18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18)
Beijing, China, August 7-12, 2005
SMiRT18-B02-6

STRUCTURAL ANALYSIS OF THE REACTOR POOL FOR THE RRRP

José Gabriel Alberro
INVAP S.E., Perito P. Moreno 1084
Phone: 54 (2944) 445400, Fax: 54 (2944) 423051
E-mail: alberro@invap.com.ar

Alberto Donato Abbate
INVAP S.E., Perito P. Moreno 1084
Phone: 54 (2944) 445400, Fax: 54 (2944) 423051
E-mail: aabbate@invap.com.ar

ABSTRACT

The purpose of the present document is to describe the structural design of the Reactor Pool relevant to the RRRP (Replacement Research Reactor Project) for the Australian Nuclear Science and Technology Organisation.

The structural analysis required coordinated design, engineering, analysis, and fabrication efforts.

The pool has been designed, manufactured, and inspected following as guideline the ASME Boiler and Pressure Vessel Code, which defines the requirements for the pool to withstand hydrostatic and mechanical forces, ensuring its integrity throughout its lifetime.

Standard off-the-shelf finite element programs (Nastran and Ansys codes) were used to evaluate the pool and further qualify the design and its construction.

Both global and local effect analyses were carried out. The global analysis covers the structural integrity of the pool wall (6 mm thick) considering the different load states acting on it, namely hydrostatic pressure, thermal expansion, and seismic event. The local analysis evaluates the structural behaviour of the pool at specific points resulting from the interaction among components.

It is confirmed that maximum stresses and displacements fall below the allowable values required by the ASME Boiler and Pressure Vessel Code.

The water pressure analysis was validated by means of a hydrostatic test.

Keywords: Finite elements, models, reactor pool, structural analysis.

1. PURPOSE

The purpose of the present document is to describe the structural design of the Reactor Pool corresponding to the RRRP (Replacement Research Reactor Project) built by INVAP for ANSTO (Australian Nuclear Science and Technology Organisation) in Sydney, Australia, which required coordinated design, engineering, structural analysis, fabrication, and mounting efforts.

2. GLOSSARY

RPO: Reactor Pool
FEA: Finite element analysis
SCS: Secondary cooling system
FSS: First shutdown system
SSS: Second shutdown system

3. INTRODUCTION

The Replacement Research Reactor is a multi-purpose nuclear facility. It will produce radioisotopes, provide irradiation services, and be used for research with neutron beams.

The RRR is a 20 MW thermal power reactor of the open pool type, water-cooled, and using heavy water as reflector.

The reactor building houses all the nuclear systems, as well as both pools (reactor and service).

The Reactor Pool is one of the main structures that make up the core containment, and must thus meet the following safety functions: a) ensure that the primary Cooling System has sufficient water (coolant) to remove core heat through forced circulation during normal operation, or through natural convection when the reactor is shut down; and b) protect workers from radiation exposure.

Figure 1 – Reactor and Service Pools

4. DESIGN

4.1 Geometry

The reactor pool is a 14-metre-high stainless steel cylindrical tank, of a 4.5 diameter. The cylindrical shell is 6 mm thick, while the floor or base is 12 mm thick. The pool weighs approximately 32 tonnes without the water.

The following materials are used to manufacture the pool:

- Cylindrical shell and inner supports: ASTM-A240-304L stainless steel
- External stiffening rings: ASTM-A36 carbon steel (or equivalent)

Figures 2 and 3 provide different views of the pool, while *Figure 4* shows the pool already completed prior to its mounting in the Reactor Building.

The tank is embedded in a heavy concrete block known as “Reactor Block”, anchored to it from the base and by means of the stiffening rings.

