the reactor on high neutron flux (high power). The SRPS would trip the reactor on high neutron flux or failure of the FSS.

Core bypass is considered to be within the design basis. The onset of core bypass would take place on a similar timescale to that associated with a pump shaft seizure. The severity, however, would not be as great. For this reason, the effect of a core bypass event is considered bounded by a pump shaft seizure (Section 16.9.4.3.2).

16.9.2.2.2.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	Proven design of flap valves
		Location in Reactor Pool prevents accidental impact during operations inside the pool
		Comprehensive QA inspection programme for welding inside the Reactor Pool
		Start-up sequence interlocks
2	Operation control and response to abnormal operation	Power reduction
		Power limitation
		Alarms on: a) Interlock on flap valve position b) low core pressure drop c) high core outlet temperature d) high core temperature difference
3	Control of accidents within the design basis	FRPS reactor trip signal on: a) low flow of the PCS b) low core pressure drop c) high core temperature difference

Level	Main Characteristics	Safety Feature
		SRPS reactor trip signal on: a) Very low core pressure drop (setting is lower than setting for FRPS) together with no end-of-stroke signal from two or more CRs b) High core outlet temperature c) Failure of the FSS

16.9.2.2.3 Core Blockage

This initiating event accounts for the partial or total blockage of a coolant channel inside a fuel assembly or the blockage of the inlet nozzle of a fuel assembly.

Blockage of a cooling channel can occur due to:

a) blistering or swelling of a fuel plate

b) fuel plate strain

c) foreign object lodged inside, or at the entrance to, the core

d) Damage to the fuel plates during handling, shuffling manoeuvres, etc.

Blistering and swelling are effects of the irradiation on the fuel plate. Section 5.3 explains these effects in detail. The blistering temperature limit is not achieved in any of the design basis transients of the plant. Therefore, no cooling channel blockage is expected due to blistering or swelling.

Section 5.3 reports that stress analyses have shown that, if lateral compressive thermal stresses on the fuel plate remain below the yield stress of the aluminium cladding, then elastic buckling is precluded. This criterion is met by limiting the maximum compressive stress in the fuel plate width direction of the fuel cladding in the as-fabricated condition, unirradiated and at operating temperature. The limit is conservative because the fuel plate average yield stress is higher than that of the cladding and the yield stress increases with irradiation. Extending the limit in maximum compressive stress in the fuel plate width direction to also include the maximum total equivalent stress also prevents the appearance of permanent distortions and deflections in the fuel plate.

To avoid channel deformations and fuel overheating due to hydraulic instabilities of the fuel plates, the maximum calculated velocity of water through coolant channels is constrained to not be higher than two thirds of the critical velocity[1] (See Section 5.8).

Protective actions adopted in the mechanical design to minimise the effect of mechanical loads on the fuel plates included:

a) A careful process of interface analysis, evaluating all aspects of compatibility among reactor grid plate, bottom nozzle and fuel clamp designs, and involving compatibility of materials and of dimensions and geometry with their corresponding manufacturing tolerances.

b) Specification of a maximum hold-down force on bottom nozzle to prevent the development of excessive stresses at the contact surfaces.

[1] "Research Reactor Core Conversion from the use of Highly Enriched Uranium to the Use of Low Enriched Uranium Fuels" IAEA-TECDOC 233, 1980.

A maximum pullout force to be applied on the fuel assembly handling pin during refuelling operations is specified in order to preclude damages and distortions on any component of the fuel assembly.

As noted earlier in this section, foreign objects that could potentially obstruct the flow in the PCS can arise from unintended residual debris generated by the construction and commissioning of the facility. They can also arise from the failure of valve seals and gaskets that may break and become dislodged as well as the fall of small foreign objects into the outlet plenum. The heat exchangers act as filters of foreign objects originating from the pump or those falling into the pool and able to penetrate the grille. The soft material downstream from the heat exchangers includes the gasket of the flange that joins the heat exchangers with the PCS piping and the butterfly valves' rubber seat. The loss of integrity of these seals is highly unlikely due to their design and the operating conditions (moderate temperature, low radiation field and high water purity).

Administrative procedures forbid clear plastic materials in the reactor hall.

Overall, there are several "filters" and design characteristics along the primary loop that not only prevent loose parts in the primary cooling system being transported to the coolant channels in the fuel, but also prevent blockages due to objects that may fall into the pool.

The following filters and design provisions prevent objects from entering the cooling channels below the fuel assemblies:

a) Lower plenum diffuser, located at the entrance to the core. It consists of a cylindrical plenum that receives the PCS inlet pipes. It has holes that allow the flow of coolant into the core and act as a filter for loose material.

b) Fuel Clamp. The coolant flows into the channel left between the outer structure of the fuel clamp and the internal bar. This provides restriction to the flow passage area. The size of the available flow area would stop the PCS flap valve retention nut should it become dislodged. This nut is the smallest object in the PCS that could become loose and enter the suction line.

c) Plate type heat exchangers act as filters for smaller objects.

Several design provisions have been adopted to prevent the blockage due to falling objects:

a) Upward flow from the core would drag away light objects falling on top of it. The fuel assembly handling pin is a cylindrical rod at the top of the fuel assembly for handling purposes. It provides an uneven surface that avoids blockage of the whole fuel assembly due to falling objects.

b) The chimney protection grille at the top of the chimney structure prevents larger falling objects from reaching the core. It is placed on top of the reactor chimney whenever the reactor is in operation and is qualified against the accidental drop of the largest silicon ingot. The size of the openings in the grid stop the smallest tool and object handled at the pool top during normal operation. QA and inspection after refuelling contribute to minimising the likelihood of failure to replace the grid after refuelling operations.

