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AUSTRALIAN RRRP SEISMIC DESIGN AND QUALIFICATION

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ABSTRACT

The present paper focuses on the structural design and qualification that has been carried out for the safety against seismic events at the Australian RRRP (Replacement Research Reactor Project).

The RRRP is a 20 MW multi-purpose nuclear research reactor designed and constructed by INVAP from Argentina, for ANSTO (Australian Nuclear Science and Technology Organisation) in Sydney, Australia.

On account of the site characteristics, the australian regulations and the engineering and design standards applicable to the project, the design requirements for the reactor included very stringent and clear guidelines that should be observed to ensure that appropriate levels of protection are provided against seismic events.

Despite the fact of being a research reactor with a thermal power two orders of magnitude lower than that of nuclear power plants, the methodology used in the seismic qualification was based on the one used for NPPs instead of using simplified methods as suggested by the literature on research reactors. With this in mind, the regulatory and enginnering frame was based on IAEA standards for power reactors and complementary guides for specific issues.

The paper describes the Design Basis Ground Motion, Seismic Levels, Seismic Classification and the particular design criteria and qualification methods used for systems as: Civil, Mechanical, Process, Instrumentation and Control, Electrical, HVAC, etc.

Keywords: Seismic, Seismic Qualification, Structural Analysis.Structural Design.

1. INTRODUCTION

The RRRP (Replacement Research Reactor Project) is an open pool type 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 objectives are to provide radioisotopes and extensive neutron beam research capabilities.

The reactor comprises four buildings, namely:

Reactor Building:	Reactor itself
Neutron Guide Hall:	Building for research and Neutron Guide facilities.
Offices Building:	Offices
Auxiliary Building:	Reactor Service Building

The design and seismic qualification is at present widely developed for power reactors. It exists a solid technical background for seismological investigations and for components qualification with an extensive knowledge based on experience and research.

Conversely, for research facilities with low power, the standards focus the seismic qualification toward simplified methods with apropriate safety margins.

In the RRRP the capacity to withstand seismic events was identified by the client and the Regulatory Authority as highly relevant since the beginning of the proyect. Based on this requirement and the experience with previous reactors built by Invap, it was adopted the methodology of power reactors.

2. REGULATORY FRAME

The seismic design and qualification was carried out under the regulatory frame of IAEA by means of the following main standards:

50-SG-S1 Earthquake and Associated Topics in Relation to Nuclear Power Sitting [1]
50-SG-D15 Seismic Design and Qualification for Nuclear Power Plants [2]

Additional standards were used in order to cover particular details not given by the general IAEA codes including US NRC Regulatory Guides and ASCE 4-98 (Seismic Analysis of Safety-Related Nuclear Structures and Commentary),

3. DESIGN BASIS GROUND MOTION

Three seismic levels were adopted, corresponding two of them for nuclear equipment and the third one only for civil equipment.

The Seismic Levels 2 and 1 have the following values:

Table 1 – Horizontal Peak Ground Acceleration SL-2 y SL-1

	PGA Horizontal *	PGA Vertical
SL-2 (Safe Shutdown Earthquake)	0.37 g	0.25 g
SL-1 (Operating Basis Earthquake)	0.09 g	0.06 g

* Each Horizontal direction

The SL-2 ground response spectra was taken as an envelope between the IGNS spectrum and that given by Regulatory Guide 1.60 [3] scaled to 0.30g.

The SL-1 ground response spectra was taken as an envelope between the IGNS spectrum and that given by Regulatory Guide 1.60 [3] scaled to 0.09g.

The SL –0 Seismic Level 0 was taken in accordance with AS1170.4 [5] and corresponds to civil structures.

The seismic levels SL-2 and SL-1 were computed by the IGNS (Institute of Geological and Nuclear Science - Australia)

Table 2 and Figure 1 show SL-2 and SL-1 Horizontal ground acceleration for 5% damping.

Table 2 – Horizontal Ground Level Acceleration SL-2 y SL-1 (5%)

Period	Frequency	Acceleration Horizontal SL-2 (SSE)	Acceleration Horizontal SL-1 (OBE)
sec	Hz	g	g
0.03	33.00	**0.37**	**0.09**
0.11	9.00	**0.78**	**0.23**
0.20	5.00	**0.86**	**0.26**
0.40	2.50	**0.94**	**0.28**
1.00	1.00	**0.46**	**0.14**
3.85	0.25	**0.14**	**0.04**

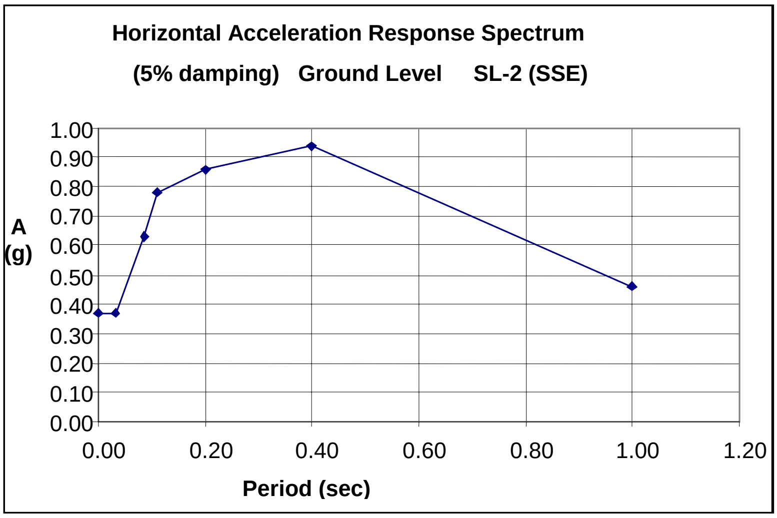

Figure 1

4. SEISMIC CLASSIFICATION

SCE were classified in the following categories in accordance with 50-SG-D15:

a) **Seismic Category 1** Items in this category were designed to withstand the consequences of SL-2
b) **Seismic Category 2** Items in this category were designed to withstand the consequences of SL-1
c) **Seismic Category 3** Items in this category were designed to withstand the consequences of SL-0
d) **Not Applicable** For the items in this category the seismic qualification does not apply, for instance:

- Items for which the qualification has no sense (software. fluids)
- Items fixed to building for which the verification was carried out to the support structure but not to themselves (cables)
- Items not fixed to building or structures (portable equipment, casks, etc)

The criteria for the classification taken from 50-SG-D15 was related to those items whose failure could cause accident conditions, items required to reactor shutdown and prevention against radioactive releases.
In the classification it was also considered the criteria of protection of items of different Categories in the case of collapse of items belonging to a lower category.

