Replacement Research Reactor Project

SAR CHAPTER 5
REACTOR

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5 REACTOR

This Chapter provides a description of the design and operation of the safety features connected with the reactor core and associated components that supports the fulfilment of the basic safety functions of the reactor facility. These safety functions are:

a) Shutting down the reactor and maintaining it in a safe shutdown condition for operational states or accident conditions.

b) Providing for adequate heat removal from the core after shutdown, including accident conditions.

c) Containing radioactive material in order to minimise its release to the environment.

Descriptions are also provided of the main reactor structures, fuel assemblies, reactivity control elements, reactivity regulation and control systems, reactor shutdown systems and materials used in the reactor. The safety design bases for these structures, assemblies and systems are identified in the relevant sections within the Chapter. Evaluations of the design and operation of them are presented, and demonstrate that they meet their specified design bases, and the safety requirements of the Replacement Research Reactor Facility (the Reactor Facility). The nuclear design, thermal-hydraulic design, and computer codes used to support the design calculations are described and discussed. Design and safety limits associated with the fuel, and nuclear and thermal-hydraulic design of the reactor are presented.

5.1 SUMMARY DESCRIPTION

The Reactor Facility is a multi-purpose open-pool type reactor. The nominal fission power of the reactor is 20 MW. The reactor is designed to have an operational life of at least 40 years. Reactor purposes are described in detail in Chapter 1, Section 1.2. The core is located inside a chimney, surrounded by heavy water contained in the Reflector Vessel. The whole assembly is at the bottom of the Reactor Pool, which is full of de-mineralised light water, acting as coolant and moderator.

The core is an array of sixteen plate-type Fuel Assemblies (FAs) and five absorber plates, which are called Control Rod Plates (CRPs). The FAs are square shaped, and within each FA there are twenty one fuel plates. Light water, which flows upwards, is the coolant for the core.

The fuel plates consist of meat and cladding. The meat is uranium silicide powder dispersed in an aluminium matrix, which is then surrounded by aluminium cladding. The fuel particles, aluminium matrix and cladding constitute the first barrier against fission product release.

Power released from nuclear fission in the core is 20 MW.

The core is cooled by a flow of de-mineralised light water moving in the upward direction in forced-circulation cooling mode. The Core Chimney, which provides physical isolation between the core and the reactor pool, collects the core cooling water before it is pumped away by the Primary Cooling System (PCS). The PCS coolant and its boundaries constitute the second barrier against fission product release.

The heavy water in the Reflector Vessel is cooled by the Reflector Cooling & Purification System (RCPS), while the irradiation facilities are cooled by the dedicated Reactor & Service Pool Cooling System (RSPCS).

The reactor can be shut down by two independent means, which are the insertion of five CRPs into the core, or the partial drainage of the heavy water from the Reflector Vessel.

The Reactor Protection Systems (RPS) are the First Reactor Protection System (FRPS) and the Second Reactor Protection System (SRPS). In Chapter 8 there is a description of the Instrumentation and Control features of the RPS. The CRP system constitutes the First Shutdown System (FSS) which has the capacity to shutdown the reactor very rapidly when required by the FRPS or by the operators. The CRPs are also used to perform the function of power regulation and control during reactor operation. The Reactor Control and Monitoring System (RCMS), which is separate from the FRPS commands this function.

Partial drainage of the heavy water from the Reflector Vessel constitutes the Second Shutdown System (SSS) which also has the capacity to quickly shut down the reactor, by command of the SRPS or the operators. The cylindrical Reflector Vessel is traversed in the axial direction by tubes of different diameters that house irradiation rigs and targets. The Reflector Vessel also comprises a containment that houses a Cold Neutron Source (CNS), and five neutron beam assemblies in the horizontal plane, i.e. two cold neutron beams that point to the CNS, two thermal neutron beams and an additional beam to serve a possible future Hot Neutron Source. All beam tubes are tangential to the core.

There are four reactor states. Whenever fuel is in the core, the reactor is in one of these four states determined by control rod drive electromagnet status, core cooling condition and core reactivity (keff):

a) *Power*: One or more control rod drive electromagnets is energised and there is forced circulation through the core. In this state, the reactor may be operated at a nominal 20 MW.

b) *Physics Test*: One or more control rod drive electromagnets is energised and there is no forced circulation through the core. In this state, the reactor may be operated at low power for testing purposes.

c) *Shutdown*: All control rod drive electromagnets are de-energised and the reactor is subcritical.

d) *Refuelling*: All control rod drive electromagnets are de-energised, the reactor is subcritical and there is no forced circulation through the core.

In the Power state the reactor is critical and the power level may be between ~100 kW and 20 MW. Power control is based on neutron flux measurements by ionisation chambers. Power control can be performed either manually by the operator, or automatically by the RCMS through the Automatic Reactor Power and Control System (ARPCS). The reactor is cooled by forced convection, using two of the Primary Cooling System pumps.

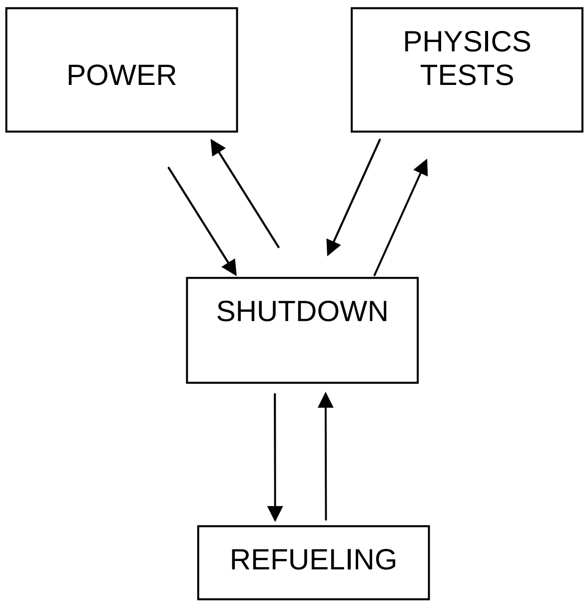
In the Physics Test state the reactor can be critical and the power level is limited to less than 400 kW. The reactor is cooled by natural convection with the Primary Cooling System pumps off.

