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# AUSTRALIAN RRRP FIRST SHUTDOWN SYSTEM SEISMIC QUALIFICATION

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## ABSTRACT

This paper presents the seismic qualification methodology used for the First Shutdown System of the Australian Replacement Research Reactor. The seismic qualification was carried out by means of analysis and testing. The analysis was developed in a first step in order to compute stresses and displacements on the mechanisms. In a second step testing was adopted as qualification method with the development of an experimental setup. The test objective was to demonstrate the effectiveness of the shutdown system under the seismic action imposed by the most demanding seismic event condition used for the design of the reactor. The key parameter measured during the test was the control plate insertion time, which is the relevant parameter from the nuclear safety standpoint. The seismic analysis showed that no undue stresses or displacements will be present on the mechanisms for the most demanding seismic condition. Consistently, the test results were that the system is able to insert the control plates within the required time. It was observed that there is no noticeable difference on the control plate insertion times for the cases with or without the presence of the seismic action.

**Keywords:** seismic analysis, seismic qualification, prototyping, experimental setup design.

## 1. INTRODUCTION

The Replacement Research Reactor (RRR) Project is a 20 MW multi-purpose nuclear research reactor designed and constructed by INVAP from Argentina, for the Australian Nuclear Science and Technology Organisation (ANSTO), the reactor is being constructed at a location near Sydney. The reactor objectives are to provide radioisotopes and extensive neutron beam research capabilities.

The reactor is open pool type and has two shutdown systems. One of them, the First Shutdown System (FSS), is a Control Rod based system made up of five similar mechanisms. Each mechanism has in turn: a Control Rod Drive (CRD), a Control Rod (CR) that includes the absorbing plates that are, a Seal Assembly, a Control Rod Guide Box (CRGB) and a line of bushings to guide the rod. The CRDs are located below the reactor core and thus the CRs penetrate the reactor pool from below “Fig.1”.

 

It is worth noticing that seismic events constitute one of the main sources for common cause failure of systems. Therefore, it is an issue requiring an important effort for the assurance of the acceptability of the different systems carrying out safety functions to demonstrate that they will be able to fulfill their safety functions under the postulated seismic event. Particularly, the shutdown safety function of the RRR includes a requirement of inserting a given negative reactivity rate that shall be accomplished at least by one of the shutdown systems for all the anticipated operational occurrences and postulated accidents, including seismic events, identified in the Safety Analysis Report. This safety function is implemented in the RRR through the FSS and the negative reactivity rate requirement translates in a requirement on the CR insertion time, i.e. the time to reach the fully inserted position starting from the fully withdrawn position, should be less than 900 ms. In the FSS, the shutdown action is carried out by injecting compressed air into the CRDs in order to accelerate the insertion of the CRs. In case the compressed air is not present, the system is designed to ensure the CR insertion under the action of gravity.

This paper presents in section 2 the approach used for the seismic qualification of the FSS. In section 3 details of the seismic analysis, including modeling and analysis results are discussed. Section 4 regards on the tests carried out to verify the behavior of the system under a seismic action including details on the design of the experimental facility used for the testing, the simulation of the seismic action and the results of the tests. Finally, in section 5 the conclusions of the qualification.

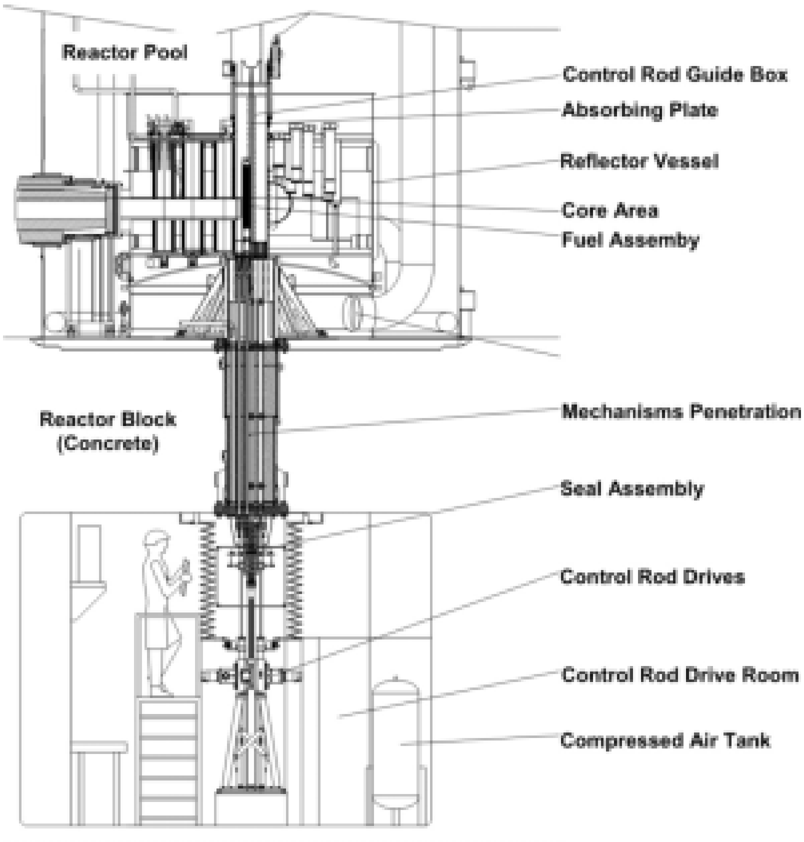


*Figure 1: First Shutdown System Layout*

## 2. SEISMIC QUALIFICATION APPROACH

The seismic qualification was carried out by means of analysis and testing.

The analysis was developed in a first step in order to compute stresses and displacements on the structure (CRD with its supporting structure and Control Rod, including absorbing plates). Structural and seismic analyses were conducted during the preliminary and detailed engineering of the system as part of the design process. Information from the seismic analyses was fed-back into the engineering through verification on the stresses not surpassing the applicable code and standards requirements and through modifications on the structural design of the system in order to improve safety margins.

