5.4 REACTIVITY CONTROL ELEMENTS

5.4.1 Introduction

The reactivity control elements consist of the CRPs, which are driven by the Control Rod Drives (CRDs) located in the CRD room below the Reactor Pool. The active components of the CRPs are plates made of neutron absorbing material that can regulate the reactor power and shut down the reactor. Neutronic aspects of these elements are discussed in detail in Section 5.7 of this Chapter. The CRDs are described in Section 5.5 of this Chapter.

5.4.2 Design Bases

Design Bases for the CRPs are given below:

1. The design will take into consideration loads which arise from:
    a) heat generation (mainly due to neutron capture)
    b) environment effects, comprising chemical and radiation effects
    c) mechanical interaction with the CRGB
2. The drag force exerted by the PCS will not exceed 75% of the CRP weight.
3. The limiting effects related with possible damage mechanisms during normal operation should be taken into consideration in order to ensure good performance during irradiation. These limiting effects are:
    a) Heat Generation Effects:
    b) Melting of hafnium absorber material.
    c) Reduction in CRGB gap due to differential thermal expansions of both components.
    d) Radiation Effects:
    e) Changes in physical, mechanical and neutron absorbing properties of CRP materials.
    f) Mechanical Loads:
    g) Wear effects in CRPs and CRGB contact zones, due to relative axial movements and to coolant-induced vibrations of CRPs
    h) Dynamic stresses on the CRP structure and on the connection to the drive rod during reactor trip.

5.4.3 Description

The core has five absorber CRPs. Figure 5.4/1 shows a 3D view of the core area showing the CRPs inside the CRGB. Four of them are Safety and Compensating CRPs and the fifth (cross-shaped central one) is the Safety and Regulating CRP, which is used to regulate the reactor power. The set of five absorber plates will be referred to as CRPs.

The CRP absorber material is Hafnium.

Further details on the materials and their behaviour under reactor operation conditions are given in Section 5.9.

5.4.4 Inspection and Testing

Inspection and testing of the CRPs is conducted following the guidelines stated in Section 5.5 for components of the FSS.

5.4.5 Design Evaluation

To withstand the loads and the effects that result from the environment to which the CRPs are to be exposed, the design has provided large safety margins to ensure their integrity.

The hafnium alloy presents appropriate metallurgical and mechanical properties and good resistance to corrosion. In addition, pitting will not present a problem during the plate lifetime estimated at 12 years. The hafnium alloy presents adequate chemical compatibility for the operating temperatures of this component (See section 5.9).

A neutronic analysis of the CRPs, given in Section 5.7, has been performed to estimate their behaviour over the postulated lifetime of 12 years. According to the analysis CRP depletion does not represent a hazard to the shutdown margin of the FSS (See Section 5.7.5.4).

The thermal-hydraulic analysis of the CRPs, given in Section 5.8.10, indicates that the cooling conditions for the CRPs gives a large margin to the limiting condition of the onset of nucleate boiling phenomenon (Refer to Section 5.8.10 for further details).

In addition, the analysis demonstrates compliance with the design basis condition on the pressure drop across the CRP to avoid its dragging upwards by the PCS flow. Under the most demanding conditions the analysis demonstrates that the maximum velocity that will be present in the CRP area will not surpass the maximum allowable velocity. It is verified that the drag force over the CRPs is lower that 2/3 of the CRP weight. The CRGB incorporates orifices that are calibrated to limit the pressure drop (and thus the drag force) over the CRPs. See Section 5.8.10 for further details.

An evaluation of the performance of the CRPs as part of the Reactivity Control System and the FSS is included in Section 5.5.

5.4.6 Seismic Evaluation

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

A detailed analysis of the CRPs has been carried out in order to evaluate their behaviour under the action of the forces arising from various load cases, including those arising from the SL-2 seismic event. For this purpose a finite element model of the CRP was used.

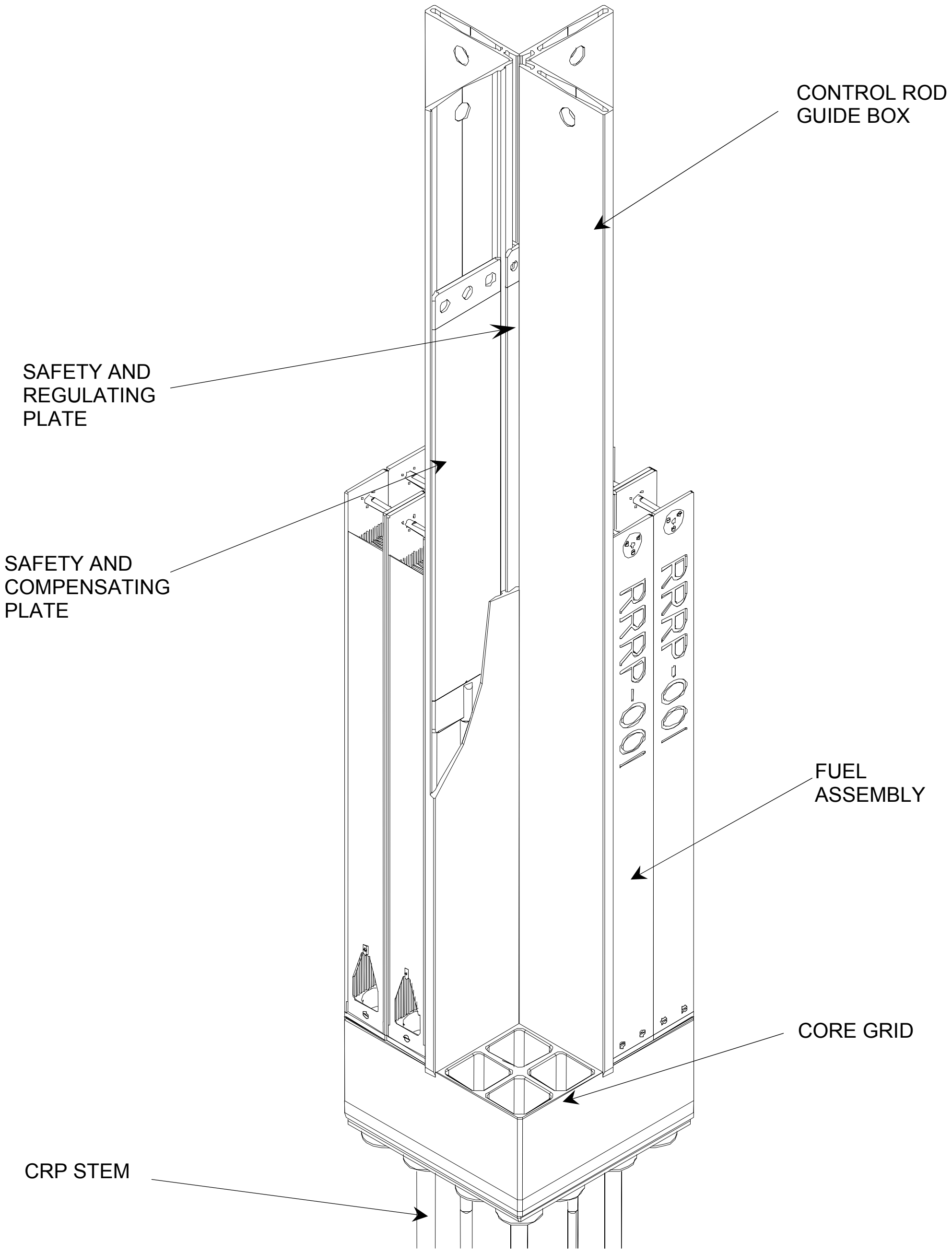
The model of the CRPs included consideration of the acceleration spectra for the building positions where the system is fixed and consideration of the fixing characteristics. In particular, the CRP was modelled laterally supported by the bushings at the Reactor Block Penetration, Core Supporting Structure, Core Grid and CRGB.