In the Shutdown state the reactor is sub-critical and the residual power is due mainly to fission product decay. Reactor cooling is by natural or forced convection. The CRPs are fully inserted into the core either as a result of manual shutdown by the operator or as a result of the actuation of the FSS, and/or actuation of the SSS.

In the Refuelling state the reactor is sub-critical and the residual power is due mainly to fission product decay. Reactor cooling is by natural convection. In this state, the FAs may be re-arranged. Spent FAs are withdrawn from, fresh FAs are inserted into, and partially burnt FAs may be shuffled in, the core. In this state the RCMS provides plant information and support features to the operator. The RCMS also verifies that appropriate reactor conditions are available prior to actual refuelling, e.g. that the CRPs are fully inserted in the core, that the PCS pumps are stopped, that the SSS is available, that the fission chamber counter readings are above minimum.

There are various design limits that have been adopted in the reactor design as part of meeting the fuel meat temperature safety limit. Specific design limits are described in context throughout the Chapter. There is only one core safety limit; fuel temperature <400 °C.

Quantity	**Limit**	**Bases for Limit**
Fuel		
Fuel Meat Temperature	400°C	Avoid blistering of cladding. This is a conservative value based on estimates for the blistering temperature of 515-575°C



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5.2 REACTOR STRUCTURES

5.2.1 Introduction

The reactor structures are a set of components that fulfil mechanical, neutronic and thermal-hydraulic functions associated with the core. On one hand they provide the needed mechanical support to the core, while on the other hand they are an integral part of the core cooling circuit. They also allow the collection and use of the neutrons produced in the core.

FAs are inserted in the Core Grid. The Core Grid provides mechanical support to the core and defines its geometrical configuration. Fuel Clamps (FCs) affix the FAs to the Core Grid. The Core Grid also supports the Control Rod Guide Box (CRGB) that contains the Control Rod Plates (CRPs).

Surrounding the core is the lower Core Chimney and the Reflector Vessel.

The Reflector Vessel contains heavy water that acts as a neutron reflector, and has penetrations for irradiation facilities, the Cold Neutron Source and beam assemblies.

The lower and upper Core Chimney bound the PCS water flow passing through the core before it is extracted through the PCS outlet piping.

5.2.2 Codes and Standards

The design of the Reactor Structures complies with the following Codes and Standards:

Australian Standard AS 1210, Pressure Vessels

ASME for the Construction of Pressure Vessels

DIN for Tolerances

ASTM for Materials

ASME for Welding Qualification

5.2.3 General Design Bases for Reactor Structures

General design bases for reactor structures that support the core and core associated components are included in this Section. Additional design bases applied to some individual components, if any, are presented in the corresponding description sections.

a) Reactor structures are designed to provide adequate functional support to reactor fuel and reactor shutdown systems to ensure that:

   (i) Shutdown can be readily carried out in operational states, anticipated operational occurrences, and Design Basis Accidents (DBAs). Shutdown can also be demonstrated for the postulated Beyond Design Basis Accidents (BDBAs).

   (ii) Cooling of the core and irradiation rigs is carried out in operational states, anticipated operational occurrences, and DBAs and is achieved in the postulated BDBAs.

b) Reactor structures are designed and constructed such that the probability of failure is very low, and they meet the safety requirements stated by the applicable standards and regulations.

c) Life limiting characteristics of the reactor structures are identified. It is ensured that they meet the requirements imposed by the applicable standards. Reactor structural components are designed to have a lifetime of over 40 years unless stated otherwise.

d) Where relevant, reactor structures design takes into account the conditions imposed by the use of heavy water.

e) Reactor structural materials are selected according to their mechanical properties, corrosion resistance, activation properties and properties related to their neutronic behaviour.

f) Unions and joints of the reactor structures allow easy assembly and disassembly. Their positions relative to the core have been chosen to minimise the activation of those components that may need to be removed for maintenance or satisfying operational requirements.

g) Reactor structures are designed taking into account decommissioning requirements.

5.2.4 Description of Reactor Structures

5.2.4.1 Reactor Pool, Service Pool and Reactor Bridge

The Reactor Pool, Service Pool and Reactor Bridge are analysed in Chapter 4, Section 4.5.

5.2.4.2 Core Inlet Plenum

5.2.4.2.1 Design Bases

In addition to the general design bases, the Core Inlet Plenum has been designed to:

a) Provide adequate water tightness in the joints with the Reactor Pool and other Reactor Internal Components, and provide support for the loads imposed by the reactor structures above it; and

b) To collect and mix the PCS water before it enters the core.

5.2.4.2.2 Description

The Core Inlet Plenum is a component of the PCS boundary. It collects and mixes PCS water before it enters the core.

In the Power State, the Core Inlet Plenum receives the inlet flow from two PCS pipes. The water flows through it and then upwards through the core grid, the core and the core chimney, which are located above the Core Inlet Plenum.

The Core Grid defines the core geometric layout and its reference plane, and provides structural support for the FAs and CRGB.

It is a square shaped reticular structure located inside the Core Chimney. This component is fixed, and it transfers its loads to the Core Supporting Structure.

The Fuel Assemblies are inserted into the Core Grid inter-reticular spaces. The grid has five orifices that allow insertion and motion of the CRP stems.

The Core Grid also distributes the water flow through the core. It has orifices with diameters such that the necessary water flow rate is ensured inside the Control Rod

Guide Box providing adequate CRP cooling. Moreover, the design of the Core Grid ensures adequate protection of the FAs, CRP and CRGB from hydraulic forces (e.g. direct impact of the PCS flow; excessive pressure drop).

5.2.4.3 Core Supporting Structure

The Core Supporting Structure is located inside the Inlet Plenum and has the function of supporting the core. This component consists of a cylinder that contains a reticulated structure in its interior to provide rigidity and to form the channels for circulation of the PCS water.

The component has a lower flange that provides a structural support to the bottom of the Reactor Pool, and an upper flange used to locate the Core Grid in place.

5.2.4.4 Control Rod Guide Box

The Control Rod Guide Box (CRGB) houses the CRPs, provides a structural frame for CRP displacement, and acts as a channel for CRP cooling.