The only situation where the core is exposed and an object could fall to the area of the pool below the core corresponds to refuelling operations, where the chimney protective grid has been removed and one FA has been moved from the core to the spent fuel rack inside the Reactor Pool. Considering that according to procedures, only one FA can be moved at a time, this would leave a square opening.

Taking into consideration the operations that are performed at the pool top, five scenarios have been identified:

a) An operator violates procedures and brings a plastic bag or similar light weight object to the Reactor Pool top during refuelling operation. The lightweight object falls into the chimney.

b) A dose meter, pen, eyeglasses or similar object falls into the chimney.

c) A coin, button or similar object falls into the chimney.

d) A large tool (e.g., wrench) falls into the chimney.

A qualitative evaluation of these five scenarios has been performed. The analysis is summarised in Table 16.9/1. Several design and administrative barriers have been identified that prevent the occurrence of a core blockage.

A proper QA inspection programme during fuel assembly manufacture, as well as inspection of the fuel assembly before loading ensures that no channel is blocked by deformation or foreign material. The fuel handling tool has a head that hooks into the FA handling pin, allowing for a safe and simple way to handle the FA. The size of this head together with the handling pin prevents the tool from damaging the fuel plate’s upper part. In addition, its design prevents damage to the fuel plates in case of misuse of the tool. The plate’s lower part is protected by the FA nozzle. Administrative procedures require additional inspection of FAs that have been hit or potentially damaged in any way during fuel handling manoeuvres. Failure to report mishandling and loading of a damaged FA into the core might lead (depending on the extent of the blockage) to hot spots and damage to the cladding. However, this damage would not exceed the equivalent of complete failure of three fuel plates, a BDBA scenario analysed in Section 16.19.

Design calculations predict that a partial channel blockage of up to 25% of the flow area in at most four fuel assemblies could be dealt with without exceeding safety margins for limiting conditions.

Complete blockage of a fuel assembly nozzle is not credible, given the size of the object necessary and the design provisions mentioned above to avoid large foreign objects from reaching the core. Nevertheless, appropriate fuel plate cooling is guaranteed due to flow reconfiguration through the inlet lower plenum formed by the side windows in each fuel assembly (see a description of the fuel assembly in Chapter 5).

On the basis of the above arguments, the occurrence of significant core blockage is considered sufficiently unlikely as to render the event beyond the design basis.

16.9.2.2.3.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	Large design margins, especially with respect to critical velocity and critical heat flux
		Upward flow (prevents blocking of coolant exit and removes lightweight objects from top of core)
		Control Rod Guide Boxes divide the core into four regions
		Comprehensive inspection of the cooling system before start-up after shutdown
		Strict procedures for operations at pool top

Level	Main Characteristics	Safety Feature
		Procedures for PCS maintenance
		Working objects made of coloured/visible material when submerged
		Demineralised water quality control to avoid corrosion
		Inspection of fuel assembly before loading into the core
		Qualified fuel assembly suppliers
		Lower plenum diffuser
		fuel assembly clamps
		fuel assembly side windows allowing flow reconfiguration
		fuel assembly handling pin
		Chimney protective grille (protects from missiles originating at the pool top)
		Heat exchanger plates with a narrow water channel
2	Operation control and response to abnormal operation	Alarms on: a) High core pressure drop

16.9.3 Power-Flow Mismatch Events

16.9.3.1 Influence of Reactor Utilisation Failure or Mishandling

As previously mentioned, mishandling of fuel assemblies and reactor utilisation failures may lead to power-flow mismatch events and a rise in reactor power. For this reason, these events have been considered within the DBIE reactivity insertion group, Section 16.8. They are not considered further here.

16.9.3.2 Emergency Make-up Water System Spurious Trip

The concern is identified of a power increase due to spurious initiation of cold-water injection by the Emergency Make-up Water System. However, the Emergency Make-up Water System cannot inject water into the PCS when the pumps are running. Emergency Make-up Water System cold water insertion during low power operation, when the PCS pumps are not running, is considered as part of the reactivity insertion group, Section 16.8. The event is not considered further here.

16.9.3.3 Improper Power Distribution Due to Unbalanced Rod Positions, Radioisotope Targets, or Erroneous Fuel Loading

Improper power distribution leads to occurrence of hot spots in the fuel. Power distribution within the core is characterised by the total power peaking factor.

As shown in Chapter 5, the thermal-hydraulic design of the core is such that the design total power peaking factor is large enough to accommodate calculational uncertainties and the range of power distribution variation induced by the following causes:

a) regulating and safety plate burn-up

b) radioisotope targets (bulk and pneumatic facilities)

c) fuel burn-up

d) temperature effects

e) xenon effects

f) operation patterns

g) erroneous fuel loading

h) erroneous regulating and safety plate moving strategy

It is stressed that the design total power peaking factor value provides a large safety margin to the safety limit (for more detail, see Chapter 5).

In addition, to reduce the impact of this event, no in-core irradiation facilities are provided. Appropriate operational and inspection procedures are in place to ensure the correct assembly of the core following fuel loading. The maximum change in PPF can be safely accommodated by the design.[2] The RCMS can cope with the worth of the maximum possible reactivity insertion due to a mistake in fuel loading with no impact on the safety of the reactor.

As regards plate position, once the xenon poisoning has been compensated for, the four safety absorbers are almost fully outside the core while the central regulating plate controls power.

Consequently, the design can cope with this event without resorting to the safety systems. The event is not considered as a DBIE and no further analysis is required.