In a second step testing was adopted as qualification method with the development of an experimental setup. The objective of the test was to demonstrate the effectiveness of the shutdown system under the seismic action imposed by the most demanding seismic event condition used for the design of the reactor, namely, the SL-2 or

Safe Shutdown Earthquake. The SL-2 level was adopted from a seismological analysis of the regional and site area. The experimental setup components are designed on a one to one scale to simulate the components that are part or that interact with the Kinematic Chain, i.e. the moving components of the FSS that are the CRs and the CRDs, of the First Shutdown System of the RRR. In order to reproduce the same dynamic behavior between the setup and the real component, some analogies were computed taking into account material properties and geometry (e.g. Control Rod). The simulated seismic action is such that it exceeds the corresponding SL-2 response spectra for the building level where the system is located. The key parameter measured during the test is the control rod insertion time, which is the relevant parameter from the nuclear safety standpoint.

The seismic qualification (analysis and testing) was complementary of other functionality tests focused on the reliability of the First Shutdown System under several control rod insertion scenarios, including operational and simulated failure situations.

## 3. SEISMIC ANALYSIS

The seismic analysis was carried out in step in order to compute natural frequencies, stresses and displacements on the different structures:

- Control Rod (including Absorbing Plates)
- Control Rod Guide Box
- Control Rod Drive

In this section, details of the seismic analysis, including modeling and analysis results are explained.

### 3.1 Modeling

**Control Rod:**

The Control Rod comprises a round bar of a 16.2 mm diameter made of Zircalloy, and the absorbing plates, which are Hafnium made rectangular plates (128 mm x 700 mm) of 6-mm-thickness. Each absorbing plate include a Zircalloy frame that allows smooth absorbing plate sliding in the CRGB in order to prevent Hafnium wearing and provide structural support as well. The round bar is welded to the absorbing plate frame on its upper end and screwed to the CRD on its lower end. A view of one absorbing plate is shown in “Fig.2”.

Mass contributions of different components are summarized below:

| | |
|---|---|
| Control Rod round bar: | 5.9 kg |
| Absorbing plate (each one): | 7 kg |

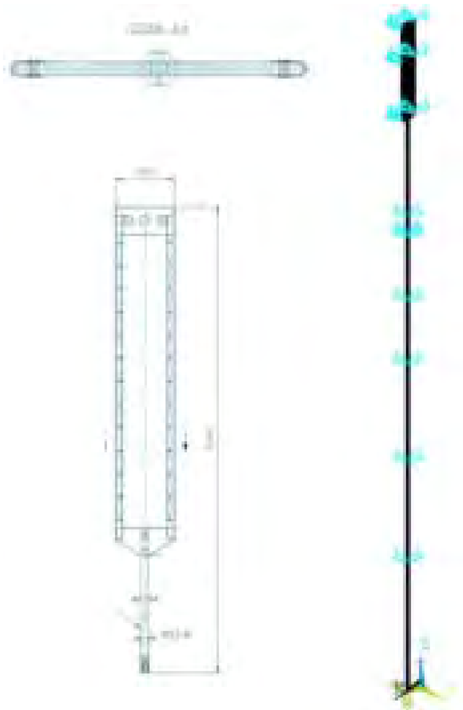

*Figure 2: Control Rod: general assembly (left) and FEA model (right). Units in mm.*

 

The CR has its lower end attached to the CRD and its upper end restrained by the CRGB guiding slots. On the other hand, the CR has some intermediate supports at the bushings and the Core Grid. The Core Grid is firmly joined to the CSS (Core Supporting Structure), which is in turns rigidly attached to the bottom plate of the Reactor Pool and laterally guided by the RVE at the Core Grid level.

Considering above kinematic relationships and in order to account for the dynamical amplification that eventually could take place between the level 0.00 and the Core Grid the acceleration spectra is evaluated including the flexibility of both: the CSS + RVE.

The CR was classified as a Seismic Category 1 component, and as such it must withstand the accelerations corresponding to the 0.37g Peak Ground Acceleration (safe shutdown earthquake), which are the maximum accelerations defined for the reactor.

Model constraints (See "Fig. 2"):

a) All degrees of freedom are restricted (fixed) at the CR lower end.
b) The CR and the Seal Box Structure are coupled (made them to act as one body) at the Seal Box level.
c) The Seal Box Structure is clamped to the Roof of Control Rod Drive Room.
d) Horizontal displacements (Ux & Uy) are prevented at the bushings assembled to the Mechanisms Penetration Assembly (3 bushings) and CSS (1 bushing).
e) Horizontal displacements are also prevented at the middle of the lower core grid and at the upper and lower surfaces of the upper core grid.
f) In order to conservatively simulate the restriction of the CRP inside the CGB, horizontal displacements in just three points (lying on each edge) are prevented: The ends of the lateral guides and the points (one per side) where the CGB is joined to the Chimney.

### Control Rod Guide Box

The CRGB is a 1600-mm high component made of Zircalloy. The CRGB has five channels that house the absorbing plates. The CRGB function is to guide the absorbing plates when moving up and down in the reactor core area. It weights 68 kg. Figure 3 shows the CRGB FEA model used to gather natural frequencies, stresses and displacements due to seismic event.

*Figure 3: CRGB assembly cross section and FEA model. Units in mm.*

### Control Rod Drive

The CRD is a component made up by a series of concentric tubes with relative movement among them. This relative movement is guided by contact points between the tubes. In view of the different relative positions of the tubes and the different positions of the contact points, it becomes necessary to understand the entire behaviour. Therefore, finite element models were developed, including all the components to gather the local dynamic features of each Drive "Fig.4".