5.2.4.4.1 Design Bases

In addition to the general design bases set out in Section 5.2.3, the following requirements apply to the CRGB:

a) To guide CRP movement without interference.

b) To protect the CRPs from flow induced vibration.

c) To provide an adequate geometry for CRP cooling.

d) To provide means to ensure that in the event of a CRP being disconnected from the CRP stem, the CRP is not dragged by the PCS flow.

e) To allow for easy replacement of the CRPs.

f) The design considers the relevant environment effects on the CRGB.

   (i) The development of lateral pressure difference across the CRGB wall, due to different water velocities in adjacent cooling channels.

   (ii) Mechanical loads due to interaction with the CRPs.

5.2.4.4.2 Description

The CRGB is a component of cruciform cross section, located inside the chimney and supported by the Core Grid. It provides housing for the five CRPs.

The CRGB allows vertical displacement of the CRPs driven by the CRDs, ensuring that there is no interference between the CRPs and the FAs during CRP movement. In addition, the CRGB protects the CRPs from the large coolant velocity along the FA.

The CRGB is supported by the Core grid, guided by the Reflector Vessel Chimney and kept in position by the CRGB fasteners that are designed to withstand the PCS flow and the drag force generated by the CRP movement. Loads exerted on the CRGB are finally transferred to the Core Chimney. An external lock mounted from the top of the Core Chimney also locks the CRGB.

5.2.4.5 Fuel Clamps

5.2.4.5.1 Design Bases

In addition to the general design bases set out in Section 5.2.3, the FCs comply with the following design bases:

a) To provide safe FA retention, preventing the ejection of FA by the PCS flow.

b) To fix the FAs with sufficient force to guarantee their contact with the grid.

c) To require low maintenance.

d) To allow easy assembly and disassembly for fast refuelling operations.

In the Power State, the FCs are fully closed retaining the FAs against the grid preventing the FAs from being dragged by the action of the PCS flow.

5.2.4.6 Reflector Vessel

5.2.4.6.1 Design Bases

The Reflector Vessel design complies with the following design bases in addition to the general design bases set out in Section 5.2.3. The Reflector Vessel:

a) Contains heavy water with the required leak-tightness to minimise tritium release.

b) Provides guidance to the flows through the core and irradiation rigs.

c) Provides adequate alignment for the CRGB.

d) Supports the irradiation rigs, the pneumatic irradiation devices, the Cold Neutron Source, a possible future Hot Neutron Source and neutron beam tubes with the required alignments.

e) Retains an adequate amount of water for irradiation rig cooling in the case of Loss Of Coolant Accident (LOCA).

f) Withstands the pressure forces, flow induced vibrations, irradiation induced growth and corrosion effects, and maintains its mechanical stability.

5.2.4.6.2 Description

The Reflector Vessel is a cylindrical shape vessel with two flat plates (top and bottom). Along the vertical axis of the vessel there is a hollow space with square cross section that constitutes the lower part of the Core Chimney. The entire assembly is water-tight in its structures.

The mechanical stability of the vessel is provided by the Core Chimney, the outer vessel wall, the irradiation tubes, and the reinforcing columns that are placed between the vessel top and bottom plates

The inner surface of the vessel is in contact with heavy water and the outer surface in contact with de-mineralised light water. The heavy water and light water circuits are fully independent of each other.

The irradiation tubes are cooled by the RSPCS (Chapter 6, Section 6.3).

The beam tubes are of rectangular cross section. Each beam tube has a circular flange.

A vertical Vacuum Containment penetrates the vessel top plate. This Vacuum Containment houses the CNS. It separates the CNS and its associated process systems from the heavy water in the vessel.

Fission counter tubes are also housed in the Reflector Vessel. They allow the active part of the counter to be at the edge of the core.

The vessel is traversed in the axial direction by tubes of different diameters, which house irradiation rigs.

5.2.4.7 Chimney

The Chimney collects and bounds the PCS water flowing through the core before it is suctioned through the lateral opening by the PCS piping to be pumped away from the reactor core.

The Chimney comprises a lower Chimney that is part of the Reflector Vessel and Upper Chimney called the Riser.

An elastic bellow joins the upper and lower Chimney and allows the absorption of relative displacement of both parts. The PCS also suctions water from the reactor pool so a downward flow is established in the upper part of the Core Chimney.

The upper and lower parts of the Chimney are mechanically independent. Loads on the lower part of the Chimney are transferred to the Reflector Vessel, whilst the Riser is supported by the Riser Support, which is a structure attached to the Reactor Pool wall that transfers the loads to the concrete block.

Affixed to the upper end of the Chimney is the Chimney Protection Grid. This grid provides protection to the core from falling objects.

5.2.4.8 Irradiation Facilities Plenum

The Irradiation Facilities Plenum collects the coolant flow that has flowed downwards through the irradiation rigs before it is pumped away by the RSPCS.

The Irradiation Facilities Plenum is not a component by itself. Rather it is a zone below the Reflector Vessel, defined by the extension of the Reflector Vessel lateral wall and the top-plate of the Core Inlet Plenum.

5.2.4.9 Irradiation Facility and Neutron Source and Beam Structures in the Reflector Vessel

The Reflector Vessel acts as housing for the Irradiation Facility Structures that, in some cases, comprise the Reflector Vessel structure as well.

5.2.4.9.1 Irradiation Tubes

Irradiation tubes for irradiation rigs are placed vertically in the Reflector Vessel. Irradiation tubes penetrate the Reflector Vessel through the top plate. Irradiation tubes are part of the vessel structure distributed in positions that are exposed to the required neutron flux. Irradiation tube diameters and lengths vary. Some of the tubes are designed to house the end-fittings of the rigs of the pneumatic transfer system, some hold the rigs and cans for bulk production irradiation, and the rest receive the rigs and containers for large volume silicon irradiation.

From the point of view of cooling, irradiation tubes penetrate through the vessel, allowing them to be cooled by the RSPCS. Irradiation tubes ends are welded to the top and bottom plates of the Reflector Vessel.

For full description of irradiation facilities please refer to Chapter 11.