16.9.3.4 Malfunction of Reactor Power Control

Two failure modes are identified:

a) Continuous reactivity addition: it originates from a failure in the regulation equipment and is dealt with within the reactivity insertion group (see Section 16.8).

b) Erroneous core power level: failure in the power control system could lead to the indication of an erroneous power level. Periodical thermal balances help to detect any malfunctioning or deviation in the reactor power control instrumentation. For complementary power range regulation, the Gamma Ionisation Chamber effectively measures the reactor global core power. CR position is not used as an input to reactor power control.

The determination of reactor power is carried out by the readings from the nucleonic instrumentation, periodic thermal balances and the Ionisation Chamber. These multiple methods for the measurement of the power minimise the likelihood that a failure in the reading of core power level by the RCMS could lead to an extraction of the regulation control rod and increase power. Assuming the very unlikely simultaneous failure of these three methods to determine the reactor power, the failure would result in the full extraction of the regulating plate. This event is considered within the design basis. The resultant reactivity insertion is bounded by the continuous extraction of the highest worth control plate and analysed as part of the reactivity insertion group, Section 16.8.

[2] Insertion of 3 fresh FAs without burnable poison

16.9.3.4.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	Correction factor in automatic power control routine
2	Operation control and response to abnormal operation	Alarms on: a) High neutron flux rate b) high neutron flux
3	Control of accidents within the design basis	FRPS reactor trip signal on: a) high neutron flux rate b) high neutron flux c) high core temperature difference
		SRPS reactor trip signal on: a) Very low core pressure drop (setting is lower than setting for FRPS) together with no end-of-stroke signal from two or more CRs b) High core outlet temperature c) Failure of the FSS

16.9.3.5 System Pressure Deviation from Specified Limits

Because the PCS is open to the atmosphere in the Reactor Building and the core flow is upwards, the core outlet pressure is fixed by the water column above the core, less the small pressure drop required to cause the design downward flow at the top of the chimney). There is no provision for a pressure control system and the water level in the main pool is maintained by means of the make-up system during normal operation.

In the highly unlikely event of a total blockage of the chimney protection grid, the PCS would be isolated from the pool (i.e., it becomes a closed loop). The interconnection flow would be interrupted, and the flow through the PCS pumps would change due to the variation in their working conditions. The variations in core flow conditions that this change would cause are within the design margins of the plant and would have no impact on the safety of the core. On this basis, the event is not considered as a DBIE. It is not analysed further.

16.9.4 Design Basis Postulated Initiating Events

From the discussion in the previous sections of this document, some of the events do not lead to accidental conditions and as such, need not be considered further as Initiating Events. Only those that merit further analysis are considered.

A summary of previous considerations and the design-basis PIE are presented below:

PIE	Not applicable	Eliminated by inherent	Sufficiently unlikely to		Design Basis Initiating Events (DBIEs)

				To be considered in another DBIE group	Bounded by another DBIE	Further Analysis
Pump shaft failure						X
Pump motor failure						X
Primary coolant flow reduction					X (pump motor failure)	
Coolant reduction due to core by-pass					X(pump shaft seizure)	
Core blockage			X			
Influence of experiment failure or mishandling				X (Reactivity group)		
Emergency Make-up Water System spurious trigger				X (Reactivity group)		
Inappropriate power distribution		X				
Malfunction of reactor power control				X (Reactivity group)		
System pressure deviation		X				

On the basis of the above, two DBIEs are identified for analysis in this section:

a) single pump shaft seizure

b) failure of two pump motors

The likelihood of PCS shaft seizure together with failure of the FSS is considered to lie beyond the design basis. Nevertheless it is analysed in Section 16.19.

16.9.4.1 Detection of the Initiating Event

For both PIEs, in addition to the corresponding alarms and warnings, the RPSs trigger the shutdown systems on the following signals:

a) for the FSS:

(i) low flow in the PCS
(ii) low core pressure drop

(iii) high temperature difference across the core

b) for the SSS:

(i) High core outlet temperature
(ii) low core pressure drop in conjunction with no end-of-stroke signal from two or more CRs
(iii) failure of the FSS

16.9.4.2 Design Basis Fault Sequence

16.9.4.2.1 Pump Shaft Seizure

a) Shaft seizes.

b) Primary coolant flow decreases abruptly.

c) Reactor shutdown.

d) Second PCS pump and RSPCS pump are manually shutdown.

e) Flow in PCS and RSPCS coasts down and natural circulation is established.

16.9.4.2.2 Simultaneous Failure of Both Pump Motors

a) Both pump motors fail and stop.

b) Primary coolant flow decreases according to the inertia flywheels of PCS pumps.

c) Reactor trip signal generated on to low core pressure drop or low PCS flow.

d) Natural circulation is established.

e) Decay heat is removed by natural circulation.

16.9.4.3 Numerical Analysis

16.9.4.3.1 Modelling Assumptions

The analysis was performed with RELAP 5. The nodalisation of the RRR presented in Section 16.3 was used as the basis for this numerical analysis. The conditions of the pool are calculated only for the volume between the upper top of the chimney and the bottom of the transfer canal. This volume of water is relatively small compared to the total mass of water in the pool. This is a conservative assumption.

The reactor is stable at full power prior to the occurrence of the initiating event. Operational core power is considered at 20 MW. Failure of the pump motors is simulated by a drop in their torque from their nominal value to zero in 1 second, according to the dynamics of the pump unit. Shaft seizure is simulated by a sudden drop in the flow, with no available inertia.

The FRPS conservatively trips the reactor low core pressure drop. The SRPS triggers the SSS low core pressure drop. The trip set point for both systems is set at the analytical limit. No credit is given to the insertion of negative reactivity by the FSS when considering the effectiveness of the SSS. This assumption, together with the failure of the FSS, is very conservative. In reality, the FSS has a low probability of failure and even if two out of five CRs do not reach the end of run, the remaining three would insert negative reactivity, limiting the peak temperatures reached in the transient.