Seismic Category 1 included all Safety Category 1 items.
Although the classification is extensive, the Seismic Category 1 included, as main examples: Reactor Building, Reactor and Service Pool, Fuel Assemby, Reflector Vessel and Core Structure, Pool Internals, First and Second Shutdown Systems, Cooling Systems structural integrity, Emergency Cooling Systems, I&C Reactor Protection systems, I&C Post Accident Monitoring, Containment Energy Removal Systems, Emergency Electrical Generation System, etc

The Seismic Category 1 included: Pneumatic & Handling System, Neutron Guide System, I&C Reactor Control and Monitoring System, CNS System, Cooling Towers, etc.

It is important to highlight that the seismic classification initially specified for each item was the required classification, whereas the final capacity was higher in the majority of cases. This means that SC1 had structural capacity to resist earthquakes greater than SL-2 and that SC2 items qualified as SC1. The reason of that was the standarization in the equipment procurement and the adoption of robust designs.

5. FLOOR RESPONSE SPECTRA

Starting from the ground acceleration response spectra, there were generated the floor response spectra for the whole building level. The generation was made with synthetic time histories compatible with the ground response spectra and using a FEA model of the building.

The generation included the typical damping 7%, 5% and 2% in both horizontal directions and vertical direction. Table 3 shows as example typical values of Peak Floor Acceleration (PFA) and the Peak Floor Response Acceleraion (PFRA) for SL-2 (SSE) in one horizontal direction.

Table 3 – SL-2 Horizontal Floor Response Spectra

Level (m)	PFA (g)	PFRA (g) 2%	PFRA (g) 5%	PFRA (g) 7%
–5	0.37	1.28	0.94	0.82
0	0.48	2.10	1.24	1.02
4	0.58	3.51	2.00	1.63
8	0.69	5.07	2.86	2.32
10	0.66	4.94	2.78	2.26
13	0.87	6.85	3.86	3.10
17	1.03	8.15	4.59	3.68
20	1.46	9.97	5.65	4.57

Figure 2 shows a typical floor response spectra corresponding in this case to Reactor Building level +13.00 (Reactor Hall).

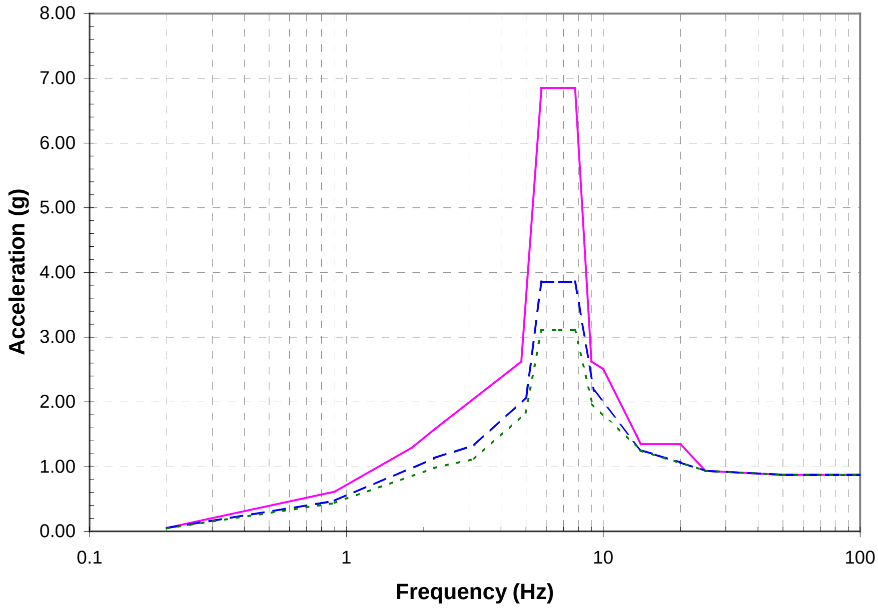

Figure 2 - SL-2 (SSE) Acceleration floor response Sprectra Horizontal Direction-level +13.00

Critical damping 2% 5% 7%

6. SEISMIC QUALIFICATION METHODS

The qualification was carried out by means of the four general methods described in IAEA 50-SG-D15:.

- Analysis
- Test
- Seismic Experience
- Indirect Methods

Analysis was used when the dynamical behaviour of the item could be adequately modelled. The analysis was carried out manually and with FEA models. The seismic input was loaded in the mathematical models by means of Response Spectrum, Time History and Equivalent Static methods.
Test was used when the SCE integrity or functionality behaviour could not be demonstrated by analysis. This was the case of complex items such as mainly Instrumentation and Control and Electrical components. Additionally, the regulatory autority (ARPANSA) requested tests for critical components such as the First Shutdown System and Flap Valves.
Earthquake Experience was adopted when similar equipment was already qualified for previous facilities. The sources for the experience were own Invap data, DOE/EH-0545 (Seismic Evaluation Procedure for Equipment in US Department of Energy Facilities) and EPRI NP-6041 (A methodology for Assessment of Nuclear Power Plant).
Finally, it was used the qualification by means of Indirect Methods related to analogy. The analogy was establish between equipment with small differences not relevant in a structural point of view and between similar equipment with different seismic loads (at different building levels).

Hydrodinamic effects were considered in the qualification of submerged components (Reactor & Service pool internals) and tanks.