5.2.4.9.2 Neutron Sources

The Reflector Vessel has provision for three neutron sources and associated structures serving different neutron beam assemblies.

a) The CNS is located inside a vertical vacuum containment that penetrates the reflector vessel top plate and supports the CNS. Two cold neutron beam assemblies point towards the CNS from nearly opposite directions.

b) The Thermal Neutron Source is not a structural component in itself, but a volume inside the Reflector Vessel where the neutrons have a thermal energy spectrum. Two thermal neutron beam assemblies point towards this volume from nearly opposite directions.

c) In addition, the Reflector Vessel has an extension tube to house a possible future HNS.

The flanges of the CNS and HNS supporting structures are located well above the reactor pool bottom and allow for minimum activation. They have seals that provide the necessary water tightness.

Neutron sources are described in detail in Chapter 11.

5.2.4.9.3 Neutron Beam Assemblies

Neutron beam assemblies inside the reactor pool are composed of several massive metal components whose main objectives are to:

a) Centre and hold the neutron guides.

b) Isolate the internal environment of the beam tubes from the Reflector Vessel and reactor pool water.

c) Isolate the internal environment of the beam tubes from the Reactor Beam Hall environment.

The bellows of the neutron beam assemblies between the Reflector Vessel and the Reactor Pool wall are covered by a structure to protect the assembly from missiles. A description of Neutron Beam Assemblies is given in Chapter 11.

5.2.4.10 Instrumentation Support Structures

Core instruments are held in place by support structures firmly affixed to the Reactor Pool wall or to the Reflector Vessel. Support structures are designed with consideration of mechanical loads in normal conditions and during seismic events. Loads that originate from maintenance and replacement of instruments are also taken into consideration.

These structures support:

a) Neutronic instruments including ionisation chambers and fission chambers.

b) Thermal-hydraulic instruments

c) Reactor Pool water level detectors including those belonging to the RCMS

d) Pool open end gamma activity detectors

5.2.4.11 Provisions for Access, Operation and Maintenance

The design of the core and associated structures provides for easy and fast access for maintenance operations. In order to minimise personnel exposure and maintain doses As Low As Reasonably Achievable (ALARA) the design provides the following:

a) direct access and simple disassembly of components;

b) use of low activation materials.

The Reactor Pool is provided with adequate manoeuvring area with:

a) access from the reactor hall operation bridge;

b) direct sight from the top of the Reactor Pool.

The operation bridge provides a safe and comfortable working place from where manipulation of Reactor Structures can be carried out with the aid of the reactor hall building crane

The layout of structures and components in the Reactor Pool and core area aims at avoiding interference between the daily radioisotope production/silicon NTD activities and the reactor operation/neutron beam users.

It is particularly important to note the feature that no irradiation facilities are located within the core, thus preventing interference with the FAs and CRP plates. It is also stressed that the location and design of the two shutdown systems completely prevents interactions with production activities that could jeopardise their performance.

The Service Pool located next to the Reactor Pool can hold reactor components and structures during maintenance operations.

The provision of a diverse range of handy and easy-to-use tools allow for various operations within the Reactor Pool. The use of such tools is governed by strict administrative control.

5.2.4.12 Shielding

The water column located above the reactor core provides reactor axial shielding. Water and high density concrete provide reactor radial shielding.

Steel plates are fixed on the beam tube ports to compensate for the diminishing in concrete width in the zone of the beam shutters. Furthermore, a shield of concrete, steel, hydrogenous material and lead is provided on every beam tube port.

Shielding structures are described in Chapter 12.

5.2.5 Inspection and Testing of Reactor Structures

Provisions for inspection and testing of reactor structures are described in this Section.

Inspection and testing is being carried out in accordance with the plans and procedures developed for each case and in compliance with the relevant codes and standards.

5.2.5.1 Manufacturing and Installation

The tests are in accordance with applicable construction and inspection and test plans and procedures.

The following tests are being performed as required by the design:

Dimensional controls

Functional controls

Geometrical controls

Manufacturing method control

Welding tests

Hydraulic tests

Inlet plenum and core chimney performance during emergency make-up water system (EMWS) actuation.

Supplier qualification plans have been developed and applied.

5.2.5.2 In-service

Tests will be performed during the Commissioning Stage following the outline given in Chapter 15.

5.2.6 Design Evaluation of Reactor Structures

Components are designed following the guidelines of applicable standards regarding design procedures. Margins for design loads are defined accordingly ensuring the required performance for every component.

A detailed stress analysis has been performed in order to ensure that no component is subject to unacceptable stress or deformation.

The detailed seismic analysis has been performed in order to ensure that the components comply with the requirements for Seismic Category 1 components.

5.2.6.1 Core Inlet Plenum

The Core Inlet Plenum design takes into account the operational and seismic conditions.

The design ensures that the reactor core components are firmly supported and secured. The mechanical design takes into consideration the most severe postulated seismic event (analysed in Section 5.2.7), the loads exerted by the Reflector Vessel and the pressure due to the Reactor Pool water column and the PCS flow (analysed together with the Reflector Vessel in Section 5.2.6.5). These analyses based on finite element calculations show that the stresses developed in the Core Inlet Plenum under the postulated load conditions are well below the yield stress, thus ensuring the integrity of the component.

Flow induced vibrations do not represent a problem for this component as the flow diffuser and geometrical arrangements keep coolant velocities well below the critical velocity for this phenomenon to start.

Irradiation damage on this component over reactor lifetime is expected to be negligible as the integrated neutron flux and the working temperatures are well below the threshold values where irradiation damage effects become significant. Additional details are given in Section 5.9.

5.2.6.2 Core Grid

The Core Grid design takes into account the operational and seismic conditions.

The design ensures that the core is secured firmly and aligned accurately. The grid withstands the forces arising from the PCS flow, the fuel clamping forces and the most severe seismic conditions.

The control of the PCS water quality and the working temperature of this component ensure that corrosion effects on this component are negligible. Additional details are given in Section 5.9.

The assessment of the Core Grid materials show good performance under irradiation during the 40 years of operation. Further details are given in Section 5.9.

5.2.6.3 Core Supporting Structure

The Core Supporting Structure design takes into account the operational and seismic conditions.