On the other hand, the set of five mechanisms was modelled to verify global behaviour.

Each control Rod drive has a mass of 63 kg.

The CRDs required to be qualified to support the action of an SL-2.

 

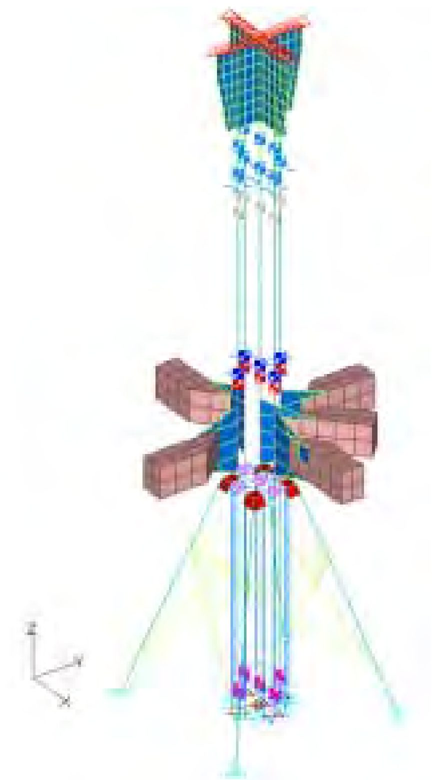

*Figure 4: CRD Assembly 3D FEM model*

## 3.2 Analysis Results

### Control Rod and Absorbing Plates

The Control Rod was analyzed laterally supported by the bushing at the Mechanism Penetration, Core Supporting Structure, Core Grid and Guide Box. Figure 5 shows the results of the analysis.

The first horizontal mode of the CR is in the order of 50 Hz, i.e. beyond the cut-off frequency, thus this component can be considered as a rigid body for the practical effects of the seismic analysis.

The action of SL-2 seismic event generates low stresses being the minimum safety margin in the order of 37.

The maximum horizontal rod displacement due to the action of SL-2 seismic event is 0.038 mm. This displacement value results adequate taking into account the real gap of the CR (12.35 mm).

Buckling safety was verified for the condition when the CR is stopped by the shock absorber, located inside the CRD, after the FSS actuation. The theoretical buckling force was found 17.5 times the maximum compressive force on the CR resulting from the FSS actuation.

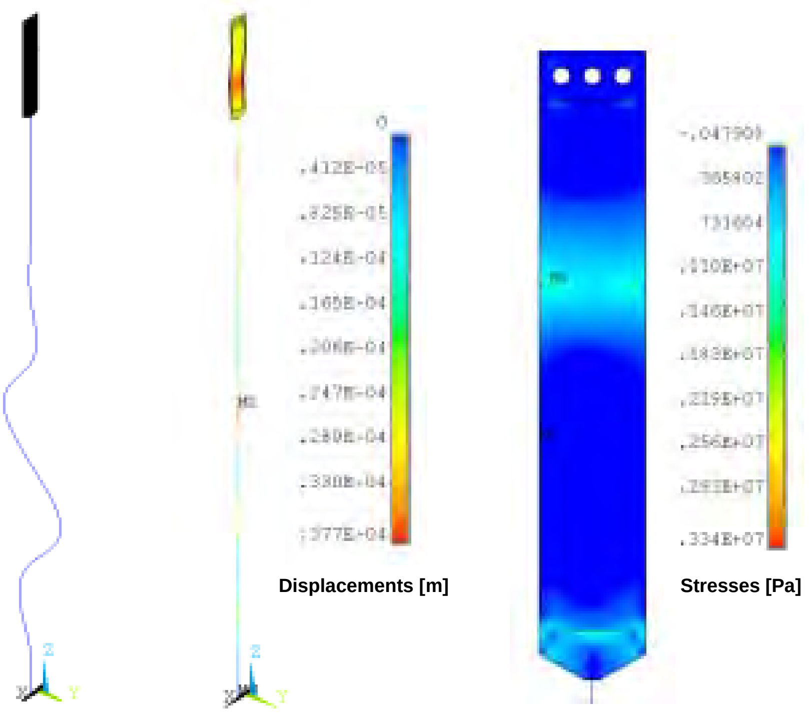


*Figure 5 - CR FEA results under postulated seismic event: First Vibration Mode, 50 Hz (left), displacements (center) and detail of the stresses on the absorbing plate (right).*

### Control Rod Guide Box

The Guide Box was found, according to the analysis, sufficiently rigid to withstand stresses and displacements. Its first natural frequency is 34.8 Hz. Figure 6 shows the corresponding displacements. The stresses and displacements of this component are well below the allowable limits. Therefore, the seismic event is not the critical load case for the CRGB. Maximum stresses are 22.5 MPa, being the safety margin (i.e. the relationship between SL-2 seismic event stresses and allowable stresses) is 8.

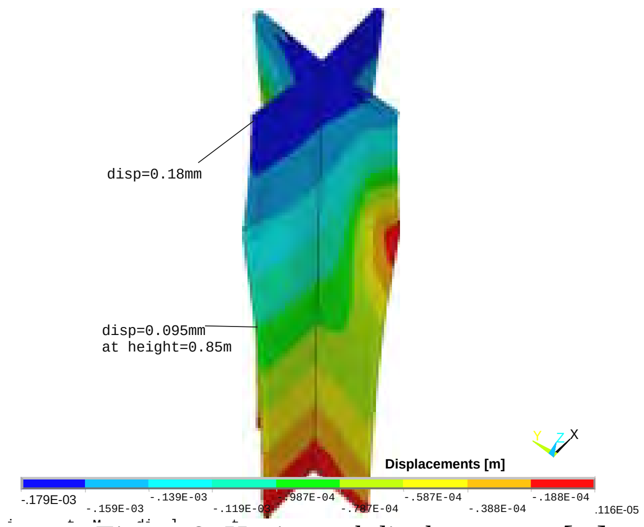


*Figure 6: Horizontal displacements [m]*

### Control Rod Drive

Since the CRD is an active component that is required to operate during a SL-2 seismic event, it is designed on the basis of serviceability conditions (limits are based on stiffness) rather than on strength conditions (limits based on stresses). This design assumption was confirmed by the very low stresses and displacements registered.