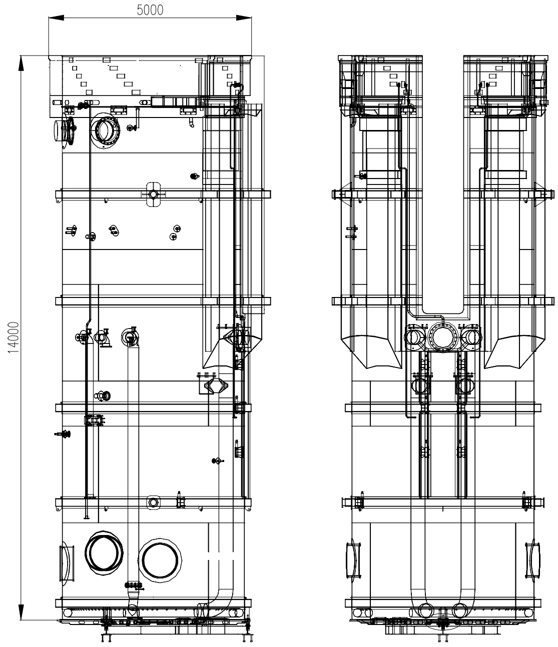


Figure 2: Reactor Pool – Views

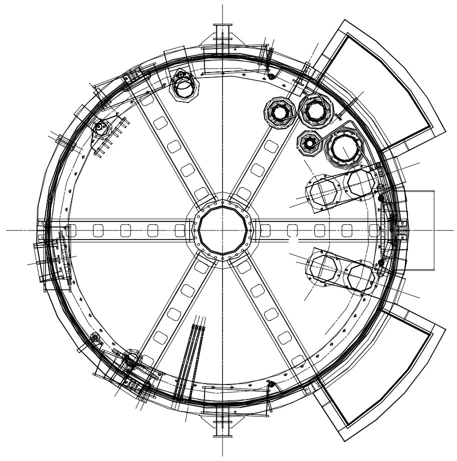


Figure 3: Reactor Pool – Plant view

Figure 4: Reactor Pool completed next to the reactor building

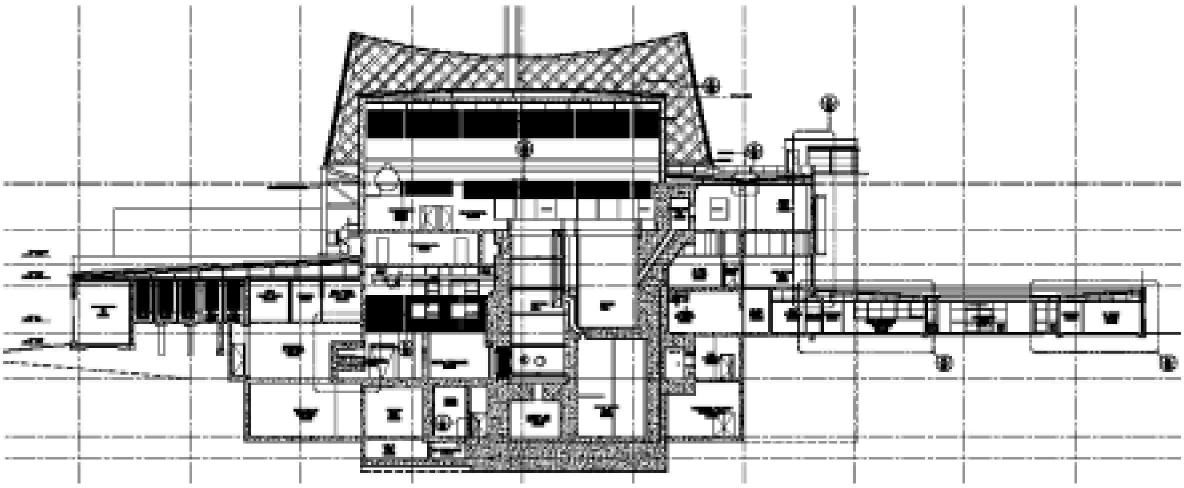


Figure 5: Reactor Pool – Location within the building

4.2 Features

The following are worth mentioning:

- Base built in 12-mm-thick sheet and 6 radial external profiles to provide rigidity and stiffness to the bottom of the pool
- Cylindrical shell, which, together with the base, makes up the tight containment. Globally built in 6-mm-thick stainless steel
- 5 horizontal external stiffening rings (C profiles) located at different heights
- Reinforcements behind the pool shell (concrete side), in coincidence with dedicated inner supports that bind the structures. These reinforcements are adequately embedded into the concrete.
- Penetrations reinforced with welded sheet (pads)
- Pneumatic chambers
- Main process penetrations located above siphon-breaker level (LOCA prevention)
- Ventilation, instrumentation, and overflow channel at the top area

- Transfer canal for connection to the service pool

The pool contains vital components for the operation of the reactor, such as the following:

- Core and associated structures
- Reflector vessel with its irradiation positions
- Riser (leads the water from the primary cooling system, and houses the control plate guide box)
- Neutron beam guide tubes
- Cold neutron source
- Pipelines
- Structures for the different services and facilities

Figure 6 shows the different components inside the pool. At the centre, we find the reflector vessel together with the core and the riser; at the bottom, we see the primary cooling system pipelines and the pneumatic pipelines; at the sides, we see the storage racks; and below them, we find the neutron beam guide tubes.

Figure 6: Top view: Components inside the Reactor Pool

5. STRUCTURAL ANALYSIS

5.1 Introduction

The structural analysis of the reactor pool was divided into two parts, global and local.

The global analysis evaluates the pool as an assembly, considering its interaction with the Reactor Block.

The local analysis examines the structural behaviour of the pool at specific points due to the interaction between components (pipeline connection, internal supports, stiffening rings, lugs).

Standard off-the-shelf finite element programs (Ansys and Nastran codes) were used to analyse the structural behaviour of the pool, and analytical calculations were applied to determine magnitude orders and compare results.