The design ensures that this structure is secured firmly and aligned with the Core Grid accurately. The structure withstands the forces arising from the PCS flow, the clamping forces and the most severe seismic conditions. The flange is designed to withstand the maximum drag force on the structure by the PCS flow.

The control of the PCS water quality and the working temperature of this component ensure that corrosion effects on this component are negligible.

Flow induced vibrations do not represent a problem for this component as the flow diffuser and geometrical arrangements keep coolant velocities below the critical velocity for this phenomenon to start.

Irradiation damage to this component over the reactor lifetime will be negligible as the integrated neutron flux and the working temperatures are well below the threshold values where irradiation damage effects become significant. Additional details are given in Section 5.9.

5.2.6.4 Control Rod Guide Box

The CRGB design takes into account the operational and seismic conditions.

The CRGB internal channel has the appropriate shape to sustain the differential pressure that develops across the wall during reactor operation in the Power state. The design ensures that the flow velocity past the CRP, and hence drag force on the CRP, is such that the CRP cannot be ejected from the core if the connection with the CRP stem breaks. The thermal-hydraulic design of the reactor core ensures that water pressure differences across the CRGB walls is limited so that deflections that could lead to reduction of cooling channel width and mechanical interference with CRP are prevented.

The CRGB hydraulic design prevents flow-induced vibrations by keeping low the coolant velocities.

The CRGB allows for easy CRP alignment.

The CRGB design ensures that this component and the Core Chimney will not suffer undue deformation. CRGB can be replaced if necessary.

Corrosion effects will be negligible considering the quality of the PCS water and the working temperature. Further details are provided in Section 5.9.

The CRGB potential interactions with the FSS have been analysed. Failure modes of the CRGB and their consequences are considered in the Failure Modes and Effects Analysis (FMEA) conducted for the FSS in Section 5.5.3.

5.2.6.5 Fuel Clamps

The FC design takes into account the operational and seismic conditions.

Calculations and verifications have been carried out regarding:

a) Stems: seismic verification of the connected assembly in accelerations and frequencies, and calculation of natural frequency and maximum strains.

b) Core Grid bushing area: calculation and verification of maximum radial forces and strains.

Taking into account the ALARA principle, the design has avoided the use of supports or fasteners that may require long periods of time for disassembly or assembly operations. In this sense, the design provides, as much as practically possible, easy insertion and removal of FC components, while at the same time minimises the need of the application of large lateral, axial or bending forces during FC operation.

Radiation effects on the mechanical properties of the components of the FCs are not expected to be significant. Damage induced by integrated doses is verified on a case by case basis for synthetic materials such as rubbers or plastics.

The characteristics of the FC materials and FC dimensions make seizure of the system or unintended release of the FA highly unlikely.

In case of a FC not correctly securing a FA and resulting in the FA being dragged by the PCS flow, the consequence would be an addition of a negative reactivity. This event would be detected by the fall in the core pressure drop that results in the triggering of both the FSS and SSS:

FCs are operated during Refuelling State to unlock the FAs. The control logic for this state requires the PCS pumps to be stopped. An interlock prevents the PCS pumps from being started.

5.2.6.6 Reflector Vessel

The Reflector Vessel design takes into account the operational and seismic conditions.

The design has taken into consideration the use of heavy water and a possible future HNS. The Reflector Vessel has been designed to withstand the forces and the thermal loads arising from:

a) Heavy water replacement. The most important operational requirement includes the drainage of heavy water and further pumping helium gas out of the vessel to produce vacuum and dry its internal walls which results in hydrostatic pressure due to the nominal water column level in the reactor pool. This operation represents the most demanding load condition.

b) The hydrostatic pressure of the reactor pool water on the outer of the vessel walls.

c) Seismic forces (including sloshing): The Reflector Vessel is a Seismic Category 1 component designed to withstand a SL-2 earthquake. A preliminary seismic analysis is provided in Section 5.2.7.

d) Deformations.

e) A BDBA of the CNS.

f) Partial discharge of the vessel due to a SSS actuation.

g) The PCS water flow in the Core Chimney.

h) The RSPCS water flow through the irradiation rigs and the Irradiation Facilities Plenum.

i) The flow of the Reflector Cooling and Purification System (RCPS).

j) The actions of the bellows connecting the vessel with the upper Chimney and the bellows connecting the beam tubes.

A structural analysis of the Reflector Vessel has been performed in order to verify its structural integrity for different mechanical and thermal loads. The structural analysis has been carried out both analytically and by means of Finite Element Analysis (FEA). MSC/NASTRAN (MacNeal-Schwendler Corporation) has been used for the structural stress and seismic analysis. ANSYS, a finite difference analysis program, has been used for thermal analysis calculations. The cases and the respective results of the preliminary analysis are:

a) Pressure loads: The Reflector Vessel has been designed to withstand the loads arising from a range of scenarios including heavy water filling and replacement operations, Second Shutdown System actuation, Primary Cooling System operation and overpressure of the cover gas. The analysis has verified that the system is capable of withstanding the loads arising from those scenarios. In this sense, the analysis included a verification of the stresses and displacements on the Reflector Vessel for a Design Load Case that is a load envelope of the loads of the cases described above.

b) Irradiation effect: This phenomenon has been modelled for those parts of the vessel close to the core, including the Core Chimney (see Section 5.2.6.7 and the vessel internal columns close to the core. The results indicate that, after 40 years of operation, the maximum calculated displacement is 0.12 mm on the top plate. Horizontal growth is negligible. The analysis concludes that the effect decreases with the radius, so it is negligible in the outer wall of the vessel. The effect also varies in the vertical direction, having a maximum at the level of the mid-plane of the Core, and being negligible at the top and bottom plates of the Reflector Vessel.

c) Loads due to temperature: temperature induced load during Power State and that caused by the SSS actuation have been analysed. When the SSS is triggered, approximately half of the volume of heavy water is dumped. Heavy water remains in the bottom half of the Reflector Vessel, and helium fills up the top half. In addition, the light water outside the vessel contributes to the cooling of the vessel so the temperature developed in the walls of the vessel is low and therefore the thermally induced stresses are low.

d) Seismic Loads: A seismic analysis of the Reflector Vessel is presented in Section 5.2.7.

e) Events involving the CNS: A separate analysis has been performed on effects to the vessel of anticipated operational occurrences, and accidents involving the CNS.

f) Load combinations: Different load combinations for the cases mentioned above have also been considered. The analysis included the load cases due to:

   (i) Pressure loads due to normal operation + temperature loads due to normal operation + own weight

   (ii) Design Load Case + temperature loads due to SSS actuation + irradiation effect + own weight

   (iii) Design Load Case + temperature loads due to SSS actuation + irradiation effect + seismic event loads (SL-2) + own weight

The results confirm that stresses developed in the vessel are significantly below the yield strength.