As a general conclusion, it is found that the SL-2 seismic event does not induce stresses or deformations on the CRPs that could damage the CRPs or impair its safety functions.

The analysis was performed using the ANSYS program.

End of Section

Figure 5.4/1 **3D View of the Control Rod Plates and Control Rod Guide Box**



End of Figures

5.5 REACTIVITY CONTROL AND SHUTDOWN SYSTEMS

5.5.1 Introduction

The five CRDs place the CRPs in the required positions to fulfil the function of power control during Power State and Physics Tests State.

The FSS provides the capability to decrease the reactor power level very rapidly as demanded by the RPS or the operators.

Partial drainage of the Reflector Vessel fulfils the function of the SSS, which is commanded by the RPS, and provides an independent means of reactor shut down.

The FSS and the SSS are Safety Category 1 Engineered Safety Features (ESFs).

5.5.2 Reactivity Regulation

5.5.2.1 Introduction

During the Power State reactivity and power are regulated, or controlled, by changing the position of the five CRPs inside the core. Rapid shutdown of the reactor by actuation of the FSS or SSS is considered in sections 5.5.3 and 5.5.4 respectively.

The CRPs position can be controlled:

a) Automatically by means of the Automatic Reactor Power Control System (Chapter 8).

b) Manually by the reactor operator from the Main Control Room (MCR).

The nuclear design of reactivity regulation by the CRPs is treated in Section 5.7.

5.5.2.2 Design Bases

Reactivity regulation complies with the following design bases:

a) In the case of loss of normal power, ensure by inherent means that the CRPs are inserted into the core.

b) The CRPs fully withdrawn position will be above the core.

c) The reactivity control system will be functionally independent from the FSS and will not prevent functioning of the FSS.

d) The system will have adequate instrumentation to indicate its condition, including CRP position.

e) The design will allow for low maintenance, easy access and simple assembling and disassembling operations.

5.5.2.3 Codes and Standards

The following codes and standards were applied for the design of the components performing reactivity regulation functions:

Overall tolerances ISO standard for machined/geometric parts.

Overall tolerances ISO standard for structural parts

ASME, Welding Qualification.

NEMA National Electrical Manufactures Association, Electrical Motors.

AS, Screws.

ASME, Filler Materials for Welding.

AS, Gears.

ASTM, Stainless Steel Rods.

ASTM, Stainless Steel Plates.

ASTM, Bronze Pieces.

5.5.2.4 Description

The reactivity control function is carried out by the following major components:

Control Rod Plates

Control Rod Guide Box (CRGB)

Control Rod Plate Stems

Control Rod Seal Box (CRSB)

Control Rod Drive (CRD) Components

Support Table

CRPs move up and down inside the CRGB. Each CRP is driven by its own CRD located in the CRD Room. So there are five identical CRDs. The CRPs are fully above the core in their withdrawn position and fully inside the core in their bottom position.

The CRPs are connected with the CRD Room through penetrations located at the bottom plate of the Reactor Pool.

5.5.2.5 Operation

During the Power and Physics Test States, the Safety and Compensating CRPs may be partially inserted in the core. The position of each CRP is monitored and recorded by the RCMS. This allows compensation of Xenon transients after a spurious trip of the CRPs. Further details on reactivity regulation strategy are given in Section 5.7.

To bring the reactor to the Shutdown State, the CRPs are inserted until they reach their lower position.

The operation of switching the electromagnets on is monitored by the FRPS that requires the following conditions regarding the FSS configuration:

a) The five CRPs must be in their lower position

b) The Pneumatic System of the FSS must be available (Section 5.5.3)

5.5.2.6 Instrumentation

Reactivity Control System instruments are:

Instrument	Indication
Proximity switch	Piston coupled
Proximity switch (x 3)	Lower position
Proximity switch	Upper position
Proximity switch	Lower position

Instrument	Indication
Encoder	CRP position
Step motor (CRMPI)	CRD moving

Refer to Chapter 8, Section 8.3 for further details.

5.5.2.7 Inspection and Testing

5.5.2.7.1 Manufacturing and Installing

A full scale prototype of the CRD was constructed.

The following items were verified by testing:

a) Life cycling characteristics: The testing of the CRD Prototype was designed to take account of the typical CRD operations and to represent 40 years of CRD operation. In this sense, Life Tests consisted of a series of Life Cycles. Life Cycles consisted of withdrawing the CRD from the fully inserted position in a sequence of withdrawing and lowering movements but with a net withdrawal, to represent the CRD control operation (e.g. the movement of the CRD during a core cycle).

   The testing of the CRD Prototype was carried out under the most demanding conditions in order to get early finding of any system weakness. With this purpose, the prototype was assembled and tested with a strong misalignment.

   The performance of the different prototype components was verified (the prototype was disassembled every 100 life cycles and 100 trip cycles) and no major failures as stuck rod, sensors failures or leaks through the Seal Box occurred during the tests. From the test results it was concluded that the Seal Box polypack seals are the only component needing periodic replacement, with the remainder of the components not needing replacement during the full reactor lifetime.