16.9.4.3.2 Pump Shaft Seizure

16.9.4.3.2.1 Accident Sequences

Shaft seizure with actuation of the FSS has been analysed. Flap valves are assumed to open and it is conservatively assumed that the operator mistakenly stops the second PCS pump after the shaft seizure occurs.

16.9.4.3.2.2 Shaft Seizure with Actuation of the First Shutdown System

This transient starts with the seizure of the shaft of a PCS pump and the stopping of the second PCS pump. Forced circulation through the core decays in accordance with the dynamics of the pump.

Analysis of DBIEs of pump shaft seizure with actuation of the FSS for short term flow rates and medium term flow rates show that during the first second the evolution of the flow is governed by the abrupt seizure of the shaft of one of the pumps. Thereafter, the flow rate reflects the new force balance between the torque of the slowing second pump and the circuit friction losses.

As a consequence of the abrupt reduction of the core flow, temperatures start to rise. The maximum cladding temperature reached is safe at the moment of the reactor trip after the shaft seizure. . After the reactor is shut down by the FSS, temperatures fall to values that depend on the balance between the decay power generated and the fluid heat removal capacity in accordance with the forced circulation.

16.9.4.3.3 Pump Motor Failure

16.9.4.3.3.1 Accident Sequences

Three accident sequences are presented:

a) Failure of both PCS pumps motors with success of the FSS and;

   (i) flap valves open
   (ii) one flap valve open

b) Failure of both PCS pump motors with failure of the FSS and success of the SSS. In both cases, the flap valves open.

16.9.4.3.3.2 Success of First Shutdown System with all Flap Valves Open and One Flap Valve Open

The sequence is initiated with the failure of the motors of both primary circuit pumps. The analysis has been performed with one and all flap valves opening after pump failure. An analysis has been undertaken comparing the flow for both cases. When only one valve opens, the flow through the flap valve is practically the same as that circulating through the core. The friction loss increases due to the reduction of the passage area from all to a single open flap valve, hence the flow through the core is slightly lower than it is when flap valves are open. However, this slight difference does not affect significantly the evolution of the transient, since maximum temperatures are reached before reactor trip.

Further analysis shows that the temperatures are only slightly higher when only one flap valve opens. From the standpoint of the analysis of the transient, there is no significant difference between both transients. Natural circulation core cooling is established with a single open flap valve and the flow rate is sufficient to remove the decay heat. Following the abrupt drop in temperature resulting from reactor shutdown, a gradual rise is produced due to the reduction in cooling flow, and not as a result of core inlet temperature variation. The temperature remains constant as the temperature front that originates in the heat exchangers does not reach the core within the time frame of the simulation. The flow transfer time from the heat exchangers to the core is longer than the analysed period. Within seconds after the opening of the flap valves, temperatures reach their respective maxima. The maximum coolant temperature is 80ºC while the cladding temperature peaks at a safe level. Soon afterwards, temperatures drop relatively quickly in accordance with the new balance between the buoyancy and friction forces of the natural convection circuit established. Towards the end of the analysed period, it can be seen that temperatures continue falling more slowly, following the decay power rate. In the long term, slow pool warming occurs.

16.9.4.3.3.3 Failure of the First Shutdown System, Success of the Second Shutdown System and all Open Flap Valves

This transient is originated by a failure in the motors of both PCS pumps. The failure of the FSS is postulated to verify the behaviour of the reactor upon the actuation of the SSS.

The SSS may be triggered by very low pressure difference across the core signal in conjunction with no end-of-run signal in 2 or more CRs, by high core outlet temperature or failure of the FSS. In this analysis, the SSS trips due to very low core pressure drop. The analytical limit was adopted for the core pressure drop set point.

For this simulation, it is assumed that the SSS is tripped due to failure of the FSS. For a DBIE involving failure of both pump motors assessment of the flow through the core and through the upper chimney is undertaken. Their evolution is similar to results obtained for the analysis of failure of both pump motors with one open flap valve. After actuation of the SSS, power starts to drop. A comparison with the evolution of the power of the sequence with actuation of the FSS shows that additional energy deposited on the fuels when the FSS fails results in an increase in the temperature of the fuel element and the coolant, with respect to the case with FSS actuation. On the other hand, since the insertion of negative reactivity by the SSS is slower than that produced by the FSS, the temperature drop is more gradual. The cladding temperature in the hot channel peaks at a safe level. Maximum coolant temperature is 79.5ºC. There are no significant differences between both cases after reactor shutdown, regardless of which Shutdown System has actuated.

16.9.4.4 Radiological Impact Analysis

The LOFAs analysed in this section do not lead to any damage to the reactor core, FA cladding, core structure or irradiation rigs. There would therefore be no release of fission products to the pool water. Fuel and rigs integrity is guaranteed by the response of the reactor safety systems.

Therefore, these transients do not have any radiological impact on the operators or the public.

16.9.5 Conclusions

The results of the analysis are summarised in Table 16.9/1. The bounding events for this DBA grouping involve a significant loss of flow. In the case of the failure of both PCS pump motors, either RPS is capable of shutting down the reactor. Heat removal from the core and rigs is adequate. In the case of seizure of a PCS pump, the FRPS is capable of shutting down the reactor. The likelihood of seizure of a PCS pump together with failure of the FRPS to shutdown the reactor is not considered credible. The consequences of this event together with those arising from localised core blockage are considered in the section dealing with Beyond Design Basis Accidents, Section 16.9. It is concluded that nuclear safety is guaranteed for all credible events involving loss of flow.