CRD natural mode shapes are all over the cut-off frequency. The first lateral mode is of the order of 45 Hz, according to the FEA model calculations “Fig.7”.

The maximum stresses on the CRD during the SL-2 event are of the order of 3% Yield Strength. This low stress level guarantees elastic behavior. The maximum absolute horizontal displacement of the CRD is 0.19mm. The maximum relative horizontal displacement between the CR round bar and the CRD is 0.11mm.

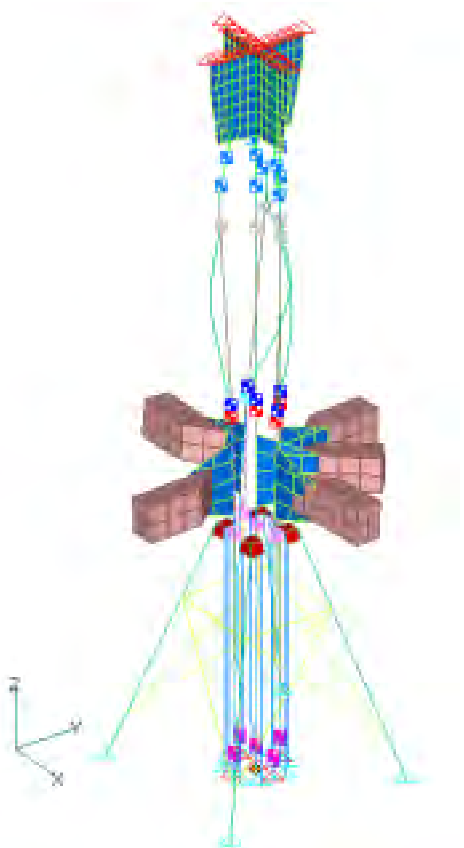

*Figure 7: CRD Assembly: First natural frequency - 46.4 Hz.*

## 4. SEISMIC TESTING

### 4.1 Experimental Setup

The setup for the seismic qualification tests of the FSS represented the mechanical conditions where the FSS will be placed in the RRR “Fig.1”. This section describes the experimental setup used in the qualification tests.

The experimental setup components were designed on a one to one scale to simulate the components that are part or that interact with the Kinematic Chain (KC) of the FSS in the RRR. The main parameters observed for the design of the setup components were geometry, constructive tolerances, natural frequencies, damping levels, presence of liquids, masses, energies acting on the system, and friction between surfaces. The design of the experimental setup kept those parameters as close as possible to the ones to be present in the RRR or, when not possible, a conservative choice was made for the design to represent a more demanding condition.

The setup comprised a carbon steel truss structure where the KC and the components interacting with it are affixed “Fig.8”. The structure was designed with wheels to allow horizontal movements. The stiffness of the truss structure was designed to vary with height in order to take account of the different stiffness characteristics at different levels in the RRR “Fig.9”. The system represented, i.e. the CRDs plus the CRs and the components interacting with them, required a setup of about 8 meters height. The whole moving assembly of the experimental setup weighted 420 kg.

The main components of the setup were then those that simulate the KC and its boundary conditions. A description of the KC components of the RRR and how they were represented in the experimental setup follows.

Control Rod Drive: This is the heaviest components of the KC. The CRDs are mounted in a dedicated room located below the Reactor Pool. A CRD prototype was used in the setup. The CRD prototype used for the testing is identical to those CRDs to be used in the RRR. The CRD prototype was affixed to the experimental setup structure simulating the structural conditions of the RRR CRDs and allowed rotating 90 degrees the CRD prototype to allow testing in the two CRD prototype main directions “Fig.10”. CRD prototype control was conducted by a dedicated programmable logic control device plus software interface for operation. CR insertion time measurement was implemented through the controlling system and had a measurement uncertainty of 50 ms due to the characteristics of the measurement chain. As well, the CRD prototype included manometers that allowed measuring the pressure of the compressed air injection.