   It was verified that the CRD Prototype provided smooth movements for the required CRP movement speeds.

b) Performance of a quantity of ascending and descending operations to take account of control rod displacement requirements during 40 years of operation: Life tests were carried out representing 40 years of CRD operation. Life tests were carried out together with Trip Tests (Trip Tests included 541 trips and 41 free fall tests, further details are given in Section 5.5.3.7.1).

c) The precision of the position measurement: It was found that the position sensors provide a reliable and adequate measurement of the CRD position. No failures of these sensors occurred during the tests.

d) Assembling and disassembling operation time to assist planning of maintenance operations and elaboration of the operation and maintenance manual: The time for mounting and dismounting the CRD Prototype was measured. The prototype also served to determine and test mounting and dismounting procedures. An adequate and simple sequence of tasks was found.

e) CRD Seal Box testing taking into account doses on seals and wear due to CRP movement: The CRD Seal Box Prototype was continuously checked during the life tests to verify that no significant leaks were present. Even with a strong misalignment of the CRP stem with respect to the Seal Box vertical axis, there is an adequate performance of the seals.

The final conclusion from the analysis of the CRD Prototype Test results showed that the CRD is a very robust and reliable system. The CRD Prototype performed in an appropriate manner during the tests associated to its reactivity regulation function. The system did not show weak or critical parts during the tests where 40 years of system operation were represented.

Dimensional controls were implemented during the manufacturing stage in compliance with requirements of detailed plans.

Pre-operational and commissioning tests will be carried out as indicated in Chapter 15.

5.5.2.7.2 In-service

Regular inspection, testing and surveillance activities will be carried out following pre-established procedures in agreement with the requirements indicated in Chapter 17 of this SAR.

5.5.2.8 Design Evaluation

The regulation of core reactivity has been designed to ensure that the control system withstands the core environment without impairment of its performance, and to ensure it has low maintenance requirements. The use of components that may require long assembly or disassembly times has been avoided.

The design of the CRD is based on the CRDs of the ETRR-2 reactor. These CRDs have performed satisfactorily over the range of operational conditions.

Radiation effects on CRD materials are estimated to be negligible. The data collected on the ETRR-2 reactor indicates that doses on CRDs are low.

All materials are stainless and environmentally resistant. Components will not contaminate the environment with foreign materials that may degrade component integrity. In particular, the materials of components close to the core such as the CRPs and the CRP stems maintain adequate behaviour under irradiation.

Variations in geometry and dimensions of components have been analysed, according to the applicable codes and standards to ensure that they are within allowable tolerances in order to avoid mechanical interference in the CRP axial movement. In addition, the tolerances imposed during manufacturing and installation of these components ensure proper alignment.

In addition, there is no bank extraction mode in the RCMS logic. The CRD control protects from continuous withdrawal of more than one CRP. Failure of one of the CRMPI results in the corresponding CRP being kept in position. The CRP position indication allows the operator to monitor the CRP position.

Anomalies in the main power to the motor cannot result in an inadvertent CRP extraction as the signal from the RCMS is required for the motor to move. Loss of main power to the motors results in the CRP falling by gravity, into the core.

Main power to the motor and electromagnet is provided by the Main Power System. A shortage of main power results in a reactor trip. Power from the Uninterruptible Power Supply (UPS) to these components is not provided.

The possibility of the CRP plates being dragged upward by the pressure of the PCS flow is prevented by the weight of each plate, which is large enough to produce free fall of the plate by the action of gravity against coolant flow. Possibilities for ejection, such as inadvertent manual withdrawal, and explosions, are considered in Chapter 16, Section

16.8.6. It is shown that fast reactivity excursions are not applicable to the Reactor Facility design.

Leaks of the CRD penetrations through the Reactor Pool are prevented by the seal assemblies. Minor leaks would be detected by the leak detection system in the CRD Room, which is provided with waterproof electrical connections and instrumentation. The CRD design includes provisions to allow the required alignment, during installation and maintenance, for proper operation.

A Failure Modes and Effects Analysis (FMEA), conducted for the reactivity regulation system components, showed that there is no credible failure that results in loss of the overall system.

5.5.2.9 Seismic Evaluation

A detailed seismic evaluation of the CRD has been performed and is presented in Section 5.5.3.9.

5.5.3 First Shutdown System

5.5.3.1 Introduction

The FSS shuts down the reactor by inserting the five CRPs into the core.

Aspects of the system regarding its nuclear design are treated in Section 5.7. The actions of the FRPS are treated in Chapter 8.

5.5.3.2 Design Bases

The FSS will comply with the following design bases:

a) CRP insertion for fast shut down will take place in such a way that a negative reactivity of 2000 pcm is provided in less than 0.5 s.

b) The shutdown margin of the FSS will be at least 3000 pcm when the five CRPs are inserted.

c) The design will comply with the single failure criterion. That is, the system will be capable of shutting down the reactor safely with a shutdown margin requirement of at least 1000 pcm, with insertion of any four out of five CRPs.

d) The system will comply with the fail-safe criterion. Namely, the system will ensure CRP insertion in case of (i) loss of power supply events, (ii) loss of compressed air supply upon trip request.

e) The shutdown reactivity will be sufficient to bring and maintain the reactor sub-critical with an adequate margin under all operational states and postulated accident conditions, with the reactivity effect associated with reactor utilisation taken into account.

f) The FSS will be functionally independent from the Reactivity Regulation function.

g) The design of the CRP plates will ensure that they cannot be withdrawn by the action of the PCS flow.

h) The CRP stems will penetrate the Reactor Pool through the bottom of the tank.

i) The design will allow for low maintenance, easy access and simple assembling and disassembling operations.

i) The design will minimise the possibility of applying excessive lateral, axial and flexural loads during handling operations.

j) Internal conditions: Compressed air will be filtered and no lubrication will be used.

k) External conditions: The CRD assembly will be located in the CRD Room which in turn will be located in the lower part of the Reactor Building.

l) Radiation fields: Damage caused by integrated doses will be verified on a case by case basis with respect to synthetic materials such as rubbers and/or plastic materials. The durability of lubricants will also be verified.

m) The system components will comply with the requirements specified for Safety Category 1, Seismic Category 1 and Quality Category A components.

5.5.3.3 Codes and Standards

The following codes and standards were applied for the design of the components of the FSS:

ISO, Machining Tolerances.

ISO, Structural Tolerances.

ASME, Welding Qualification.

NEMA National Electrical Manufactures Association, Electrical Motors.

AS, Screws.

ASME, Filler Materials for Welding.