End of Section

Table 16.9/1 Qualitative evaluation of core blockage scenarios

Scenario	Design barriers	Administrative barriers	Detection	Comments
Plastic bag or similar light weight object	Natural circulation plume will push object upwards. High velocity and pool structures would tear object up when pump is switched on. Fuel clamp could catch object and prevent it from blocking the plates. If the bag falls onto the bottom of the plenum, it would remain there (stagnant fluid).	Plastic bags and like objects are forbidden from the Reactor Pool top. Only one FA is removed at a time. An opening remains for the plastic bag to go through. Start up procedure requires operator to start up the pump and measure core pressure drop to verify no core blockage is present before power can be raised.	Calibration of pressure drop for a fully blocked FA (cold conditions) during commissioning. Fission products detected in the PCS water. Pool top activity.	Operator must violate administrative prohibition to bring plastic bags and like objects to the Reactor Pool top. Plastic bag needs to enter through an opening several metres below the pool top, against ascending flow (natural circulation plume), therefore the bag would most likely remain on the upper surface of the core. In case the plastic bag falls on top of the fuel clamp, the clamp would retain the bag due to its locking action (the bag would not prevent the clamp from locking) and the FA side window would ensure cooling in all cooling channels.
Dose meter, pen, lighter, screwdriver, etc.	Fuel clamp will not allow clamping action due to the presence of the object. If the object falls onto the bottom of the plenum, it will remain there (stagnant fluid).	Zippered pockets.	Fission products. Pool top activity.	If the object lies at an angle with respect to the plates in such a way that does not inhibit clamping action, it could block partially only a couple of channels and lead to partial damage to two or three plates. This is the case presented in Section 16.19. This type of object could shatter due to the high velocity and the pieces could block cooling channels separately. This case would be similar to that presented in Section 16.19.
Credit card,	Fuel clamp will not allow clamping	Zippered pockets.	Fission	If the object lies at an angle with respect to the

Scenario	Design barriers	Administrative barriers	Detection	Comments
ANSTO ID card or like object.	action due to the presence of the object. If the object falls onto the bottom of the plenum, it will remain there (stagnant fluid).		products. Pool top activity.	plates in such a way that does not inhibit clamping action, it could block partially only a couple of channels and lead to damage to two or three plates. This is the case presented in Section 16.19. This type of object could shatter due to the high velocity and the pieces could block cooling channels separately. This case would be similar to that presented in Section 16.19..
Coin	In case object falls to the bottom of the plenum, it will remain there.	Zippered pockets.	Fission products. Pool top activity.	Partial blocking of one or several cooling channels (due to the geometry of the coin) does not lead to loss of cooling and damage. This scenario is bounded by the analysis presented in Section 16.19.
Large tool	Fuel clamp will not allow clamping action due to the presence of the object. If the object falls onto the bottom of the plenum, it will remain there (stagnant fluid).		No damage expected	A large tool will not go through the opening in the core

Figure 16.9/2: Summary of Loss of Flow Analyses

		PCS pump shaft seizure, Actuation of FSS, all flap valves open	PCS pumps motor failure, actuation of FSS, all flap valves open	PCS pumps motor failure, actuation of FSS, 1 flap valveopen	PCS pumps motor failure, actuation of SSS, 4all flap valves open
Flow regime in the core at the end of the analysed period		Natural circulation	Natural circulation	Natural circulation	Natural circulation

End of Tables

16.10 ANALYSIS OF LOSS OF HEAT SINK EVENTS

16.10.1 Introduction

This Section provides an analysis of accidents caused by the loss of the Secondary Cooling System (SCS) in the facility.

The analysis applies to the effect on the core and irradiation rigs of a loss of heat sink.

This initiating event refers to a loss of heat sink occurring during full power operation of the reactor. Losses of heat sink occurring at low power and at shutdown are not considered. When the core and irradiation rigs are being cooled by natural circulation, the SCS is not needed. Once the reactor has been shutdown, the water contained in the Reactor Pool can absorb the decay heat for 10 days before evaporative losses need to be replaced.

This PIE group considers all the malfunctions and anomalies that have the potential to reduce heat removal via the primary heat exchangers towards the SCS.

Failures of parts of the SCS are postulated, including failures of the cooling tower basin. In all cases, at the start of the sequence the reactor is operating at full power and full flow. PCS forced circulation is available and no primary coolant losses are considered.

The reduction or interruption of cooling in the SCS would result in slow variations in the conditions of the PCS. These slow transients would be dealt with by the RCMS with no need for intervention of the RPSs. In the unlikely event that the RCMS did not respond to the trend, the FRPS would detect the effects of a reduction of the SCS coolant flow or variations in the cooling capabilities via high core inlet temperature. The increase in core inlet temperature is due to the decrease in cooling capabilities of the SCS. As indicated, this increase would be slow and its effects on the dynamics of the core would be slower still. Upon detection of the variation in core inlet temperature, the reactor would be shutdown long before any adverse effect could be observed in the core. In this section, the most severe transients are simulated to demonstrate that the RPSs can cope with failures in the SCS with no negative consequences for the reactor or the irradiation rigs.

The following sections consider various Postulated Initiating Events in order to determine the plant DBIEs. On the basis of the discussions presented, a single bounding DBIE is identified for further analysis. The final sections detail the particular event sequence and its numerical analysis.

16.10.2 Initiating Events for Loss of Heat Sink

16.10.2.1 Blockage in Pipes or Heat Exchangers of the Secondary Cooling System

Blockages in the SCS, although unlikely, could occur due to the presence of foreign objects in the pipes or heat exchangers. Soft gaskets can be broken and dislodged and obstruct the flow in the SCS. Foreign material might enter the SCS through the cooling pools. The pools are covered but they are not sealed, thus dust or other small particles can enter the SCS.