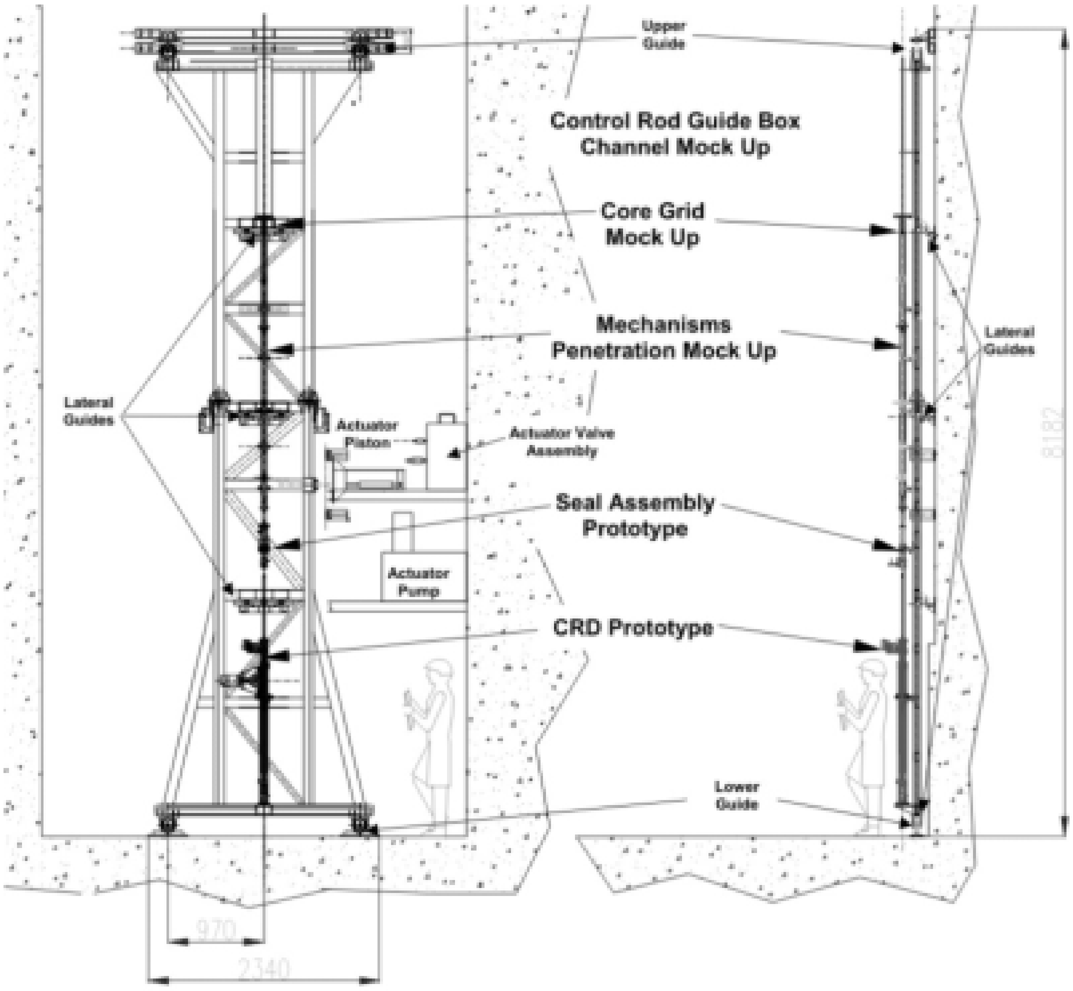


*Figure 8: Experimental Setup Front and Lateral View*

Seal Box Assembly: This is a stainless steel piece containing seals that separate the water-flooded area from the room where the CRDs are placed. The setup included a prototype of the Seal Box Assembly identical to those to be used in the Reactor Facility “Fig.10” and that allowed flooding with water all the setup components above the level of the Seal Box Assembly Prototype.

Mechanism Penetration: In the reactor, this is a massive component that includes stainless steel tubes flooded with water from the Reactor Pool. Its function is to support the bushings that guide the CRs in the area between the CRD Room and the Reactor Pool. The setup included a mockup of the penetration including the bushings. The mockup was filled with water. The penetration tube and bushings have the same geometrical dimensions and tolerances.

 

*Figure 9: Experimental Setup Truss Structure.*

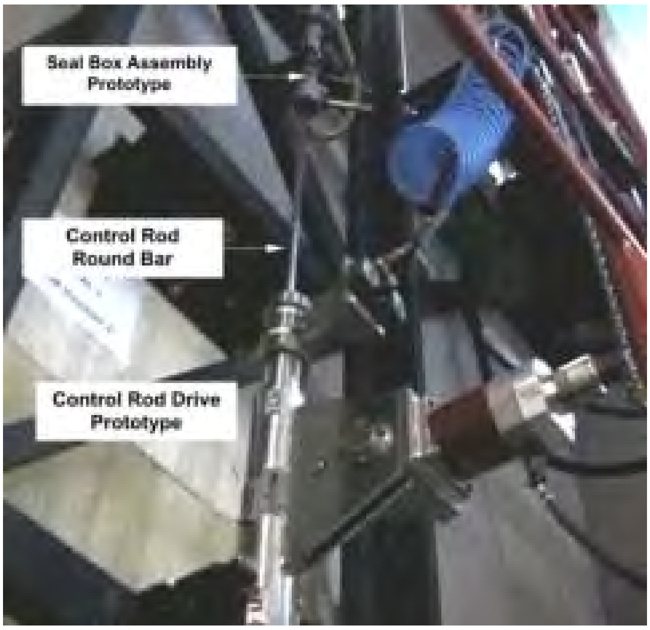


*Figure 10: Control Rod Drive Prototype (Configuration 2) and Seal Box Assembly Prototype.*

Core Grid: This is a massive Aluminium component located beneath the reactor core. The core grid defines the reactor core geometrical layout, its reference plane and provides structural support for the fuel assemblies and the CRGB. The core grid has orifices allowing the coolant to flow. It also allows the CR to penetrate and move freely. The setup included a mockup of one core grid penetration made of Aluminium. This penetration mockup was physically included in the CRGB mockup.

Control Rod: In the reactor, the CR is comprised by a round bar and an absorbing plate as described above. In the setup, a stainless steel tube filled with an ad-hoc made substance was used in such a way that, this filled tube had the same stiffness and mass of the Zircalloy rod. The rod was built using the same dimensions and tolerances as the one to be used in the RRR. In the setup, a mockup of a absorbing plate made of Aluminium was used. The frame for the absorbing plate mock up was made of carbon steel and had the same geometrical dimensions and tolerances of that to be used in the RRR. In this case, it should be noticed that the friction coefficients for Steel-Aluminium are higher that for Zircalloy-Zircalloy, thus the case simulated in the setup constitutes more demanding approach as the frictional forces were higher. The bulk of the absorbing plate mockup was made of Aluminium slides that were engineered to have the same stiffness of the Hafnium absorbing plates but weighted less. This reduction in the absorbing plate mockup weight took account of the upward forces acting on the absorbing plates of the RRR due to the coolant drag force.