AS, Gears.

ASTM, Stainless Steel Rods.

ASTM, Stainless Steel Plates.

ASTM, Bronze Pieces.

5.5.3.4 Description

The main components of the FSS are:

Control Rod Guide Box (CRGB)

Control Rod Drive (CRD)

Control Rod Seal Boxes (CRSBs)

Pneumatic System Components

The Pneumatic System accelerates the CRP fall by the injection of compressed air.

5.5.3.5 Operation

The CRP movement following the FSS actuation is guided inside the core by the CRGB.

A trip order produces the following actions:

a) disconnects the electromagnets

b) opens the trip valves of the Pneumatic System

c) cuts the power supply to the motor

5.5.3.6 Instrumentation

All instruments associated with the FRPS and SRPS have triple redundancy.

Instrument	Indication
Position switch (x3)	CRP lower position
Switch	Switch on/off
Pressure switch (x3)	Pressure low
Switch	Valve open/closed
Switch	Compressed air supply enabled
Pressure switch	Low pressure
Pressure switch	High pressure

Refer to Chapter 8, Section 8.3 for further details.

5.5.3.7 Inspection and Testing

5.5.3.7.1 Manufacturing and Installation

A full scale prototype of the CRD was constructed in order to test the performance of this system regarding its shutdown function.

The tests carried out on the prototype included:

a) Life cycling tests:
The testing of the CRD Prototype was designed to take account of the trip requirements over the Reactor life. In this sense, the tests were designed to represent the trips that the Reactor is expected to have, plus a margin. In this sense, Trip tests consisted of series of Trip Cycles. Trip Cycles consisted of withdrawing the CRD from the fully inserted position up to the fully withdrawn position, then trigger a FSS trip (measuring the insertion time) and proceeding to the recovery of the system

The testing was carried out under the most demanding conditions in order to get early finding of any system weakness. With this purpose, the prototype was assembled and tested with a strong misalignment.

The performance of the different prototype components was verified (the prototype was disassembled every 100 life cycles and 100 trip cycles) and no major failures as stuck rod, sensors failures or leaks through the Seal Box occurred during the tests.

b) Measurement of CRP insertion time:

The measured insertion times in this prototype confirms the assumptions made for the CRP insertion times in the safety analysis presented in this SAR. In this regard, the test results showed an excellent prototype performance, as this reference value of 900 ms is never surpassed (in fact a huge margin to this value was obtained for the different pressures tested). It is worth noticing that the tests were carried out at compressed air pressures within the range that the facility Compressed Air System is be able to provide.

c) Assessment of behaviour under a simulated failure of the compressed air injection: Free fall tests were carried out in order to verify that the CRD Prototype drives the CRP to its bottom position upon trip request and without injection of compressed air. Although there are no insertion time requirements for this case that simulates a system failure, the insertion times were recorded to further characterise the system. There were 41 free fall cycles with the compressed air injection pressure set to 0.0 kPa. The mean free fall time obtained from the tests was 702ms whilst the maximum measured free fall time was 799ms (Table 5.5/1).

d) Tests under simulated abnormal conditions: Series of tests were carried out simulating abnormal conditions at trip time. These tests were carried out with a strong prototype misalignment.

Three abnormal conditions were simulated:

For the first condition, the average CRP insertion time was 453 ms with a standard deviation of 14 ms.

For the second condition, the CRP reached its bottom position in all cases. Although no CRP insertion time requirement applies for this case, trip times were registered for further characterisation of the system. Under these conditions the average CRP insertion time was 430 ms with standard deviation of 5 ms.

For the third condition, the CRP reached its bottom position in all the cycles of this test. Again, no CRP insertion time requirement applies for this case but the CRP insertion time was measured for further system characterisation. The average CRP insertion time was 545 ms with a standard deviation of 16 ms.

As a final conclusion, the results of the different tests carried out on the CRD Prototype show that the CRD is a very robust and reliable system when carrying out its shutdown function. The results also indicated that the CRD will perform in an appropriate manner for the range of design basis conditions. The tests results showed compliance with the CRP insertion time criterion. Results also showed successful prototype behaviour under single or simultaneous abnormal conditions, confirming the robustness of this system. The prototype did not show weak or critical parts during the tests where 40 years of reactor operation were represented.

The wide margins to the CRP insertion time criterion for the FSS and the behaviour of the prototype under abnormal conditions confirm the assumptions made in the SAR.

In addition, each CRP will be verified during its manufacturing and assembly operations. Additional details on the tests to be conducted during pre-operational and commissioning phases are given in Chapter 15.

5.5.3.7.2 In Service

The system will be regularly inspected, tested and maintained in accordance with applicable surveillance requirements and maintenance procedures in order to ensure that its operation complies with design specifications.

Details on applicable surveillance conditions are included in Chapter 17.

5.5.3.8 Design Evaluation

The FSS function is to shut down the reactor rapidly when required, and to keep it sub-critical under any foreseeable condition.

The design of the Reactor Facility FSS is based on the design of the ETRR-2 reactor FSS. The system has performed as required and without failures during the testing and commissioning of the ETRR-2 reactor.

The FSS provides the necessary means to ensure that the reactor will be brought to a sub-critical condition in the time required during any operational state, anticipated operational condition or accidental condition. Tests on a one to one scale CRD Prototype have been carried and it has been verified that the insertion time requirement is fulfilled on the prototype (See Section 5.5.3.7.1). The trip time shown in the description, based on the data collected on the testing of this prototype, is reflected in the safety analysis performed in Chapter 16.

The FSS actuation can be requested either by the FRPS or manually by the operator. The operator cannot interfere in any way with the triggering signal by the FRPS. The operator cannot interrupt the action of the FSS once it has been initiated by the FRPS or manually.

The free drop of the CRP plates is enough to provide a reactivity insertion of 2000 pcm in 0.5 s (Section 5.7.5.4). The Pneumatic System speeds up the CRP plates drop. Assessment of the adequacy of the mission time of the FSS is discussed in Chapter 16. The SRPS monitors the FSS mission time after a trip request and triggers the SSS if less than four CRPs are found inserted within the required time interval.

If the FSS is actuated, there is no component capable of preventing the CRP from falling by gravity in the case of failure of the pneumatic system (i.e. not pressurised).