The combination of the three seismic spatial direction was considered in the qualification (both analysis and test) using the SRSS methods for components in general and 100%+30%+30% for building analysis.

6.1 QUALIFICATION STANDARDS

The standards used in the seismic qualification and structural analysis were:

Table 4

SCE	CODE
Civil Structures (concrete)	ACI 318 Building Code Requirements for Structural Concrete ACI 349 Code Requirements for Nuclear Safety Related Concrete Structures AS 3600 Concrete Structures
Civil Structures (steel)	AS 4100 Steel Structures
Tanks	ASME Boiler & Pressure Vessel Code, Section III, Division 1, Subsection ND ASME Boiler & Pressure Vessel Code, Section VIII
Internal Pools structures and not pressurized components	ASME Boiler & Pressure Vessel Code, Section III, Division 1, Subsection ND ASME Boiler & Pressure Vessel Code, Section III, Division 1, Subsection NF
Piping	ASME B31.1 Power Piping AS 4041 Pressure Piping
Electrical & Electronic components	IEEE 344 Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Generating Power Station.

7. SEISMIC DESIGN AND QUALIFICATION

The following sections show particular criteria adopted in the design and qualification of SCE.

7.1 BUILDING STRUCTURES

Because of functional requirements, the Reactor Building has particular features that provide a high capacity to resist earthquakes. They are the central Concrete Reactor Block and a large number of concrete wall partitions.
The Reactor Building height is of 31.5m (with an additional steel aircraft protection grillage). The main basement level is at –5.00m and it is placed on bedrock. The first oscillation mode corresponds to horizontal lateral direction with a period equal to 0.184 seconds.
The Building Structures qualification was carried out by analysis.
Figure 3 show FEA models of the Reactor Building and its internal Reactor Block used in the analysis.

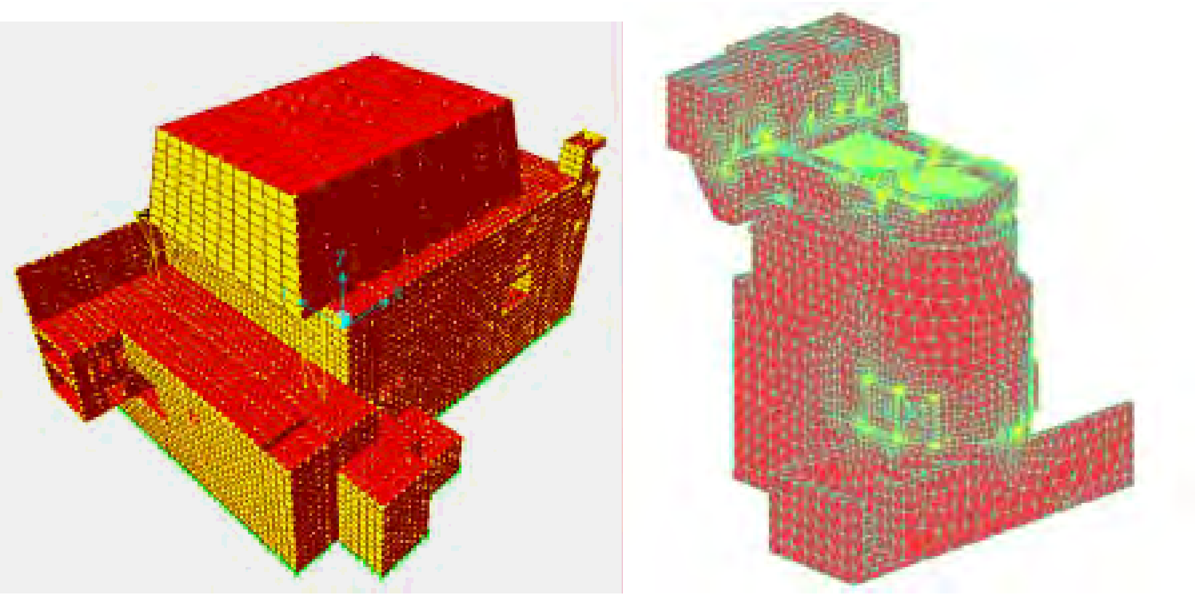

Figure 3 - Reactor Building & Reactor Block FEA models

7.2 MECHANICAL COMPONENTS

7.2.1 Reactor and Service Pools

The pool contains the main amount of cooling water (light water), the core and the internals.
They are rigidely embedded into the Reactor Block (Heavy Weigth Concrete) because they were used as formwork during the concrete pouring. The pools deformation during a seismic event will be that of the Block, therefore the global seismic action on the pools were studied as an imposed deformation.

The Reactor Pool is cylindrical of 4.50m diameter and 14m height. The Service Pool is rectangular of aproximately 5.3 x 4.5 x 9.2 m. Both pools are built with a 6mm thickness stainless steel shell and with an appropriate array of reinforcements.