Control Rod Guide Box: As described above, this is a Zircalloy structure to be located in the RRR core area. A mockup of one of the lateral channels of the CRGB made of Aluminium was used in the experimental setup as shown in “Fig.12”. The mockup had the same geometrical dimensions and tolerances than the CRGB of the RRR. The CRGB channel mockup was flooded with water. The CRGB channel mockup was able of being rotated 90º in order to allow testing of the KC in the two absorbing plate main directions.

A hydraulic actuator was used to input the simulated seismic action to the experimental setup. The actuator comprised a pump, a valve assembly and a piston. The piston was placed and connected to the truss structure near the gravity centre of the whole experimental setup (i.e. truss structure plus the KC). The piston moved the truss structure left and right when fluid at high pressure is delivered by the pump through the valve assembly. The valve assembly included an actuated valve that allows controlling the movement of the piston. The actuator was controlled by a dedicated electronic system plus a software interface.

The experimental setup was designed to allow rotating 90º the non-symmetric components in order to allow the testing of the KC in these two directions. The non-symmetric components of the KC are the CRGB mockup and the CRD Prototype (because of the CRD motor) “Fig.11”. Thus the experimental setup was tested for two configurations of the KC namely: Configuration 1, where the CRD motor and CRGB longer side was parallel to the direction of the movement “Fig.12” and Configuration 2, where the CRD motor and CRGB longer side was normal to the direction of the movement “Fig.13”.

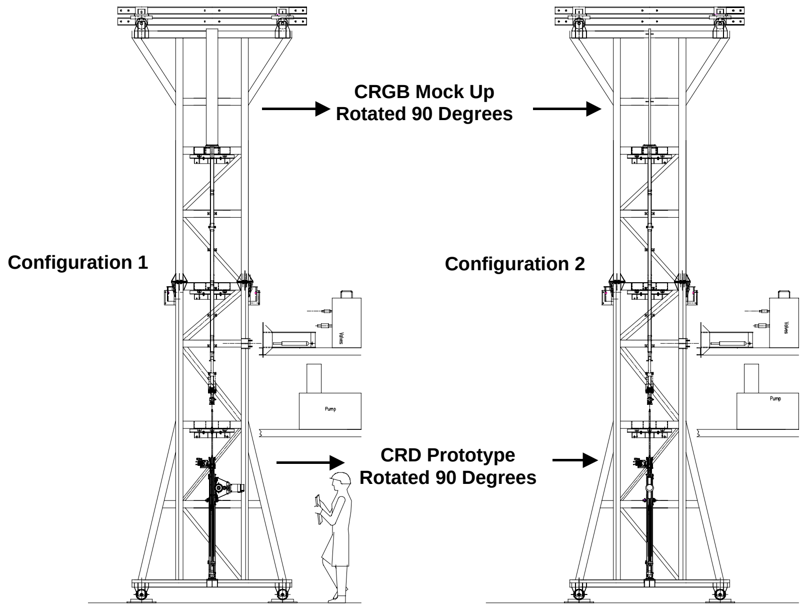


*Figure 11: Scheme of experimental setup configurations 1 and 2.*

An important parameter of the experimental setup is its natural frequency. This parameter was measured by using the impact method. The measured natural frequency of the setup was 13 Hz. This measured natural frequency was lower than the expected real structure frequency in the reactor, but well inside the range of frequencies exited by the simulated seismic actions. As the calculated frequency of the supporting structure lies in a lower acceleration zone of the required spectrum, the tests are conservative.

 

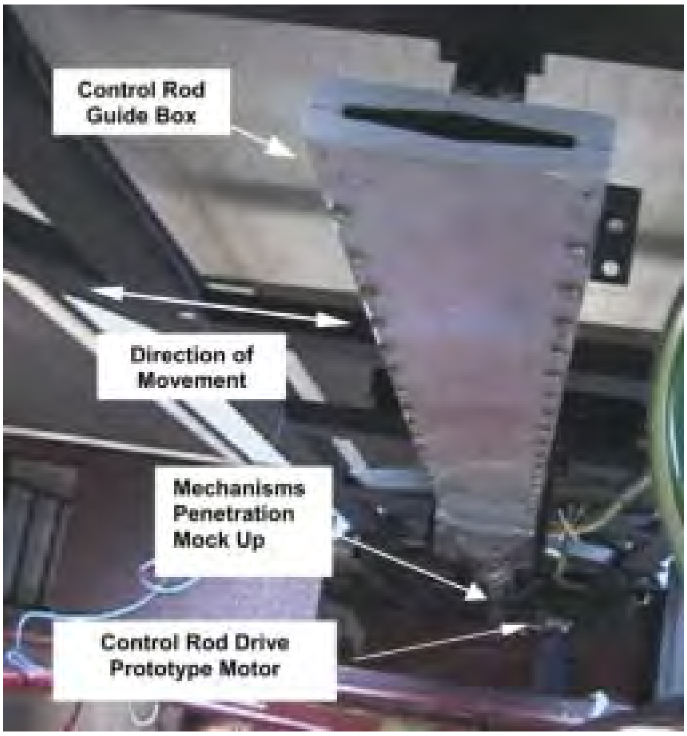


*Figure 12: Pictures of CRD prototype and CRGB mock up mounted as per configuration 1*


*Figure 13: Pictures of CRD prototype and CRGB mock up mounted as per configuration 2*

## 4.2 Simulation of the Seismic Action

Reactor Building Horizontal SSE Design Floor Spectrum for Level +0.0 m (5 % of critical damping) curve was used to generate the reference spectrum. The reference spectrum used for this test was built quadratically combining both horizontal spectra and adding a 1.15 test factor. This reference spectrum was taken as the required spectrum for generating the simulated seismic action.

As indicated in the preceding section, a hydraulic actuator input the simulated seismic action to the experimental setup by moving the reticular structure. The hydraulic actuator input a signal that repeats periodically.