Safe design and high trip reliability result from a number of features of the FSS, namely:

a) Only four of the five CRPs are necessary to shut down the reactor with the required shutdown margin, 1000 pcm (SM-1 – see 5.7).

b) The weight of the CRP and CRD pneumatic cylinder is enough to insert the CRP into the core by free fall, against the pressure exerted by the PCS flow during the most adverse conditions.

c) The pressure of the Pneumatic System can overcome the inertia forces and even the electromagnet force in case it is not disconnected.

d) CRPs are guided all the way by the CRGB guaranteeing correct performance when the actuation of the FSS is required. CRGB design ensures that it will not retain or prevent CRP plates insertion during a trip.

e) An interlock prevents startup when the Pneumatic System is not pressurised.

A FMEA has been conducted for this system. The conclusions of the analysis are summarised below:

a) Failure to drop one of the CRP.

   It includes events such as the sticking or breaking of the absorber plate, the CRP stem, alignment mismatch, Pneumatic Cylinder and Guide Cylinder.

   This failure does not represent any safety hazard, as insertion of only four of the five CRP plates is necessary to shut down the reactor safely.

   A subsequent extraction of the CRPs is prevented until all the CRPs are detected to be in their lowest position.

   Strict CRD alignment surveillance procedures will be applied after CRD installation and after maintenance operations in order to prevent the CRPs from being stuck due to alignment problems. Moreover, the preliminary design calculations show that the force exerted by the actuation of the Pneumatic System overrides forces arising from an alignment mismatch.

b) Stuck Pneumatic Cylinder.

This failure would result from events such as the failure to disconnect the power supply to the step motor or seizure of motor-transmission assembly.

In this case, the Pneumatic Cylinder will be kept in the position previous to the trip signal while the piston together with the CRP will move downwards so these events do not prevent the FSS actuation.

c) Electromagnet not switched off.

In this case, the Pneumatic System action overrides the electromagnet force and causes the CRP to drop. This fact was confirmed during the testing of the CRD Prototype. CRP insertion times were measured for this event. Insertion times were found always below the maximum acceptable value (See Section 5.5.3.7.1).

d) Loss of the Pneumatic System.

Events leading to the failure of the Pneumatic System may cause the design basis related to negative reactivity insertion upon trip request, i.e. item a) in section 5.5.3.2, not being achieved. Nevertheless, the FSS design ensures CRP insertion on reactor trip by means of inherent fail safe features. The events identified in the FMEA are:

(i) Loss of compressed air supply: De-pressurisation of the Pneumatic System: The FMEA concludes that no single failure prevents the FSS actuation and reactor shutdown.

Total failure of the FSS is considered to be unlikely. Nevertheless, the Second Shutdown System is provided as an independent and diverse way to shut down the reactor.

5.5.3.9 Seismic Evaluation

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

A detailed analysis of the CRDs has been carried out in order to evaluate their response under the action of the forces arising from the SL-2 seismic event.

The margin over the SL-2 seismic event is quite large. Since the component remains below elastic limits, the analysis for higher acceleration values can be computed by means of a linear estimation.

On the basis of stresses, the margin will be in the order of ≈28 times SL-2. On the basis of strains, and considering a maximum CRP displacement equal to 1mm, the margin will be in the order of ≈5 times SL-2. It is worth noting that both for stress and strain, the entire plastic capacity to absorb energy still remains over the given margins.

The welding of the upper and lower frame was also studied and it was found that these weldings are adequate to withstand a SL-2 event.

5.5.4 Second Shutdown System

5.5.4.1 Introduction

The Second Shutdown System (SSS) is capable of rapidly and automatically shutting down the reactor by partially dumping the heavy water stored in the Reflector Vessel. This system provides an alternate, completely independent means for reactor shut down.

5.5.4.2 Design Bases

The SSS fulfils the following design bases:

a) Provide a backup, inherently safe, diverse and independent way to shut down the reactor from all operating states and accident conditions, and subsequently to maintain the shutdown condition.

b) Be physically separated, to the extent practically feasible, from the FSS and be arranged so that credible events causing damage to the reactor region where the FSS is located have a minimum prospect for compromising the functional capability of the SSS.

c) Provide the way to dump the necessary quantity of heavy water to shutdown the reactor with the required insertion of reactivity of 3000 pcm in no more than 15 s and stop any CRP withdrawal when triggered by the SRPS.

d) The dumping of heavy water must be such that the shutdown margin introduced without limit of time is more than 1000 pcm.

e) Comply with the single failure criterion.

f) Be able to be actuated either automatically by the SRPS or manually from the Main Control Room or Emergency Control Centre.

g) Permit demonstration of its functional performance requirements.

h) Withstand natural environmental disturbances such as earthquakes.

i) Not produce an inherent trip in the case of loss of normal power.

e) The system components will comply with the requirements specified for Safety Category 1, Seismic Category 1 and Quality Category A components.

5.5.4.3 Codes and Standards

The following codes and standards were applied for the design of the components of the SSS:

ASME Rules for the Construction of Pressure Vessels.

ASME Pressure Piping Code.

Piping material classification is provided in Chapter 6.

5.5.4.3.1 Equipment Qualification

The dumping of Reflector Vessel heavy water as a means for shutting down the reactor has been successfully used in different reactors, including Nuclear Power Plants (NPP). Examples are early Canadian heavy water NPPs and INVAP’s RA-8 Critical Facility.

5.5.4.3.1.1 Second Shutdown System Mock Up

A mock up of the SSS in 1:1 scale has been constructed based on the actual design to be employed in the Reactor Facility. The main objective of the mock up is to measure the dumping time for the SSS including studying the Triggering Valves opening time.

The mock up system consists of the following components:

Reflector Vessel mock up

Support structure

Expansion Tank mock up

Trigger valves

Storage tank

Pipelines

Results of water height in the Reflector Vessel as a function of time were obtained from drainage of water experiments performed with the SSS mock up (See Figure 5.5/12). These results were used to evaluate the reactivity inserted by the SSS as function of time, which is detailed in Section 5.7.

5.5.4.3.2 Manufacturing and Installation

The quality control specifications and procedures followed the general pattern established for high quality and international best practice.

Quality control of welding, heat treatment, dimensional tolerances, material verification and similar factors have been maintained throughout the manufacturing process to assure reliable performance of the mechanical components of the system.

Criteria for acceptance after installation of the SSS have been incorporated in specifications and test procedures covering the pre-operational phase and the commissioning phase.

Additional details on the tests to be conducted during pre-operational and commissioning phases are given in Chapter 15.

5.5.4.3.3 In Service

The system will be regularly inspected, tested and maintained in accordance with applicable surveillance requirements and maintenance procedures in order to ensure that it is able to operate in accordance with its design specifications.