As in the case of the PCS, if a piece of soft material becomes dislodged and enters the secondary side of a plate-type heat exchanger, only a small fraction of the total flow area would be obstructed. The heat exchangers act as coarse filters, retaining relatively large pieces of debris. The soft seal and gasket material is subjected to mild operating conditions (low temperature, no radiation field, controlled pH of water, control of nondissolved solids in water). Breakage of this material during normal operation is considered unlikely.

The SCS main pump sumps are connected to the cooling tower basin via openings protected with a grille that acts as filter. This filter avoids the suction of large objects that could damage the SCS pumps.

A side stream cleans away the suspended solid particles.

Any blockages that might occur within the SCS would result in a small decrease of secondary flow and, consequently, a slow increase in core inlet temperature. Once this increase is detected, power reduction or reactor shutdown is carried out by the RCMS and RPSs, according to the flow decrease.

Blockages of pipes and the heat exchangers in the secondary system are considered to lie within the design basis. The effects of blockages are bounded by the simultaneous failure of both SCS pumps.

16.10.2.1.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	Equipment provided by leading manufacturers with extensive experience and proven operational record
		Side stream separator
		Appropriate maintenance programme for valves, pumps, heat exchangers and cooling towers
		HX-type plate type acts as system sieve
		Start-up walk-through
		Appropriate operator maintenance procedure
2	Operation control and response to abnormal operation	Automatic increase in cooling tower fan speed
		Automatic power reduction
		Automatic power limitation and bank insertion
		Alarms on: a) low SCS flow rate b) high core inlet temperature c) high core outlet temperature
		Control loop to keep core inlet temperature constant

16.10.2.2 Incorrect Valve Position

A valve of the SCS placed in the incorrect position has the potential to lead to a SCS coolant flow reduction and subsequent rate of energy removal from the PCS. Depending on the extent of the flow reduction, the RCMS would request a power reduction or bank insertion of the CRs. In the event of a large rise in inlet or outlet temperatures, the RPSs would initiate a reactor trip.

Since the SCS piping penetrates the Containment, there are manual valves at each penetration point to isolate the Containment in case of an accident releasing fission products. The operating procedures require the operator to check the status of these valves before start-up. Since all the process systems are started before power raise, after start up of the SCS pumps the operator must check the flow rate in the SCS to verify that that the isolation valves are open.

The SCS has a manual bypass valve to control the temperature of the PCS in extremely cold winter weather. When the outside temperature falls to low values in winter, the fans of the cooling towers are stopped. However, for very low temperatures, the natural convection in the cooling towers would be enough to reduce the PCS temperature below the minimum acceptable value. In this case, a bypass valve would open in the SCS. Part of the SCS flow would be diverted and the temperature of the PCS kept within the normal operating range. In the event that this valve is left open in very hot weather, the temperature at the core inlet would slowly increase. The position of this valve would be checked and an operator would close the valve.

All manual valves in the SCS are locked in position to prevent inadvertent operation.

This event would lead to a degraded performance of the SCS. It is considered within the design basis. Its consequences are bounded by the simultaneous loss of both pumps of the SCS.

16.10.2.2.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	Appropriate maintenance programme for valves, pumps, heat exchangers and cooling towers
		Locks for SCS Containment isolation valves
		Start-up walk-through of the SCS
		Appropriate operator maintenance procedure
		Minimal operator activities are required during reactor operation on SCS valves
2	Operation control and response to abnormal operation	Automatic increase in cooling tower fan speed
		Automatic power reduction
		Automatic power limitation and bank insertion
		Alarms on: a) low SCS flow rate b) high core inlet temperature c) high core outlet temperature
		Control loop to keep core inlet temperature constant

16.10.2.3 Rupture of Secondary Cooling System Boundary

A loss of secondary coolant represents a decrease in the heat removal capability of the SCS and a leads to an increase in core inlet temperature. It may be caused by a rupture in the pipework or failure of a valve. There are no large valves in the SCS that could be left open and cause a significant loss of coolant. Open valves in drain lines would lead to small coolant losses that can be handled by the RCMS, identified and corrected. In the event of no action being taken, the RPS would act. As in previous situations, there would thus be a power reduction or shutdown resulting from a bank insertion or reactor trip.

In the unlikely event of a rupture of the SCS boundary, if the rupture is produced inside a room, the water spray can affect the equipment in that room. If the rupture occurs in the PCS pump room, the spray can fall on the PCS pump motors. The electrical insulation of these motors is designed to withstand a water jet arising from a SCS pipe rupture. The PCS pump room has water detection on the floor. A rupture would be identified and then isolated. The PCS pump switchboards are located in a separate room and would not be exposed to a water spray in case of SCS boundary rupture. The water from the SCS rupture would flow into the LOCA pool at the Reactor Building basement. The SCS water inventory is larger than the capacity of the LOCA pool. There would therefore be some flooding if no action were taken by the operators to isolate the leak. The LOCA pool can be drained via the waste system.

The piping of the SCS used for the Long Term Pool Cooling mode of the RSPCS is Seismic Category 1, while the remaining piping is Seismic Category 2.

Pipe failure is deemed highly unlikely due to the mild operating conditions and good water quality in the SCS. Nevertheless, it is considered within the design basis. Its consequences are bounded by the simultaneous loss of both SCS pumps.