Considering the operating temperature and the quality of both de-mineralised light water and heavy water in contact with the vessel, the analysis indicates that the general effects of corrosion are expected to be insignificant.

For irradiation effects, the analysis concludes that the material properties remain within acceptable limits up to and exceeding 40 years of reactor operation.

Vessel joints provide the required water tightness and low rate of heavy water degradation.

Cooling is provided for the Reflector Vessel for all operational states by means of the RCPS, the PCS and the RSPCS. An analysis of the cooling conditions of the vessel during Power Operation has been carried out. The analysis takes into account the effect of neutron and gamma heating of heavy water and the flow conditions inside the vessel imposed by the RCPS inlet and outlet pipe configuration. The analysis, which involved finite element computations of the flow inside the vessel, shows that the flow established inside the vessel ensures an adequate cooling of the vessel and the heavy water. A description of the RCPS, PCS and RSPCS circuits are provided in Chapter 6.

5.2.6.7 Core Chimney

The design of the Core Chimney and its support structures takes into account the operational and seismic conditions.

Flow induced vibrations have been taken into consideration. The chimney support structure provides a strong frame capable of withstanding the forces imposed by the flow through the Upper Chimney.

A detailed structural analysis of the Core Chimney has been performed in order to verify its structural integrity. Different mechanical and thermal load situations have been analysed. The structural analysis has been carried out both analytically and by means of Finite Element Analysis (FEA). MSC/NASTRAN has been used for the structural stress and seismic analysis. ANSYS, a finite difference analysis program, has been used for thermal analysis calculations.

a) Design Load Case: this case represents a load case that envelopes the loads arising from heavy water filling and replacement operations, Second Shutdown System actuation, Primary Cooling System operation and overpressure of the cover gas.

b) Irradiation effect: The Core Chimney and the Reflector Vessel are designed in such a way that the irradiation will not generate significant stresses.

c) Seismic Loads: A detailed seismic analysis of the Core Chimney as a part of the Reflector Vessel is presented in Section 5.2.7.

d) Load combinations: A load combination case has been considered that includes the loads arising from the design load case pressures, temperature loads, irradiation effects, and own weight (including Reflector Vessel weight) in order to assess the stresses that develop on the Core Chimney.

Fluid dynamic studies and finite element analysis have been performed to determine the flow patterns around the Core Chimney and the stability of the downward flow to ensure that no water passing through the core reaches the top of the Reactor Pool. Further description of the flow is given in Chapter 6, Section 6.2.

A protective grid located at the upper end of the Chimney protects the Chimney itself and the components located inside, including the core, from falling objects. The grid has been designed to withstand the impact of a falling silicon ingot.

5.2.6.8 Irradiation Facilities Plenum

The Irradiation Facilities Plenum design takes into account the operational and seismic conditions.

The loads on this component represented by the hydrodynamic action of the RSPCS have been used as input for the design. In addition, joints have been designed to ensure that an undue by-pass over the maximum acceptable rate from the Core Inlet Plenum to the Irradiation Facilities Plenum does not take place. A test will be carried out during the Commissioning Stage to verify that the rate of this by-pass is sufficiently small. Further details about Commissioning are given in Chapter 15.

5.2.6.9 Irradiation Facility and Neutron Source and Beam Support Structures

The design of the irradiation facility and neutron source and beam support structures takes into account the operational and seismic conditions.

Accurate determinations of the loads and operational requirements on irradiation facilities have been carried out and have been used as input for the design of their support structures. This ensures that the structures withstand mechanical loads and satisfy irradiation facility alignment requirements.

A detailed structural analysis of the CNS Vacuum Containment has been performed in order to verify its structural integrity and to evaluate its interaction with the Cold Neutron Beam Assemblies. Different mechanical and thermal load situations have been analysed. The structural analysis has been carried out both analytically and by means of FEA. The MSC/NASTRAN code has been used for structural stress and seismic analyses.

The ANSYS code, a finite difference analysis program, has been used for thermal analysis calculations. The results of the thermal analysis have then been used for structural stress analysis calculations.

A separate SAR for the CNS has been elaborated where further analysis of the operation, anticipated operational occurrences and accidental situations have been analysed in detail.

5.2.6.10 Instrumentation Support Structures

The design of the instrumentation support structures takes into account the operational and seismic conditions.

The loads imposed by instrumentation operation, such as vibrations and instrument movements, have been included in the input data for the design of the support structures. This ensures instrument integrity during operation.

5.2.7 Seismic Verification of Reactor Structures

The results of the seismic analysis are presented in this Section. This analysis includes the assessment of the structural integrity of the Reflector Vessel Core Inlet Plenum, Chimney and Neutron Beam Assemblies inside the Reflector Vessel.

The seismic analysis is performed considering accelerations arising from the SL-2 seismic event, the pressure due to the Reactor Pool water column and Zircaloy irradiation effects. Additionally, the resistance of the components under analysis has been analysed for the SL-2 seismic loads combined with those arising from other scenarios (refer to sections 5.2.6.6 and 5.2.6.7)

FEA has been performed by using the MSC/NASTRAN code.

Modal analysis is employed to evaluate seismic dynamic amplifications. In order to get an estimation of the fundamental oscillation mode of these structures, the components have been modelled considering the water they contain.

The analysis concludes that the calculated maximum stress reached in this event in the Reflector Vessel and Chimney are negligible when compared with the yield strength. The results also show that the maximum stresses are reached in the Core Inlet Plenum but these stresses are below the limit. Normal and shear stresses on Inlet Plenum bolts have been calculated and verified to be below the allowable stress limits.