The Triggering Valves will be cycled once per normal shutdown and the system actuated once per year or major shutdown, whichever is appropriate.

5.5.4.4 Design Evaluation

The SSS has been designed employing extensively used codes such as the CHEMCAD 5.0.01 Chemstations Inc. software that was used to perform system mass and energy balance. CRANE Companion 2.50 ABZ Inc. was used for single pipe calculations.

Large safety margins have been employed to ensure boundary integrity of the system regarding design pressure, corrosion, heavy water quality and seismic hazard.

The SSS is triggered by the SRPS that has its own set of triggering sensors, thus allowing the triggering of the SSS independently from the FSS. Trigger signals for SSS (from the SRPS) provide diversity from signals that trigger the FSS, except for the cases of core pressure drop and seismic activity. Trigger signals for the SSS are further discussed in Chapter 8, Section 8.2.

The RCPS cannot prevent SSS actuation. Once the SSS has been triggered no RCPS component can interfere with the vessel partial dumping process.

The SSS circuit does not share any pipeline with the RCPS circuit assuring that no dumped heavy water can be pumped back to the Reflector Vessel once the SSS has been triggered. Heavy water is prevented from being pumped back into the Reflector Vessel by an inhibition imposed by the SRPS on the heavy water make up pumps.

A FMEA has been conducted for this system. The analysis concluded that the SSS is an independent and diverse means of achieving reactor shutdown when required by the SRPS own signals or in the event of the failure of the FSS. (As such it will be required to operate if more than one of the CRP plates within the FSS has not dropped into the core when required to do so by the FRPS).

5.5.4.5 Seismic Evaluation

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

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

a) The acceleration spectra for the building positions where systems are fixed

b) Consideration of the fixing characteristics

c) Consideration of the mass of water contained within the system

d) Stress evaluation in piping, components and fixing points

This seismic analysis is part of the stress analysis performed for Reflector Cooling and Purification System (RCPS), thus the details of the analysis are presented in Chapter 6, Section 6.6.10, (results for the model of the Storage Tank to Reactor Pool section).

The seismic evaluation for the RCPS included the pipelines of the SSS outside the Reactor Pool including main component interactions (pipes, valves, vessels, fittings). Different load cases were considered.

The analysis was performed using CAESAR II 4.30 program for the analysis of stress on pipelines. The summary of results shows that the stress on the pipelines of the SSS for the different load cases does not exceed the limits set by the applicable codes (see Chapter 6, Section 6.6.10).

5.5.5 Information for Combined Performance of Shutdown Systems

5.5.5.1 Vulnerability to Common Mode Failures

FSS and SSS are located such that they are protected from common mode failures due to missiles, failures of moderate energy piping (no high-energy piping is included in the design of the Reactor Facility), and fire. Protection of the essential systems against missiles, pipe breaks, seismic and fire is discussed in Chapter 4.

FSS and SSS operation principles are different, and the systems provide two diverse ways to shut down the reactor.

Both systems have fail safe configurations.

In addition there are two RPS with their own set of trigger signals, the FRPS commanding the FSS, and the SRPS commanding the SSS and FSS. Each RPS system is based on a different technology. For further descriptions of the RPS systems refer to Chapter 8, Section 8.2.

The features above mentioned ensure independence between FSS and SSS.

5.5.5.2 Accidents Taking Credit for Both Shutdown Systems

Functioning of either of the shutdown systems alone is sufficient to shut down the reactor. All the design basis accidents dealt with in the SAR consider either the sole actuation of the FSS, or actuation of the SSS. A trip order from the SRPS includes the triggering of the FSS in addition to the SSS in order to prevent further CRP extraction but no credit to the action of the FSS is given in the analysis for this case. The SSS is capable of coping with any design basis accident sequence that involves failure of the FSS.

End of Section

Table 5.5/1 CRD Prototype Testing – Summary of Trip Test Results

Pressure	Number of Test Cycles	Mean Trip Time (*)	Standard Deviation	Maximum Measured Trip Time (*)
[bar]	[#]	[ms]	[ms]	[ms]
0.0	47	702	38	799
1.0 (+)	10	432	2	436
1.0 (+) misalignment < 0.5 mm	10	369	13	382
1.3	278	434	22	503
1.5	238	422	18	493
2.0	13	391	24	423
2.0 misalignment < 0.5 mm	10	340	9	349
2.5	4	392	15	411

NOTES:

All results correspond for misalignment of ~1 mm and pressure of 1.2 bar on the seal assembly except where indicated.

(*) Times indicated as measured (no corrections made).

(+) Tests carried out for pressure of 4.0 bar on the seal assembly.