16.10.2.3.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	Appropriate maintenance programme for valves, pumps, heat exchangers and cooling towers
		Start-up walk-through
		Appropriate water treatment system
		Mild operating conditions: low pressure, low temperature, treated water
		Large design margins for mechanical equipment.
2	Operation control and response to abnormal operation	Automatic power reduction
		Automatic power limitation and CR bank insertion
		Alarms on: a) low SCS flow rate b) low cooling tower basin level c) high core outlet temperature d) high core inlet temperature

16.10.2.4 Secondary Cooling System Pump Failure

If one of the two operating SCS pumps fails, the secondary flow would decrease and the core inlet temperature would rise. The failure of a single pump is handled through operational procedures as the transient is slow enough to allow start up of the standby SCS pump and continue operation. If no action is taken, the FRPS would trip the reactor on high core inlet or outlet temperature. The SRPS would trip the reactor on high reflector temperature or failure of the FSS.

Simultaneous independent failure of both pumps is highly unlikely. In the event that both pumps failed due, for example, to interruption of power supply to the pumps, the flow in the SCS would stop. The FRPS would initiate reactor shutdown on high core inlet temperature. The PCS pumps are stopped after shutdown with the core flow coasting down. The flap valves in the PCS open and natural circulation removes decay heat.

Failure to shutdown the reactor is deemed unlikely due to the two independent and diverse shutdown systems. Failure to establish natural circulation is also considered unlikely, since opening of only one valve is sufficient to establish adequate natural convection.

The simultaneous failure of the SCS pumps is considered within the design basis. It is considered to provide a bounding transient in terms of severity in the case of loss of heat sink. It is considered a DBIE and analysed. It is assumed that the failure of the SCS pumps causes an instant total loss of the SCS flow. Both actuation of the FSS and failure of the FSS with subsequent actuation of the SSS are considered.

16.10.2.4.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	Appropriate maintenance programme for valves, pumps, heat exchangers and cooling towers
		Plate type heat exchangers act as filter protecting the pumps from debris
		Start-up walk-through
		Appropriate operator maintenance procedure
		Three pumps, 50% capacity each
2	Operation control and response to abnormal operation	Vibration monitors in SCS pumps and motors
		Automatic power reduction
		Automatic power limitation and bank insertion
		Alarms on: a) high vibration in SCS pumps or motors b) high temperature of pump motor and rotating parts c) low secondary system flow rate d) high core outlet temperature e) high core inlet temperature
		RCMS pump trip on very high vibration in pump or motor
3	Control of accidents within the design basis	FRPS trip signal on: a) high core inlet temperature
		SRPS trip signal on: a) High core outlet temperature b) Failure of the FSS.

16.10.2.5 Failure of Cooling Tower Components

Each cooling tower has its own fan. In the event of failure of a fan, core inlet temperature would rise, although the SCS flow rate would remain constant. The design of the SCS is based on four out of the five towers removing the heat load in full power operation. In the event of one of the four operating towers being lost, the standby cooling tower is started. Due to the large volume of the cooling tower basin, a large thermal inertia is available to enable the start up of the standby fan. Following the loss of one cooling tower fan, the control loop increases the speed of the other fans to compensate for the increase in core outlet temperature. If this strategy is not effective (e.g., the fans are already operating at maximum capacity on a hot day), the RCMS either reduces power or orders a bank insertion of control rods.

This event is considered within the design basis. Its consequences are bounded by the simultaneous failure of both SCS pumps.

16.10.2.5.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	Appropriate maintenance programme for valves, pumps, heat exchangers and cooling towers
		Start-up walk-through
		Appropriate operator maintenance procedure
		Five cooling towers, 25% capacity each
		Large capacity of cooling tower pool
2	Operation control and response to abnormal operation	Automatic power reduction
		Automatic power limitation and CR bank insertion
		Alarms on: a) vibrations of cooling tower fans b) low level in the cooling tower basin c) high core outlet temperature d) high core inlet temperature

16.10.2.6 Lack of Make-up Flow

Evaporative and blow-down losses from the cooling tower basin are compensated for by make-up to the basin. Should there be no make-up flow, the pond is sufficiently large to provide one hour to take corrective actions before the RCMS signals a low water level in the cooling tower basin. The SCS pump suction line is taken from the bottom of the cooling tower basin. In addition, the feed line from the LHSTC has a low-pressure alarm to indicate that the feed line flow is not available. The lack of make-up flow has no immediate effect on the facility. The cooling tower basin has a large volume that enables the timely implementation of corrective actions.

Lack of make-up flow is considered to lie within the design basis. Its consequences are bounded by the simultaneous loss of both SCS pumps.

16.10.2.6.1 Defence in Depth Barriers

Level	Main Characteristics	Safety Feature
1	Conservative design and inherent safety features	Appropriate maintenance programme for valves, pumps, heat exchangers and cooling towers
		Start-up walk-through
		Appropriate operator maintenance procedure
		Five cooling towers, 25% capacity each
		Large capacity of cooling tower pond
2	Operation control and response to abnormal	Automatic power reduction
		Automatic power limitation and bank insertion

	operation	Alarms on: a) low pressure in the LHSTC water supply line b) low level in the cooling tower basin c) low SCS flow rate d) high core outlet temperature e) high core inlet temperature

16.10.3 Design Basis Postulated Initiating Events

A summary of previous arguments is presented below:

PIE	Not applicable to the design	Sufficiently unlikely to occur		Design Basis initiating Events (DBIEs)		
				To be considered in another DBIE group	Bounded by another DBIE	Further Analysis
Pipe or heat exchanger blockage in the SCS loop					X (loss of both SCS pumps)	
Incorrect valve position					X (loss of both SCS pumps)	
Rupture of SCS boundary					X (loss of both SCS pumps)	
Simultaneous failure of both SCS pumps						X
Failure of cooling tower component					X (loss of both SCS pumps)	
Lack of make-up flow					X (loss of both SCS pumps)	

The DBIE identified for further analysis is:

The reactor is operating a full power and full flow when both pumps of the SCS fail simultaneously. The reactor is shutdown by the RPSs. The PCS pumps are stopped and flap valves open on reducing PCS flow. The decay heat is removed by natural circulation.