The simulated seismic action carried different frequencies and amplitudes in such a way that its corresponding response spectrum covered the reference spectrum from frequencies lower than the experimental setup natural frequency.

 

Two different signals were used to simulate the seismic action (simulated seismic actions 1 and 2). Both of them cover the reference spectrum from frequencies lower than the natural frequency of the experimental setup and beyond. At lower frequencies the corresponding response spectra cover the reference spectra on different ranges. Figure 14 show typical time histories of the accelerations that correspond to the simulated seismic inputs used for this test (i.e. the simulated seismic actions).

Figure 15 shows the response spectrum calculated for the two simulated seismic actions and the enveloping response spectrum resulting from both signals and are compared with the reference spectrum for this test (described above). It can be seen that the envelope spectrum covers the reference spectra from 5 Hz and beyond and that for the natural frequency of the experimental setup the enveloping response spectrum surpasses 1.9 times the reference spectrum.

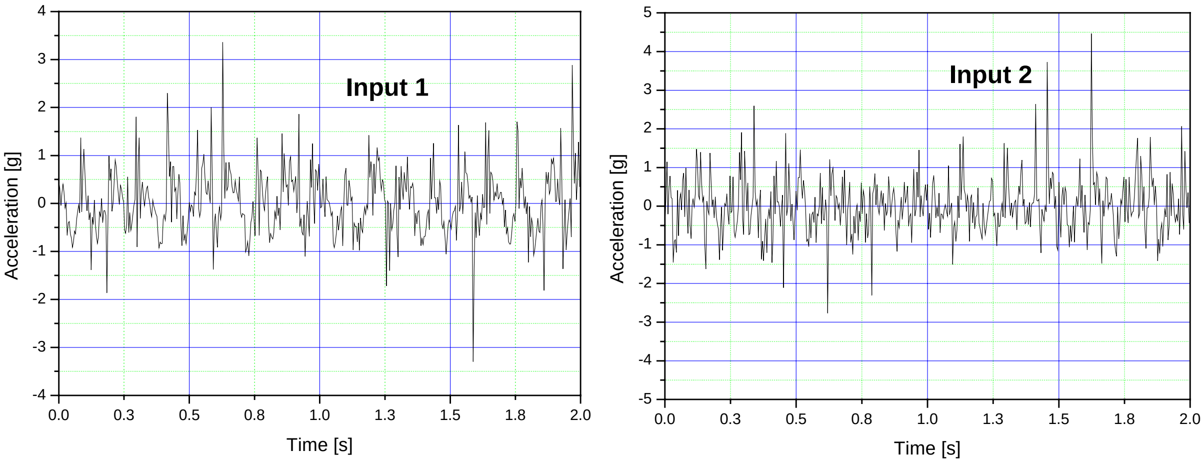


*Figure 14: Typical acceleration time histories of simulated seismic inputs 1(left) and 2 (right).*

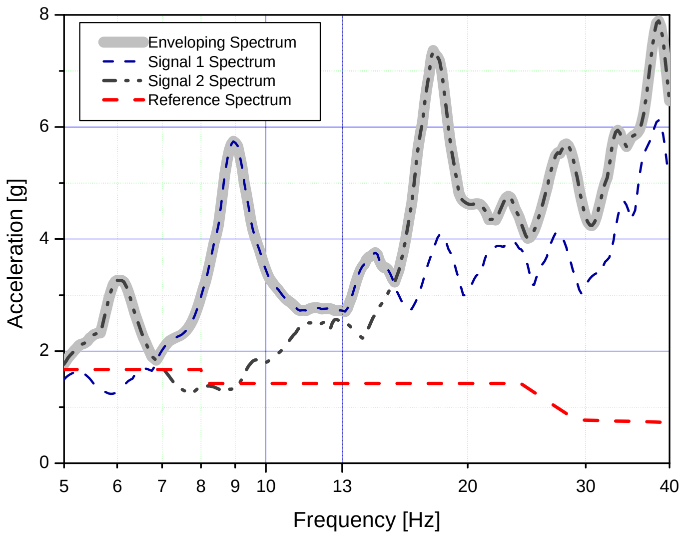


*Figure 15: Comparison of response spectra for simulated seismic inputs 1 and 2 against the reference spectrum for the test.*

## 4.3 Testing Methodology

The testing consisted of two series of tests with and without the action of a simulated seismic action respectively.

The series of tests without the seismic action input were carried out in order to provide with the information necessary for the experimental setup characterisation that will serve as reference to assess the adequacy of the prototype assembly and for comparison with those that will be measured during the tests with seismic action input. These tests included trip tests, free fall tests and a measurement of the experimental setup natural frequency. During the trip tests, the CRP insertion times were measured for a compressed air injection pressure of 250 kPa, i.e. a compressed air pressure within the design range. For the free fall tests, the injection of compressed air was inhibited by keeping the CRD Prototype triggering valves closed when the trip is requested and it is verified that the CR reaches its bottom position after the system actuation. For both trip and free fall tests the CR insertion time is measured starting with the CR in its fully withdrawn position. For the measurement of the experimental setup natural frequency, the impact method was used. These tests were carried out for the two experimental setup configurations described in § 4.1. The trip and free fall tests conducted in the series described here aimed to confirm the behavior of the system identified in the FSS characterisation tests that were conducted previous to the seismic qualification tests described in this paper. The FSS characterisation tests represented the 40 years of system operation including CR movement and trip demands and provided information regarding CR insertion time as a function of the compressed air pressure and the system behavior under different simulated failure conditions, included the absence of the compressed air injection.