End of Tables

Figure 5.5/1 View of the Control Rods

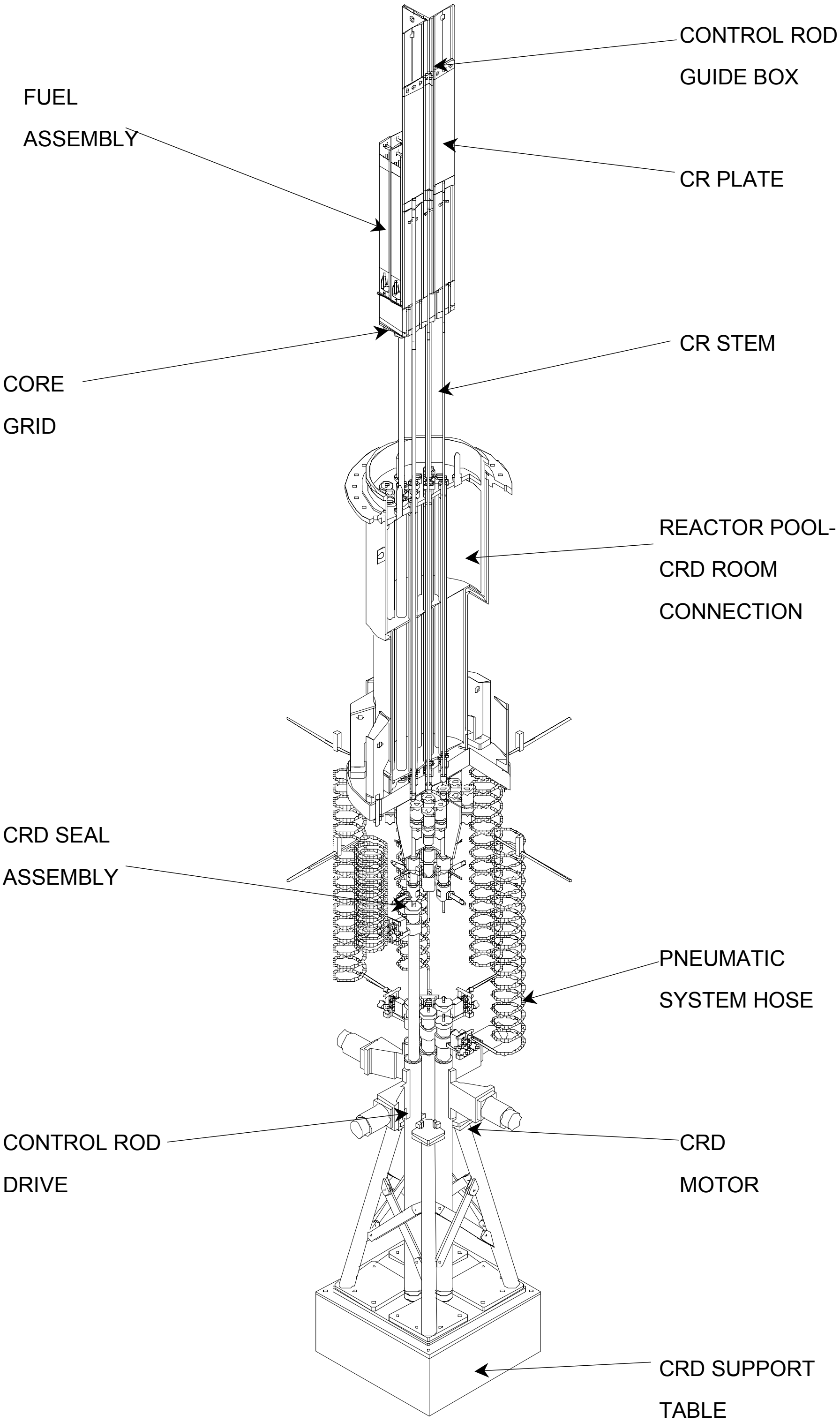


Figure 5.5/7 CRD Prototype Testing – Dependence of Mean and Maximum Measured CRP insertion Times with the Compressed Air Pressure