16.10.3.1 Detection of the Initiating Event

Both pumps in the SCS stop. The RPSs trigger the shutdown systems on any of the following signals:

a) for the FSS:
   (i) high core inlet temperature
b) for the SSS
   (i) High core outlet temperature
   (ii) Failure of the FSS

16.10.3.2 Design Basis Fault Sequence

a) Both pumps of the SCS suddenly stop.

b) Alarm raised on low flow in the SCS.

c) The heat transfer through the PCS, RC&PS and RSPCS heat exchanger falls sharply.

d) Core inlet temperature increases.

e) There is power reduction or reactor shutdown due either to a bank CR insertion or to a reactor trip depending on the rate and size of the temperature increase.

f) PCS pumps are manually stopped to allow natural circulation cooling, using the pool as the heat sink.

g) Flap valves open.

h) Decay power is removed by natural circulation.

16.10.3.3 Numerical Analysis

The transient associated with the loss of heat sink has been simulated using RELAP 5.

16.10.3.3.1 Modelling Assumptions

The nodalisation of the PCS presented in Section 16.3 was used as the basis for this numerical analysis.

The core geometry, the properties of the fuel and coolant and the worth of the shutdown systems are detailed in Chapter 5.

The conditions of the pool are calculated only for the volume comprised between the upper top of the chimney and the bottom of the transfer canal. This volume of water is relatively small compared to the total mass of water in the pool. This is a conservative assumption.

The reactor is stable at full power prior to the occurrence of the initiating event. The power being deposited in the core is conservatively taken as 20 MW.

The total loss of heat transfer to the SCS is assumed to occur in one second.

The reactor is shutdown following:

a) FRPS signal on high core inlet temperature

b) SRPS signal on high core outlet temperature (this the latest acting signal).

16.10.3.3.2 Primary Cooling System

The FRPS requests reactor trip after onset of the loss of heat sink. This time is the sum of the time it takes the hot water front from the heat exchangers to reach the location of the temperature sensors plus the time it takes to reach the high core inlet temperature set point, plus the delays in the FRPS and instrumentation..

Analysis of normalised core power and heat removal via the heat exchangers for a DBIE involving loss of both SCS pumps with FSS actuation shows that the transient does not affect the functioning of the PCS pumps. The flow rate through the core does not change significantly, except during the first few minutes due to the temperature increase and the resulting decrease in friction pressure drop. In the long term the total flow reaches a stable values, higher than the normal operation steady state.

For coolant temperature on loss of both SCS pumps with FSS actuation the temperature at the outlet of the heat exchangers rises rapidly while the temperature at the inlet plenum starts increasing after a delay. The reactor trips when the inlet temperature reaches the set point, and the core outlet temperature follows this power decrease until it meets the hot water reaching the core following a degraded heat removal consequence of the SCS failure.

The maximum cladding temperature is safe with a corresponding maximum coolant temperature of 66.4ºC. The fuel assembly temperatures experience an increase up to the point of reactor trip. Thereafter, in the long term, the temperatures increase slowly, following the rise in pool water temperature. There is a slight dip in coolant temperatures at as a result of the water from the first drop in temperature making its way back to the core.

The same transient has been simulated with actuation of the SSS. In this case, the sharp decrease in core outlet temperature does not appear due to slower decrease in reactor power.

Analysis of coolant and cladding temperatures on loss of both SCS pumps with SSS actuation has been undertaken. The SRPS requests reactor trip when the hot water from the heat exchanger reaches the core, plus the time it takes to reach the high core outlet trip set point, plus the delay due to the SRPS and SSS actuation and electronics. The maximum cladding temperature is safe with a corresponding maximum coolant temperature of 68.6º C. Slight dips in temperature result from the water from the initial drop in temperature making its transits around the PCS. As a consequence of the longer shutdown time the temperatures increase above the values they reach with actuation of the FSS. Again, the long term increase of the fuel assembly temperatures follows the variation in Reactor Pool water temperature.

16.10.3.3.3 Reactor and Service Pools Cooling System

This transient was analysed to determine the effect on the irradiation rigs. Actuation of the SSS was considered as this bounded the effect of the actuation of the FSS.

The analysis determines the temperature of the coolant in the pool and in the rigs' suction plenum (outlet from the rigs). The SRPS trips the reactor on high core outlet temperature. The maximum irradiation rig cladding temperature is safe, occurring on the inner surface of the rig. The maximum coolant temperature is 47.5ºC at the outlet of the channel. When the heat sink is lost, the temperature of the pool increases slowly while the power generated by the rigs falls abruptly after reactor trip. Thus, the temperature at the outlet from the rigs also decreases. In the long term, this temperature increases following the variation of the pool water temperature (inlet to the rigs). Similarly, the temperature of the hot rig (U-Mo target) decreases with the reactor trip and increases slowly following the increase in pool water temperature.

16.10.3.4 Radiological Impact Analysis

No core or rigs damage arises from these transients. Therefore, there is no radiological impact.

16.10.3.5 Conclusions

The bounding event for this DBA grouping involves the loss of both SCS pumps. Either RPS is capable of shutting down the reactor. Heat removal from the core and rigs is adequate. It is concluded that nuclear safety is guaranteed for all credible events involving loss of heat sink.

End of Section