On the other hand, the series of tests with input of a simulated seismic action were aimed to provide with the necessary information to demonstrate that the FSS is able to fulfil its safety function under the action the postulated seismic event. This series with seismic action input consisted of seismic qualification trip tests and seismic qualification free fall tests that were conducted in the same manner to the trip and free fall tests described for the series without seismic action input. For each of the two configurations of the experimental setup described in § 4.1, trip and free fall tests were conducted under the two simulated seismic actions described in § 4.2. For each simulated seismic action, the test consisted of series of 10 trip runs. The full test consisted then of 40 trip runs. Each series was carried out consecutively one cycle after another without any intervention on the experimental setup.

### 4.4 Testing Results

Table 1 and Table 2 present a summary of the results of the trip and free fall tests for configuration 1 and 2 (described in § 4.1) respectively.

The results of the trip tests show that the CR insertion times measured resulted below the requirement of 900 ms for the two experimental setup configurations and the two simulated seismic inputs, being 476 ms the maximum CRP insertion time measured (configuration 2, simulated seismic action 1).

The CRP insertion times measured differ, in average, in less than 70 ms. This difference is not significant taking into account the uncertainty in the measurement of the CRP insertion time. Additionally, the CRP insertion times measured deviations of the order of that obtained without seismic action.

The series of 10 trip cycles that were conducted for each simulated seismic action were carried out consecutively with no failures or abnormal functioning of the CRD Prototype.

The inspections carried out on the CRD Prototype showed that no failures were induced by the simulated seismic action. This result maintained for the different series of trip tests carried out for the different configurations and simulated seismic actions.

On the free fall tests it was verified the compliance with the requirement that the CR reached its fully inserted position after the trip request. This requirement was fulfilled in all the free fall test runs carried out for the two experimental setup configuration and the two simulated seismic inputs.

The CRP insertion times were measured during free fall tests for further characterisation of the system. The CRP insertion times measured differ, in average, in less than 70 ms. Additionally, the CR insertion times measured deviations of the order of that obtained without seismic action.

The series of 10 free fall cycles that were conducted for each simulated seismic action were carried out consecutively with no failures or abnormal functioning of the CRD Prototype.

The inspections carried out on the CRD Prototype showed that no failures were induced by the simulated seismic action. This result maintained for the different series of free fall tests carried out for the different configurations and simulated seismic actions.

*Table 1: Summary of test results for experimental setup configuration 1.*

| | Number of Test Runs | Mean CR Insertion Time | Standard Deviation | Maximum Measured CRP Insertion Time |
|---|---|---|---|---|
| | [#] | [ms] | [ms] | [ms] |
| Trip no seismic action | 6 | 390 | 47 | 455 |
| Trip with simulated seismic input 1 | 10 | 442 | 8 | 453 |
| Trip with simulated seismic input 2 | 10 | 457 | 58 | 581 |
| Free fall no seismic action | 6 | 661 | 45 | 710 |
| Free fall with simulated seismic input 1 | 10 | 707 | 12 | 722 |
| Free fall with simulated seismic input 2 | 10 | 727 | 52 | 861 |

*Table 2: Summary of test results for experimental setup configuration 1.*

| | Number of Test Cycles | Mean CRP Insertion Time | Standard Deviation | Maximum Measured CRP Insertion Time |
|---|---|---|---|---|
| | [#] | [ms] | [ms] | [ms] |
| Trip no seismic action | 6 | 421 | 17 | 449 |
| Trip with simulated seismic input 1 | 10 | 476 | 24 | 512 |
| Trip with simulated seismic input 2 | 10 | 405 | 22 | 420 |
| Free fall no seismic action | 6 | 650 | 23 | 677 |
| Free fall with simulated seismic input 1 | 10 | 701 | 12 | 727 |
| Free fall with simulated seismic input 2 | 10 | 659 | 18 | 685 |

## 5. CONCLUSIONS

The analysis of the FSS KC components showed that the SL-2 seismic event induces stresses that are well below the requirements imposed by the applicable standards whilst the calculated deformations indicate that there will be no undue interactions between the KC and its surrounding components. The margins to the limiting conditions observed on stresses are obtained not only due a conservative approach in the design of the FSS but also in the fact that there are other requirements, such as serviceability in the case of the CRDs, that impose requirements on other parameters of the systems, e.g. its natural frequency or even on site mounting conditions, that result in robust components and, according to the analysis, the development of very low stresses under the action of the postulated seismic action.

The experimental setup used represented conservatively the environment that will experience the FSS KC. The simulated seismic actions used were such that their corresponding response spectra covered the reference spectrum and included the natural frequency of the experimental setup and the natural frequencies of the main components of the FSS KC. This allows concluding that the experimental setup plus the seismic actions used constituted a very conservative approach to the conditions that the FSS KC will experience during a seismic event.

The CRP insertion times measured during the seismic qualification trip tests were always below 900 ms, showing full compliance with the requirement of the specification. On the other hand, during the seismic qualification free fall tests it was verified full compliance with the requirement of the CRP being fully inserted after a trip request.

Taking into account the way that the series of test were carried out and the verifications made after the different series of tests, it can be concluded that the seismic action does not impose a condition capable of altering the intended functioning of the FSS when carrying out its shutdown function.

It is noticeable that the full testing (i.e. trip tests plus free fall tests) included 80 simulated seismic events where the system showed at all times compliance with the requirements. In addition, the simulated seismic actions imposed to the experimental setup have characteristics that surpassed that of the requirement, i.e. the SL-2 seismic event. Also notice that 80 of such seismic events are a number that is highly beyond the expected number of occurrences for this event during the Reactor Facility lifetime (i.e. the expected occurrence of the SL-2 seismic event is once every 10000 years). This confirms the robustness of the FSS for carrying its shutdown function under the postulated seismic event.

The whole qualification process demonstrated to be a clear and effective way of demonstrating the acceptability of the FSS to carry out its assigned safety function under the postulated seismic event. All the information emerged from this qualification process allowed INVAP to obtain the necessary permits from the Australian regulatory body for the manufacturing and installation of this system.