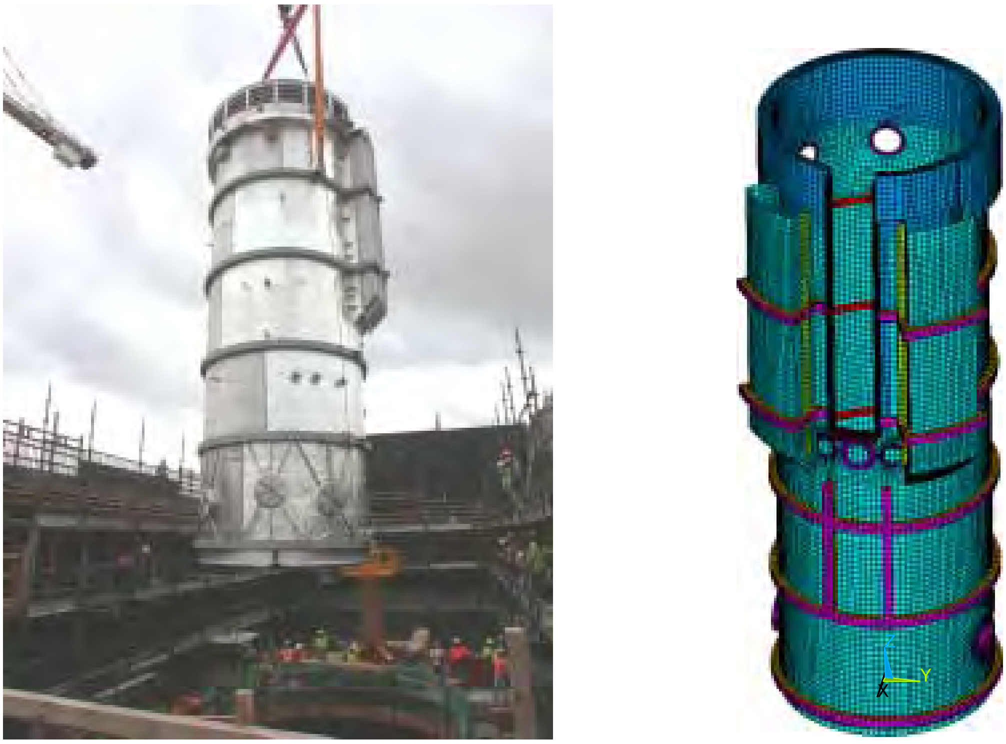

Figure 4 - Reactor Pool & Reactor Pool FEA model

The pools are supported for a number of structural components (racks, piping, etc). Such internal components are fixed to the pool by means of supports which were designed in order to transmit the loads directly to the the concrete block without jeopardize the pool shell.

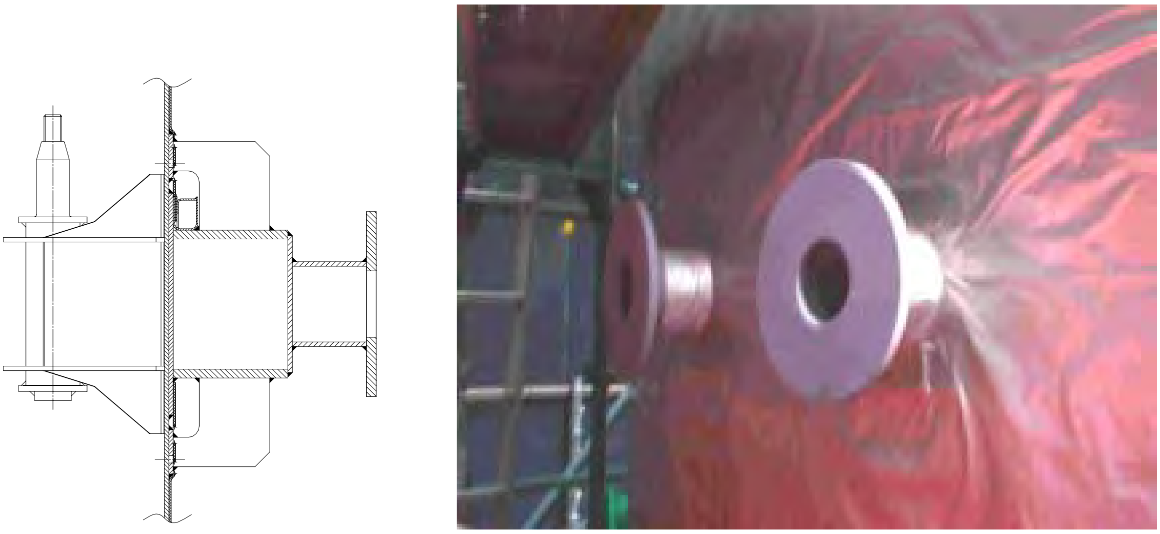

Figure 5 - Pools Supports Reinforcements

7.2.2 Pools Internals

Pools Internals include in general Core&Reflector Vessel, cooling systems large piping, small pipings, racks for fuel and irradiation ingots storage, nucleonic instrumentation and Cold Neutron Source services.
All pool internals components were designed and qualified as Seismic Category 1.

CORE - REFLECTOR VESSEL

The Reflector Vessel is located in the Reactor Pool. It is fixed to the pool bottom plate with a skirt type support which also constitutes a chamber for cooling system.
The vessel has also a number of connections, both for neutron beams and cooling. In order to do not transmit forces at these main connections, flexibles joints (bellows) were designed for the five neutron beams and the top primary cooling system piping.
Additionally, lateral supports were designed to resist seismic horizontal actions acting on large masses such as Cold and Hot neutron sources and Primary Cooling System pipe.