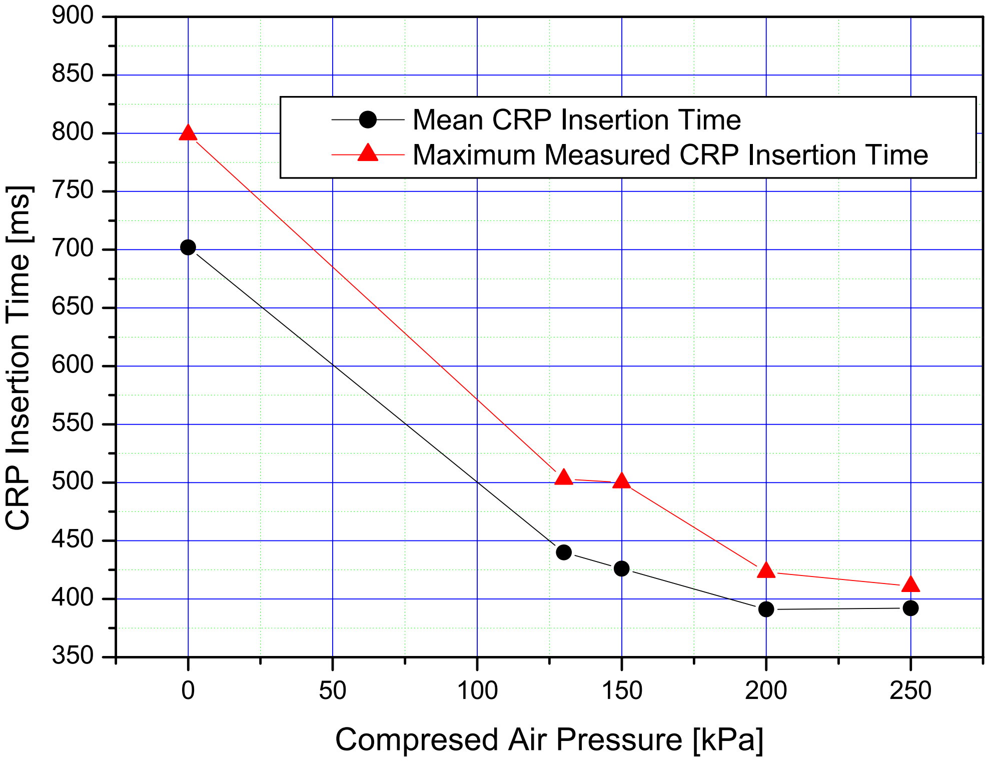


Figure 5.5/10 Second Shutdown System Mock Up

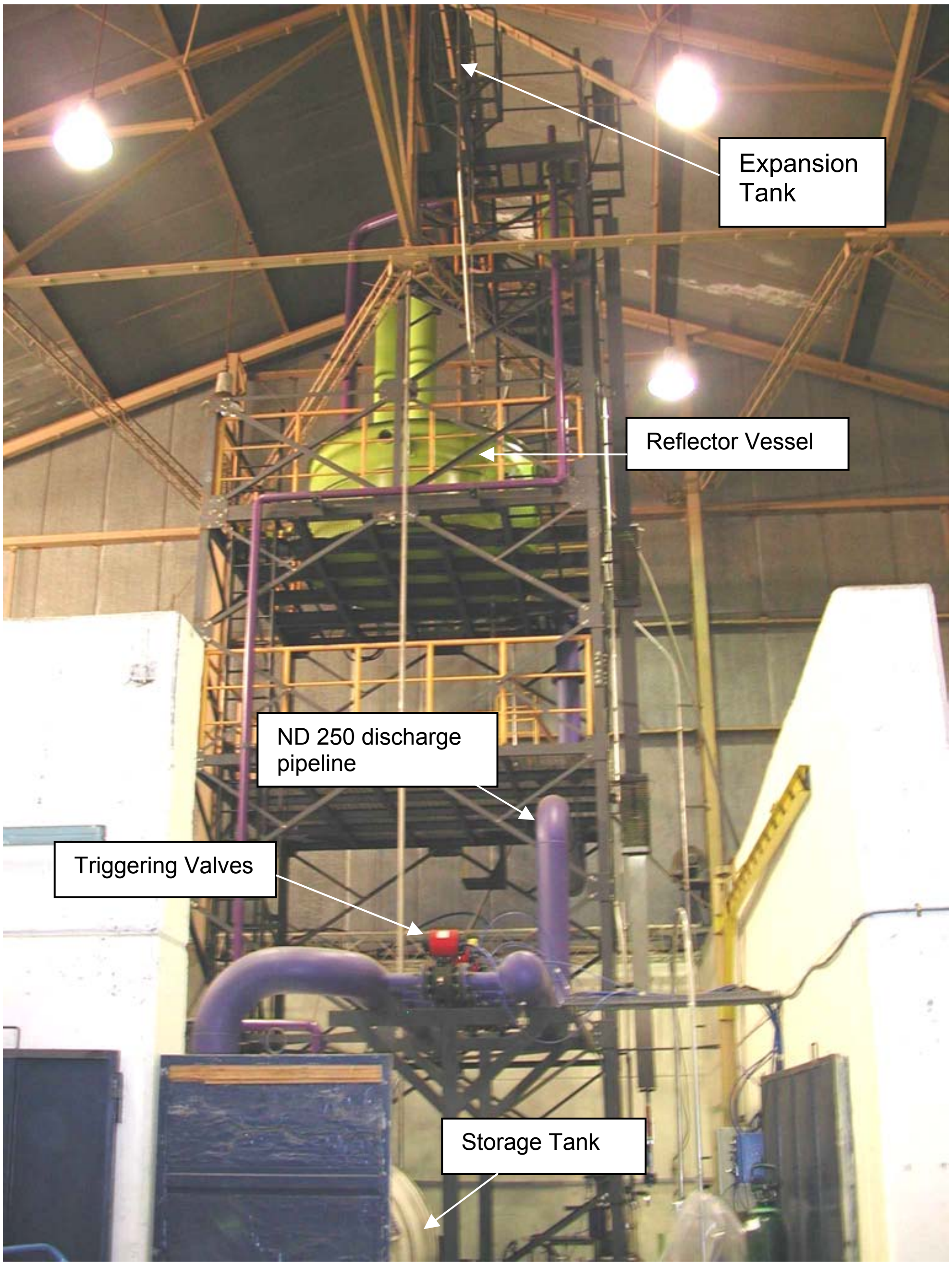
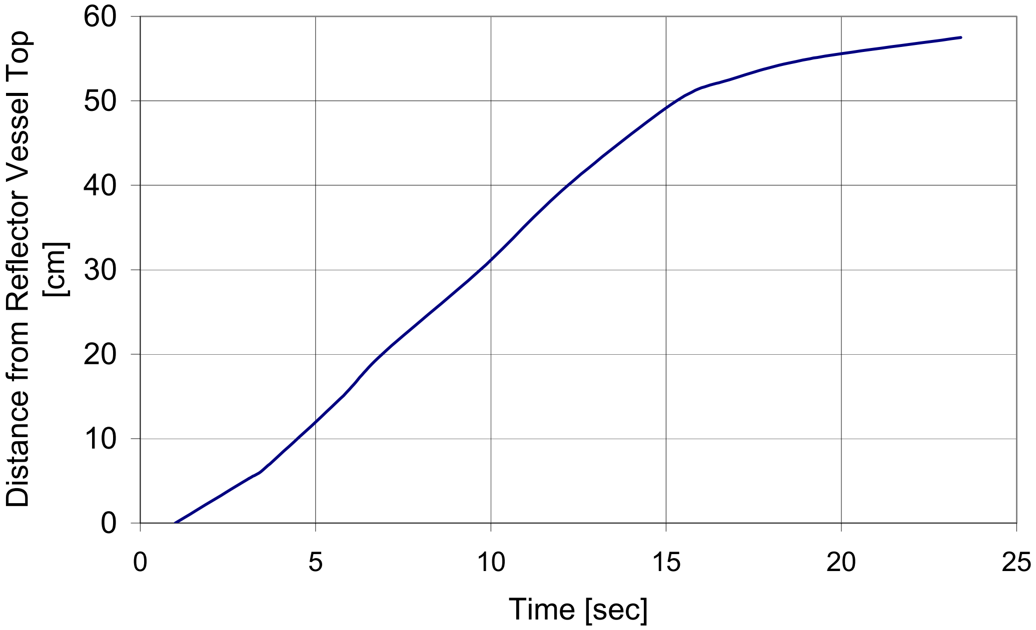


Figure 5.5/12 **SSS Mock Up – Measured Reflector Vessel Water Height as Function of Time**



End of Figures

5.6 NEUTRON MODERATOR AND REFLECTOR

5.6.1 Neutron Moderator

The Reactor Facility design uses demineralised light water as neutron moderator and coolant. The neutron moderator slows down the fission neutrons. The resulting low energy neutrons (thermal neutrons) produce most of the fissions in the uranium.

Main data for the neutron moderator is given below.

Parameter		Value	
Moderator material		Light Water	
Moderator density [g/cm^3]	Operation	Pumps: On	0.992
	Shut down	Pumps: Off	0.998
		Pumps: On	0.998
Composition of moderator, elements and weight %		H 11.191 w% O 88.809 w%	
Moderator quality		Conductivity < 1 μS.cm^{-1}	
pH		Neutral	

5.6.2 Neutron Reflector

Heavy water is used as the neutron reflector in the Reactor Facility. The neutron reflector scatters neutrons leaving the core. Neutron reflectors are materials with low neutron absorption cross-section, but with high neutron scattering cross-section.

Heavy water is contained in the Reflector Vessel (Section 5.2) that provides the required water leak tightness.

The reflector is cooled by the RCPS. A description of the RCPS and events leading to reflector degradation are presented in Chapter 6. The increase of the reflector effect resulting from an inadvertent refilling of the reflector tank is considered in Chapter 16, Section 16.8.5. The slow rate of refilling eliminates this event from being a design basis Postulated Initiating Event. Loss of heavy water is considered in Chapter 16, Section 16.12. It is shown that no tritiated water will be released to the atmosphere and that exposure of the operators to tritiated water or water vapour can be avoided.

Main data for the neutron reflector is given below:

Parameter	Value
Reflector material	Heavy Water (D_2O)
Reflector density [g cm^{-3}]	Density 1.095
Reflector composition, elements and weight %	H 0.01007 w% D 20.09957 w% O 79.89036 w%

Parameter	Value
Reflector isotopic purity (Heavy water content)	
Fresh	99.90%
Minimum Allowed	99.75%
Reflector quality	Conductivity < 1 μS.cm^{-1}
pH	Neutral

End of Section