The maximum calculated displacement at the Beam Assembly flanges has been used for the design of the bellows. This value of displacement has been evaluated using the corresponding floor response spectra.

A detailed analysis of the Neutron Beam Assemblies inside the Reflector Vessel has been conducted in order to evaluate their structural integrity. Considerations include the forces arising from the Reactor Pool water column pressure, and the SL-2 seismic event acceleration. These results also show that the event of loss of heavy water through the Beam Assemblies due to the Postulated Initial Event of an SL-2 seismic event is highly unlikely (see Chapter 16 Section 16.12 for more details).

End of Section

Figure 5.2/8 Reflector Vessel

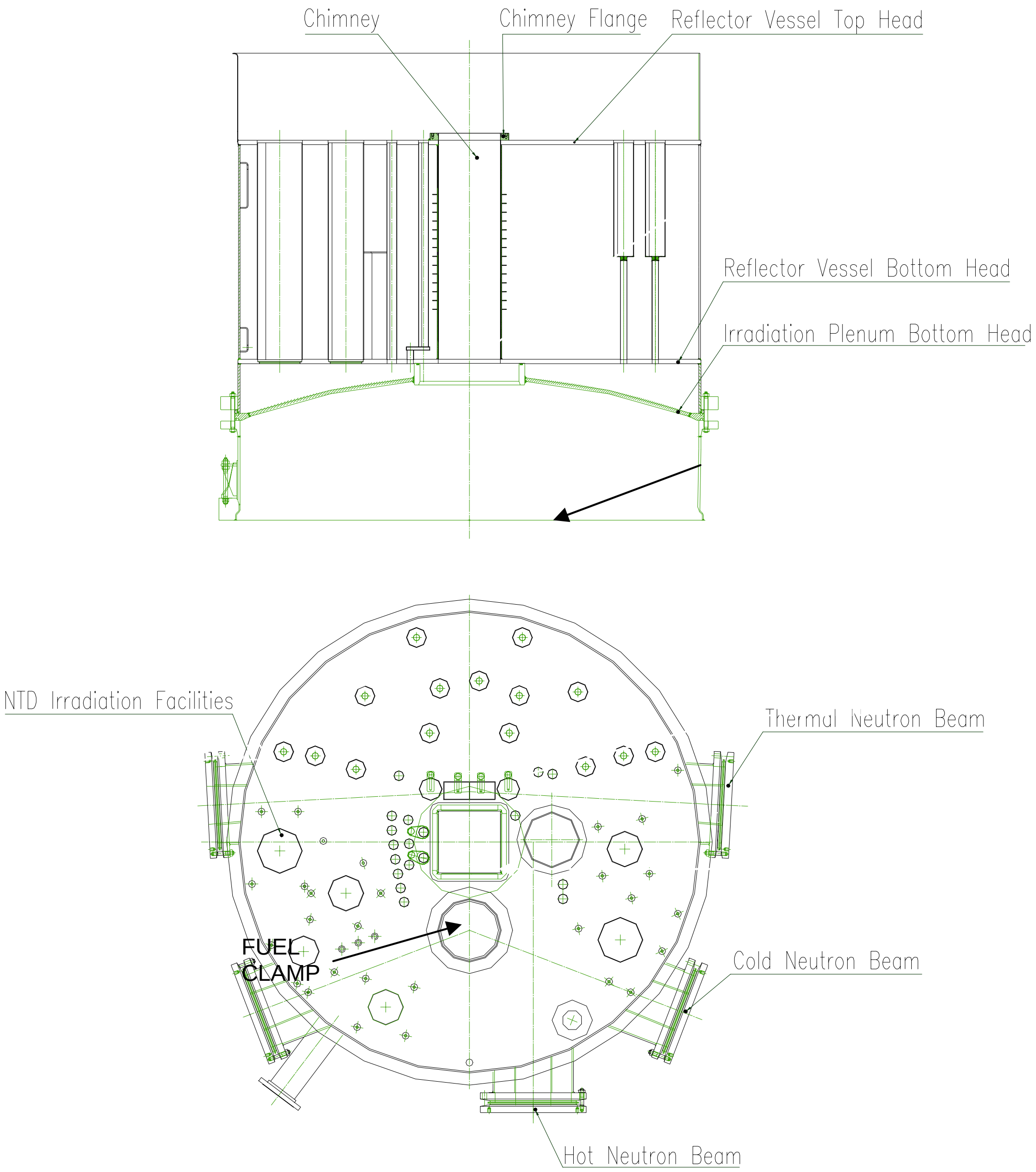


Figure 5.2/9 Core Chimney

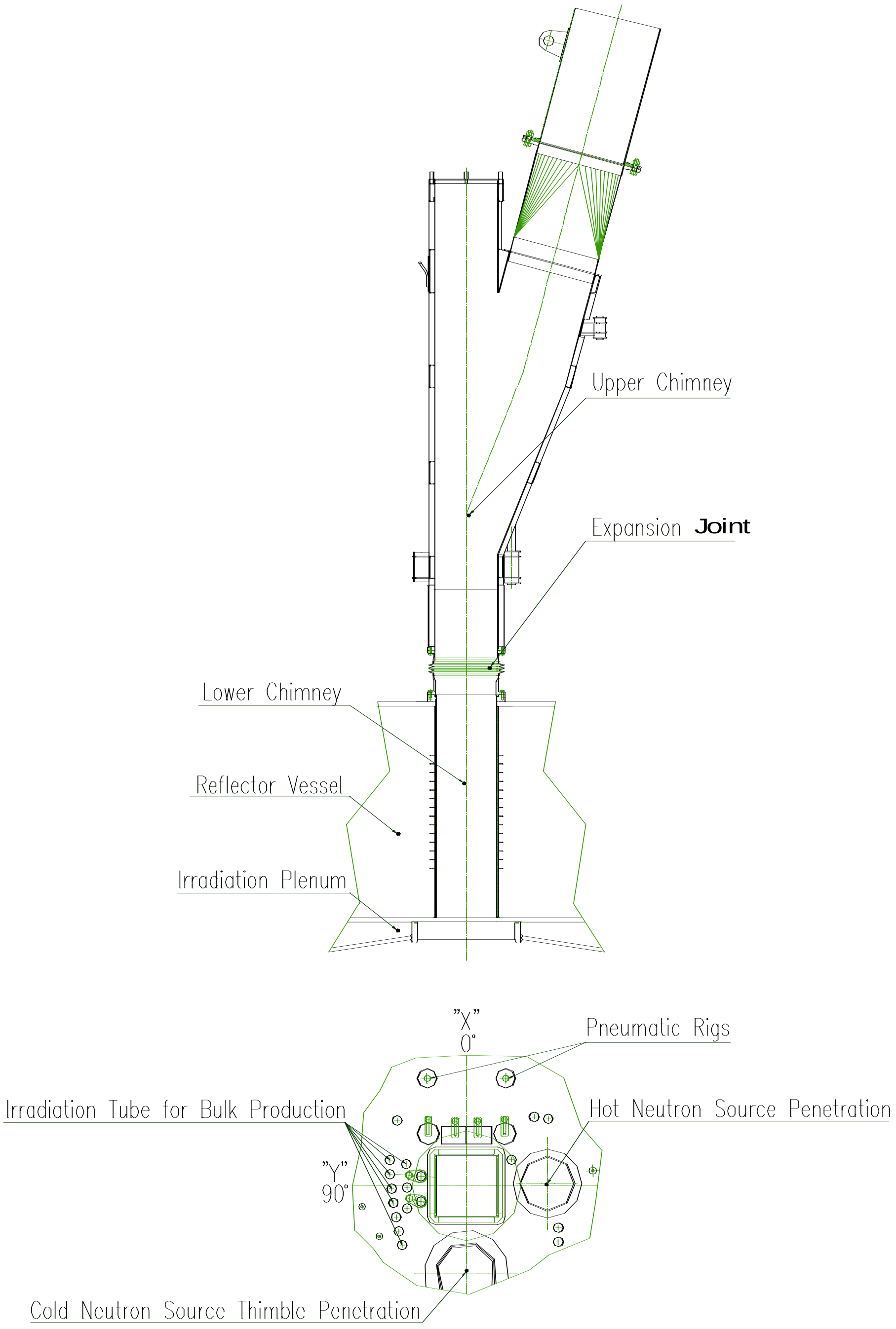
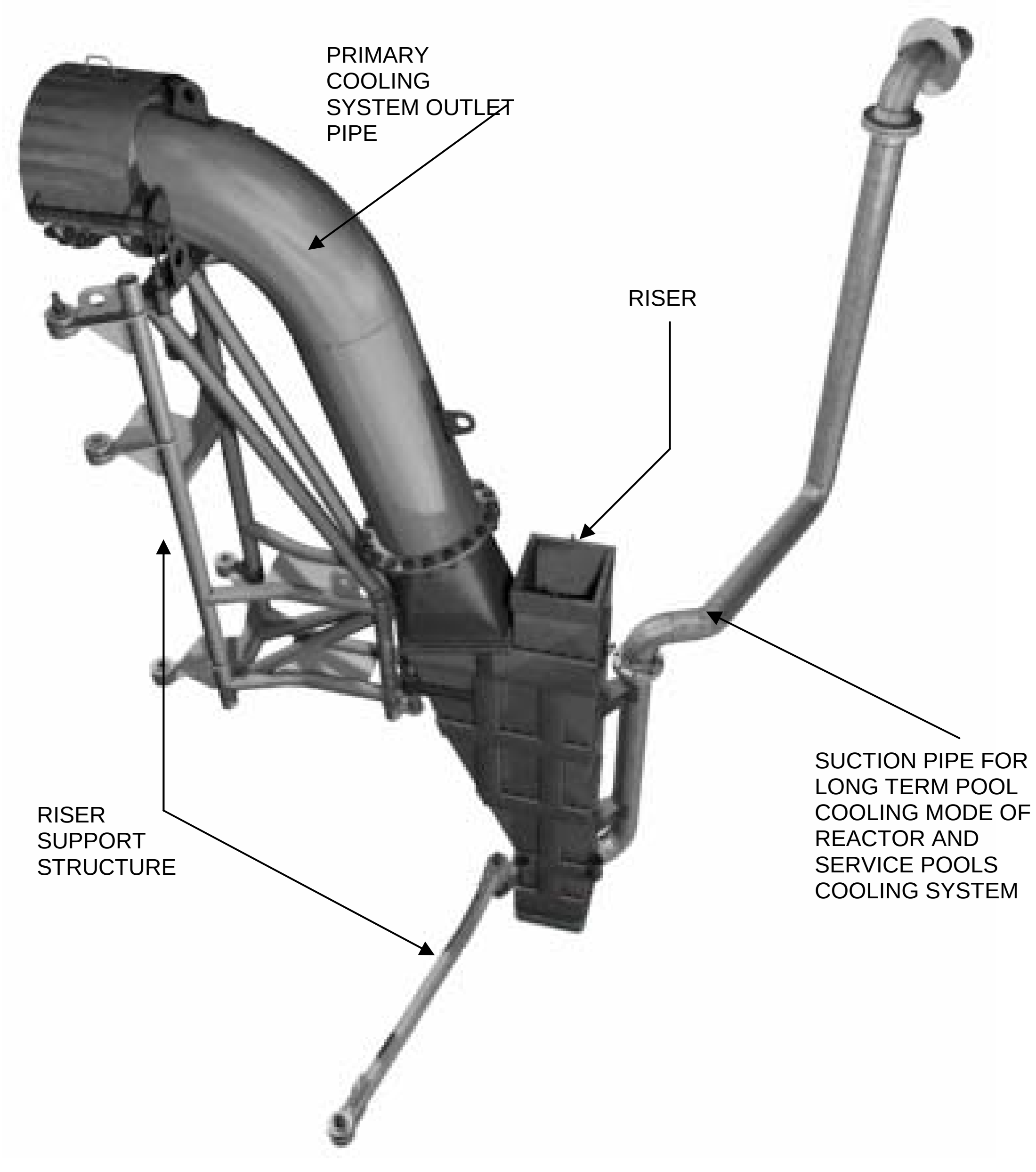


Figure 5.2/10 **3D View of the Riser (Upper Chimney) and Riser Support Structure**



End of Figures