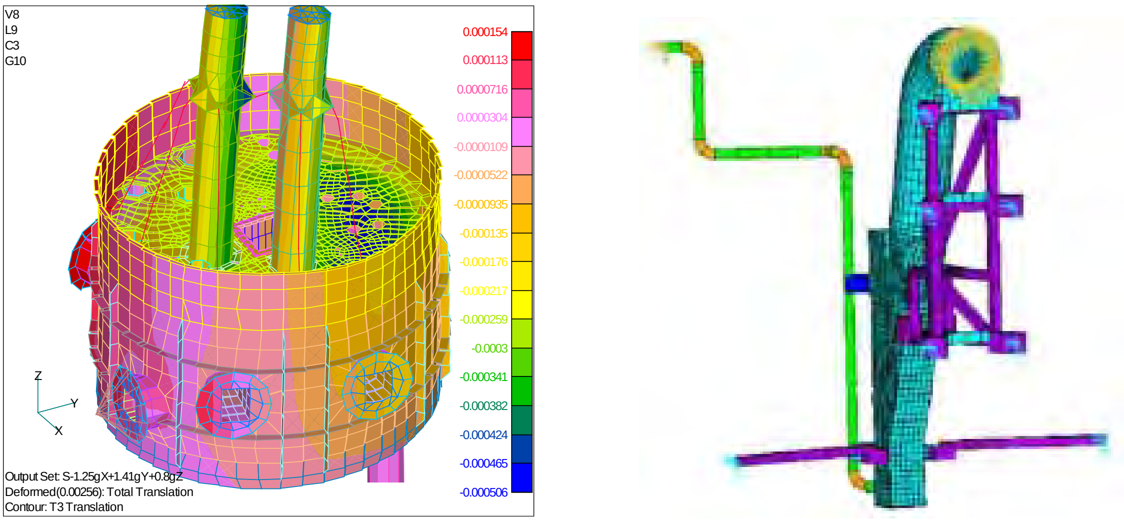

Figure 6 – Reflector Vessel, Neutron Beam, Core Chimney and Riser FEA models

FIRST SHUTDOWN SYSTEM

The First Shutdown System (FSS) is made of five Absorbing Plates located inside the Core and moved by their corresponding drives located in a room below the Reactor Pool.. The whole system also comprises the Control Rods, Absorbing Plates Guide boxes and fixation devices. Part of the system is on air (Drives in the Control Drive room) and part is submerged in water (inside the Reactor Pool).

The FSS was initially qualified by analysis using FEA models. Mode shapes, seismic induced displacements and stresses were computed for control rods, plates, boxes and drives in the different insertion states.
Figure 7 shows FEA models of some FSS components used in the analysis.

Afterwards, the Australian Regulatory Authority (ARPANSA) required a qualification by test because it is an active system which has to act during the earthquake.
For the functional FSS test, a full scale setup was built with a complete device. It was also simulated the submerged condition by flooding with water the Control Rod Guide Tube and the Absorbing Plate Guide Box. The whole test device was mounted in a mobile structure (aprox 8m height) actuated by an hydraulic actuator. During the test, the SL-1 (SSE) motion was simulated and, simultaneously, the FSS was triggered and the Plate insertion time was mesured. It was verified that the insertion time remains below the requirement (900 msec).

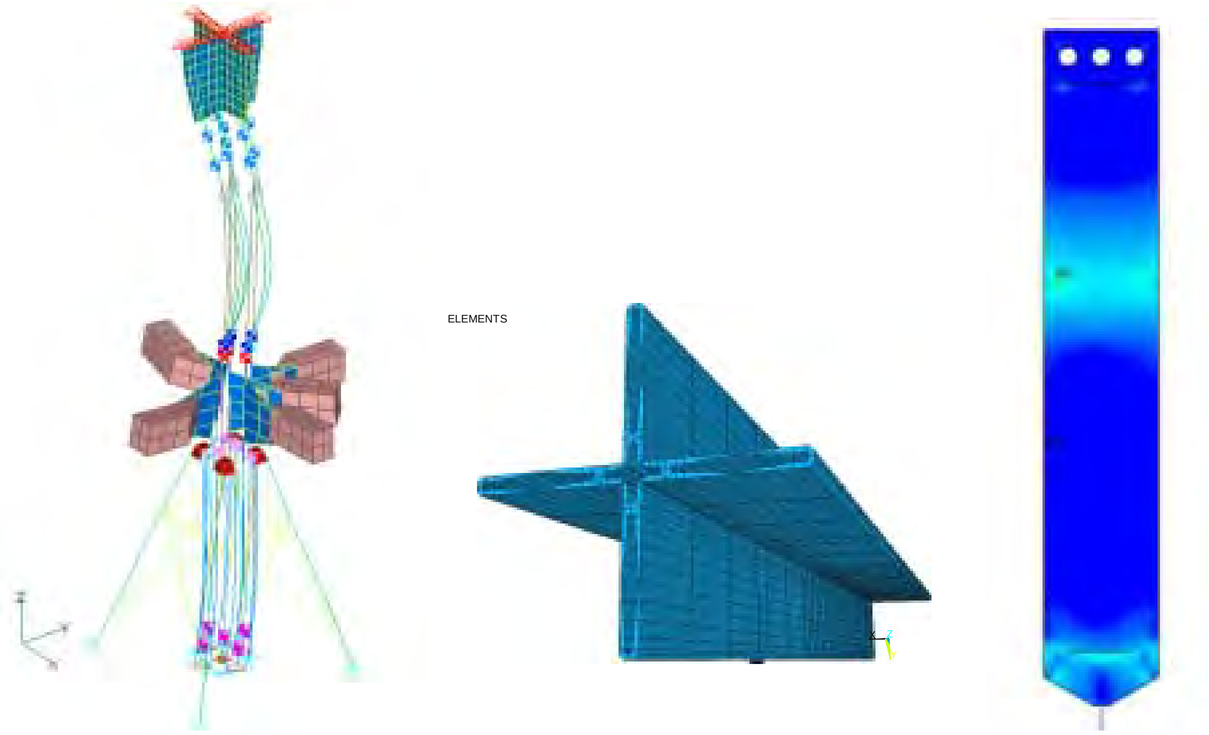

Figure 7 - FSS components FEA models

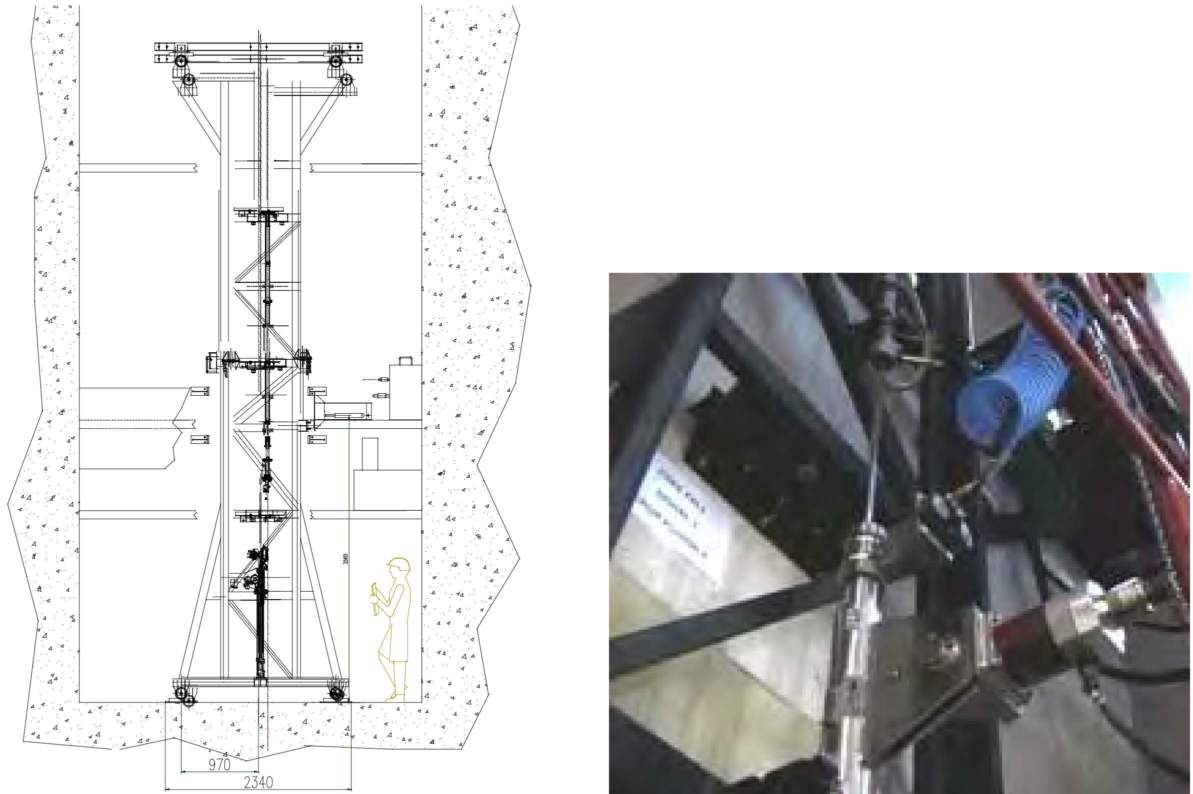

Figure 8 -   FSS seismic test

FLAP VALVES

Primary Cooling Systems Flap Valves and Reactor and Service Pool Cooling System Flap Valves were qualified both by analysis and test.

The test was required by the Australian Regulatory Authority because, although the valve is not an active component that has to act during the earthquake, it has a mobile part (the floating) for which no damage is required.

Figure 9 - Flap Valves test

FUEL ASSEMBLY

The Fuel was qualified by analysis. The analysis comprised the Fuel itself and all the fixation devices.

Additionally it was developed a destructive test of the joint between the fuel plates and the fuel nozzle in order to get the real margin (not theoretical) between the loads induced by seismic event plus water dragging and the failure load.

Figure 10 shows the FEA model used in the analysis and the joint test.

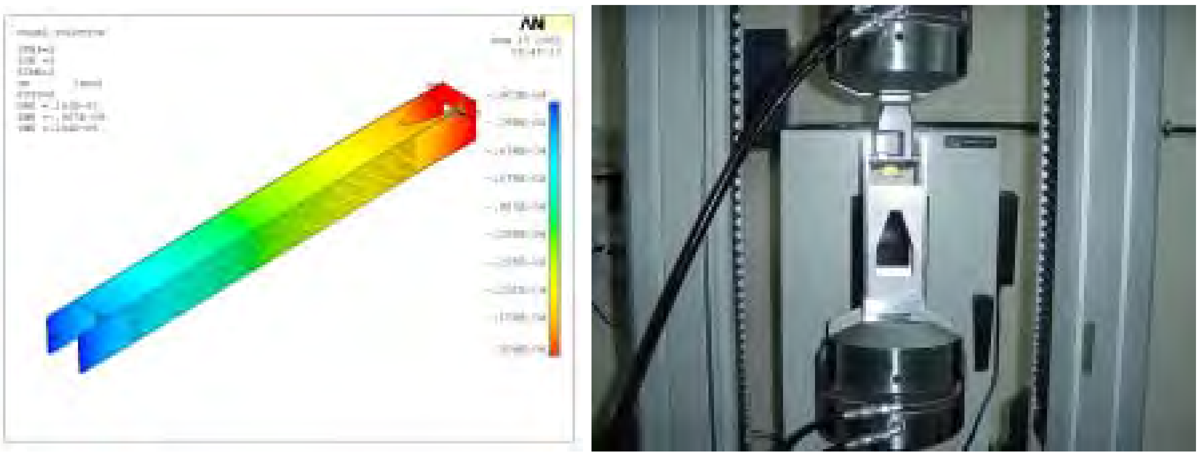

Figure 10 - Fuel Assembly FEA model & Joint test

7.3 PROCESS SYSTEM

TANKS

Tanks were qualified by analysis.
Particular provisions were adopted for Seismic Category 1 tanks. In this case additional reinforcements such as support diagonals and lateral bracing were designed in order to provide enough stiffness, structural capacity and to avoid local damaged in the tanks shells.
Moreover, for a few cases of very large tanks such as Primary Cooling System Decay Tank, the support were designed by means of a skirt type support.

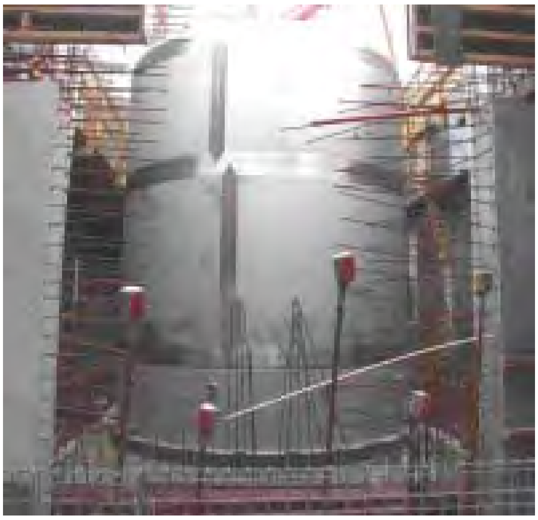

Figure 11 - Tanks with reinforced supports

PROCESS CONTROL EQUIPMENT

Process Control Equipment includes a large number of items used in the control and mesurement of fluids. They were divided in Components and Instruments. Components encompass Pumps, Valves, Heat Exchangers, Filters, Compressors, Blowers and Heaters. Instruments include devices to mesure Temperature, Flow, Level, Pressure, Vibration, Position and Analyzers.
The Process Control Equipment was mainly qualified by earthquake experience because COTS equipment has demonstrated to have sufficient capacity to withstand strong seismic events greater than that corresponding to the proyect.

Figure 12 – Primary Cooling System Pump and Heat Exchanger

7.4 HVAC

Heating, Ventilation and Air Conditioning include equipment both for Safety Category 1 systems which were classified as Seismic Category 1 and for conventional areas (Seismic Categories 2 and 3).
The equipment includes Fans, Air Handling Units, Filters, Water Chillers, Coils, Dampers,.
The qualification was made by a combination of methods of analysis (fans, filters, coils, water chiller, dampers), test (fans, aire handling units) and analogy. Some components located in ductworks were tested jointly with a duct span.
Special provisions were designed for seismic isolation and for vibration isolation for Fans and Water Chiller.
The qualification of Water Chillers was made by analysis and inspection of the equipment. It was decided to install additional reinforcements (diagonals) to give more stiffness and therefore to reduce the relative deformations in order to avoid functional failure in the coils and piping. The continuity with the external pipeline was solved by flexible connections.


Figure 13 - Water Chiller with seismic isolators and reinforcements Fans with isolators


Figure 14 - Air Handling Units and Fan tests

7.5 INSTRUMENTATION & CONTROL

For the purpose of seismic qualification, it was considered that the equipment is made up of Structures and Components. By Structure, it was understood every type of mechanical part that acts as support, housing or fixation, including cabinets, consoles, racks, bases, supports, fixations, shields and raceways. By Component, it was understood the parts contained and supported by the Structures, of the following types: Electronic boxes and their internal parts, sensors, cables, etc.
Another point of view taken into account was the equipment procurement. Equipment had three main different sources, namely: INVAP production, Supplier with certified seismic qualification and Supplier without certified seismic qualification. The scope of the qualification comprised:

SEISMIC CATEGORY 1 Structures

	Source	Qualification
a)	INVAP	INVAP
b)	Supplier with certified seismic qualification	The Supplier qualifies and submits the corresponding certification
c)	Supplier without certified seismic qualification	Analysis by the Supplier with further verification and/or approval by INVAP

SEISMIC CATEGORY 1 Components

	Source	Qualification
a)	Supplier with certified seismic qualification	The Supplier qualifies and submits the corresponding certification.
b)	COTS, without seismic qualification	The Supplier qualifies with further verification and approval by INVAP or INVAP qualification
c)	Components specifically developed for the project	Specific qualification and/or verification by INVAP.

SEISMIC CATEGORY 2 Structures

	Source	Qualification
a)	INVAP	INVAP
b)	Supplier	Analysis by the Supplier with further verification and/or approval by INVAP or Analysis by INVAP

SEISMIC CATEGORY 2 Components
No seismic qualification was required for components corresponding to Seismic Category 2 since standards COTS components have sufficient capacity to withstand SL-1.

As example, the Reactor Protection and Post Accident Monitoring systems (both Seismic Category 1) correspond to a supplier with seismic qualification documentation.
The equipment qualified by Invap was made by analysis, test and analogy. Particular provisions were taken for the appropriate design of cabinets and consoles. They were design with reinforcements (such as diagonals) and fixations between adyacent cabinets.
A dedicated test qualification program was developed by INVAP for componets and COTS equipment. The plan included: TV Monitors and camera, Fission and ionization chambers, Connectors, indicators and push buttons, Radiation Monitoring System equipment (detectors, electrical and electronic boxes, pump motor protection box), Speaker, Power supplies, Float level switch, Video amplifier and video switcher, Environmental speaker, Audio amplifier and devices, Nucleonic NIM modules and NIM power supply, Relay modules, etc.

Figure 15 – I&C equipment tests – TV monitor, camera and electronic components in racks

7.6 ELECTRICAL SYSTEM

The qualification plan for electrical system included Transformers, UPS, Batteries, Switchboards, Diesel Generators, Fuel tanks, Cabletrays, Busways, Instrumentation, Ligthnings, supports structures and anchorages.
The qualification was mainly carried out by analysis and test. Analysis was used for cabletrays, busways, Transformers, Generators, Switchboards, fuel tanks and cabinets. Tests were used for Instrumentation, Switchboards, UPS, Batteries and Switchboard internal components. Dedicated tests were developed at Invap Argentina and Australia whereas qualified purchased equipment were delivered with their corresponding documentation by the suppliers.
In the case of Generators, located outside the Reactor Building, they were mounted on seismic isolators.


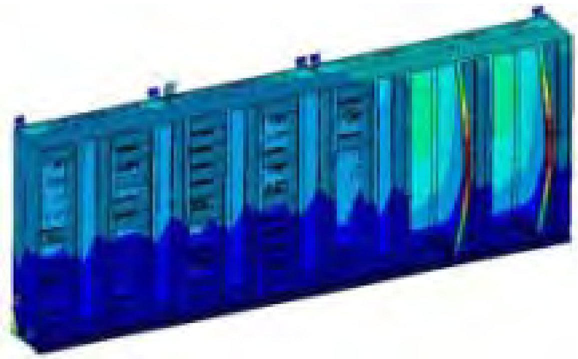

Figure 16 – Switchboard Seismic Test and Switchbaord FEA model

7.7 FIRE

The Fire system comprise pipeline, tanks , pumps and valves (manual and actuated), detectors and the gaseous supression system. The components were qualified by analysis (pipeline, tanks, supports) and with experience and analogy (as process control equipment).
The pipeline was designed providing appropriate support and lateral bracing.
Special care was taken in the fixation of Inergen tanks (gaseous supression sytem) providing lateral fixation of each tank in order to avoid overturning.


Figure 17 – Fire Sytem Valves and Piping

7.8 DISTRIBUTION SYSTEMS

PIPING

Piping was qualified by analysis. The adopted method for the analysis was taken in accordance with the Seismic Category and piping diameter, as follows:

Table 5 – Piping analysis

Seismic Category	Diameter	Analysis Method
1	$\phi \geq 75$ mm	Dynamic (Response Spectrum or Time History)
	50mm $\leq \phi <$ 75 mm	Equivalent Static
	$\phi <$ 50mm	Spacing Tables
2	$\phi \geq 75$ mm	Equivalent Static
	$\phi <$ 75mm	Spacing Tables

The spacing tables for low diameter piping were computed for the RRRP in order to envelope the worst accelaration jointly with the rest of load states such as dead weigth, pressure and temperature.
The piping supports were designed with beam structures for large piping and with unistrut type fixations for small pipings. Appropriate lateral bracing were considered in the supports and in combination with sliding supports in order to absorb thermal expansions.

Figure 18 – Pipig Support

HVAC DUCTS
HVAC Ducts were designed with connections between sections in order to provide axial and bending capacity to resist the seismic action.
Ducts Supports were solved by means of unistrut type supports. Special focus was made in the lateral bracing both in transversal and longitudinal direction.
Seismic tests were developed for HVAC components mounted on ducts such as electrical heaters and dampers.

Figure 19 – Ducts mounting and Heater & Damper test

CABLETRAYS

Cabletrays were designed with connections between sections in order to provide axial and bending capacity to resist the seismic action.

Cabletrays Supports were solved by means of unistrut type supports. Special focus was made in the lateral bracing both in transversal and longitudinal direction.

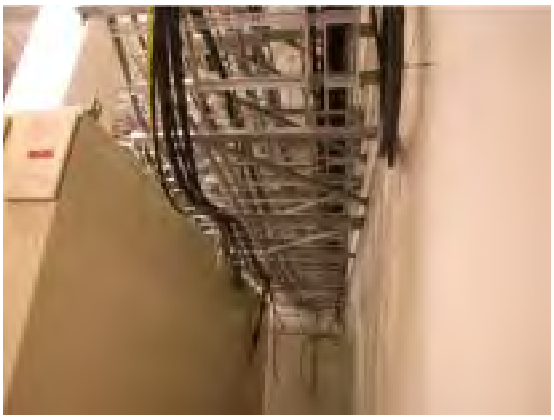

Figure 20 – Cabletrays and supports with lateral and longitudinal bracing

7.9 ANCHORAGES

Different types of anchorages were used in the reactor both cast-in and drill-in.

Cast-in anchorages were used in:

- Embedded plates used for the fixation of large piping. These embedded plates were fixed to the concrete by means of beams welded at the back side of the plate and also stud bolts.
- Large bolts (such as Primary Cooling System Decay Tank)
- Unistrut type embedded rails.

Drill-in type were used mainly for equipment fixation due to the flexibility that such anchorages allow during the location and mounting. Both type of drill-in were used, chemical and expansion.

Figure 21 – Array of embedded plates with supports and Unistrut embedded rails

All the equipment was fixed to the building structure.

Redundancy was used in the design of anchors. The concept of redundancy was based on that the failure of a bolt should not produce the lack of the structural capacity of the fixation and that it should not modify the constraint characteristics with the consequent change in vibrational behaviour.

Specially for the fixation of Seismic Category 1 items, the structural verification was made with the lack of at least one bolt or, instead, verifing the fixation and next to install additional extra bolts.

8 DOCUMENTATION and RESOURCES

The documentation was arranged with a serie of general reports that set the general methods and criteria issued at the beginning of the project, then the qualification reports developed during aproximately three years and finally (at the end of the project) a last index report which listed the reactor SCE or systems and their corresponding report were the qualification was carried out.
The serie included:

a)	Methods and Criteria for Structures and Components Seismic Qualification	(Master report)
b)	Seismic Hazard Assessment	(Reports about the Seismological Investigations)
c)	Seismic Classification of Systems and Subsystems	(Seismic Categories for SCE)
d)	Seismic Design Floor Response Spectra	(Floor Spectra)
e)	Seismic Qualification Reference	(Set the qualification method to be used at each SCE)
f)	Qualification reports	(Specific qualification reports for each SCE)
g)	Seismic Qualification Reference Documentation	(Final index addressing corresponding qualification report)

The number of issued reports covering seismic qualification was around 300. Some of these reports were specific for seismic qualification and others covered the structural verification including the seismic loads in combination with the rest of loads.
The human resources involved in the qualification was in the order of 20000 hours.

9 CONCLUSION

The seismic design and qualification was a major task for the Australian RRRP. There were involved a large number of Structures Components and Equipment of the whole reactor systems. The four qualification methods were used (analysis, test, experience and analogy). The sources of SCE were very diverse, comprising since specific components developed for the project to purchased equipment with and without seismic qualification.
This amount of effort was the result of the requirements of the client and the regulatory authority who gave significant importance to the safety against seismic events and who followed very closed the qualification process for each item.

10 GLOSSARY

SCE	Structures, Components and Equipment
SSE	Safe Shutdown Earthquake
OBE	Operating Basis Earthquake
IAEA	International Atomic Energy Agency
PGA	Peak Ground Acceleration
IGNS	Institute of Geological & Nuclear Sciences
RRR	Replacement Research Reactor
FEA	Finite Element Analysis

11 REFERENCES

[1] 50-SG-S1 Earthquake and Associated Topics in Relation to Nuclear Power Sitting
[2] 50-SG-D15 Seismic Design and Qualification for Nuclear Power Plants
[3] USNRC Regulatory Guide 1.60 Design Response Spectra for Seismic Design of Nuclear Power Plants
[4] ASCE 4-98 Seismic Analysis of Safety-Related Nuclear Structures and Commentary
[5] AS1170.4 Minimum Design Loads on Structures Part 4 Earthquake Loads