The complexity of its geometry was represented through models such as pipeline penetrations, pneumatic pipeline inlet chambers, and opening to communicate with the transfer canal.

The applicable standard for the design, analysis, and fabrication of the pool is the ASME Boiler and Pressure Vessel Code, section III, subsection ND.

5.2 FEA models

The reactor pool model was built using the Ansys and Nastran programs, as shown in *Figure 7*, *Figure 8*, *Figure 9*, and *Figure 10*. Rectangular and triangular shell elements were used, as well as linear elements (beams).

The following components were considered:

- Cylindrical shell
- Bottom shell
- Ventilation, instrumentation, and overflow (VIO) channel
- Pneumatic pipeline chambers
- Transfer canal
- Stiffening rings and interface plate
- Penetrations
- Penetration reinforcements (pads)

Moreover, detail local finite element models were built for pool structure internal supports, as shown in *Figure 11*.

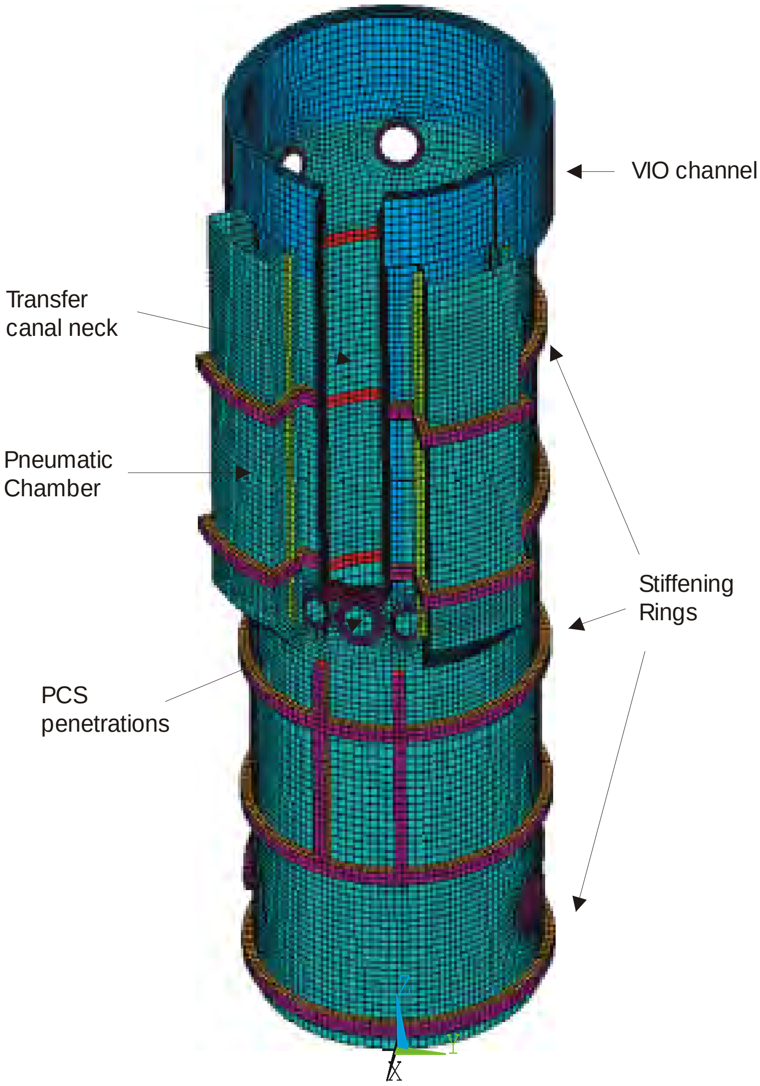


Figure 7: RPO FEA model

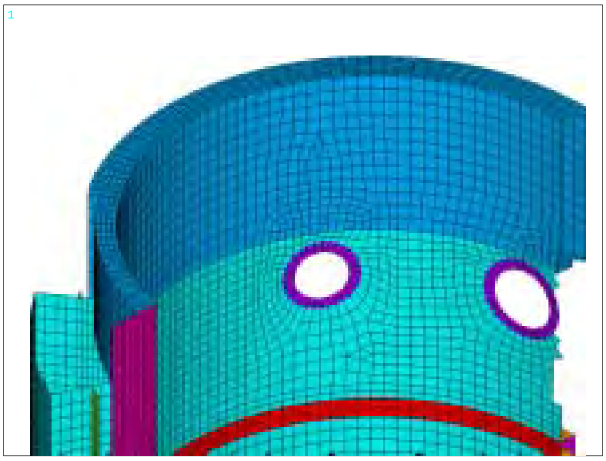


Figure 8: RPO FEA model: Service penetrations

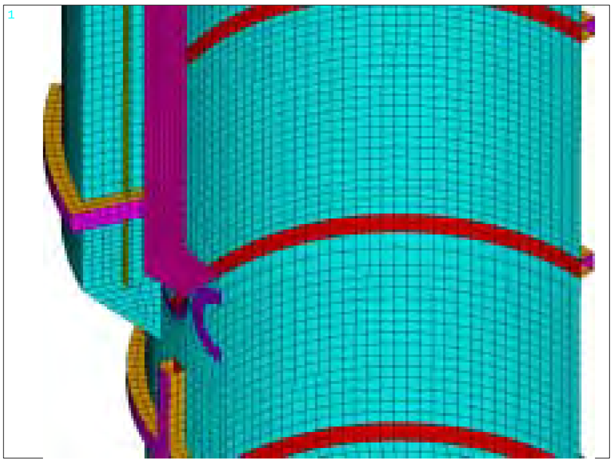


Figure 9: RPO FEA model: Central area, transfer canal, and pneumatic chamber

Figure 10: RPO FEA model: Neutron guide tube penetrations

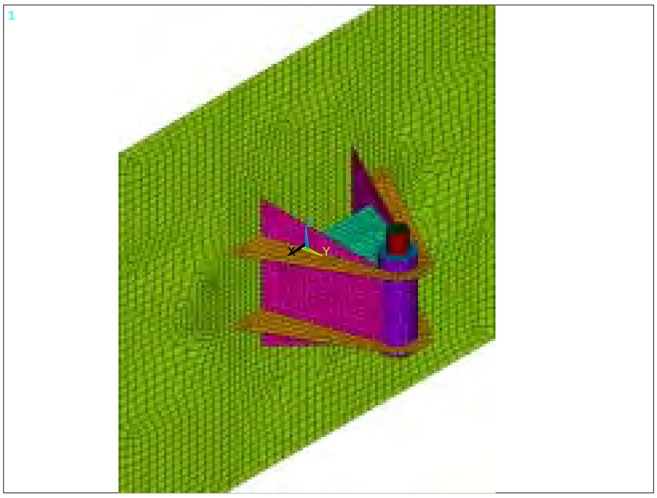


Figure 11 – Riser support FEA model

5.3 Applicable standard

The resulting stresses were compared with the allowable values required by the ASME Boiler and Pressure Vessel Code, considering the different service levels (A, B, C, and D). Service levels are based on the conditions registered on a component after it is stressed by a certain load cases (undamaged, repair, removal, etc.). The following levels were established for the case of the pool:

Table 1: Service levels

Stress	Service level
Hydrostatic pressure (installed)	A
Hydrostatic test	A
Thermal expansion (normal operation)	A
Seismic event	B
Thermal expansion (transients)	B
Thermal expansion (accident)	D

5.4 Load Cases

The Reactor Pool analysis consists in demonstrating the structural integrity of the pool for the following load cases:

- Seismic event
- Operation hydrostatic pressure
- Hydrostatic test
- Thermal expansion (normal operation and different special conditions)
- Local stresses on supports due to earthquake, impact, lifting operation

And the following combinations:

- Operation pressure + Normal operation thermal expansion
- Operation pressure + Transient thermal expansion (Loss of SCS with SSS)
- Operation pressure + Accident thermal expansion (Loss of SCS with SSS)
- Operation pressure + Accident thermal expansion (LOCA)
- Operation pressure + Normal operation thermal expansion + Earthquake
- Lifting and transportation

Seismic event

The Pool 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.

The Reactor Pool is rigidly connected to the Reactor Block (the pool was directly used as framework during the block concrete pouring), which means that the pool moves together with the block. Thus, the maximum stresses due to the Seismic Event will be given by the maximum displacements of the reactor block. In other words, the Seismic Event is analysed loading the model with imposed displacements.

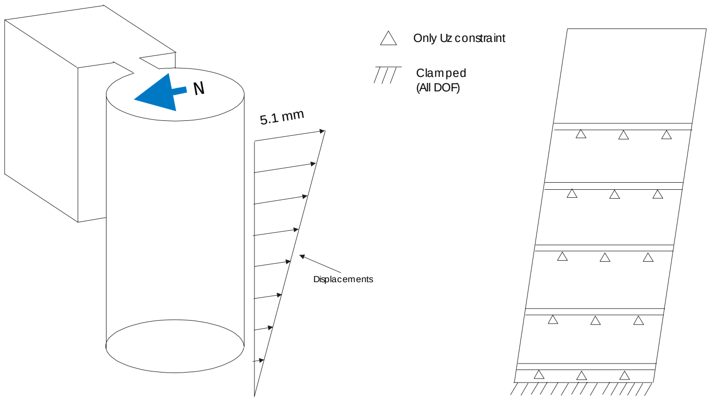


Figure 12: Imposed displacements and constraints imposed by the Reactor Block

Hydrostatic pressure

The Reactor Pool must withstand hydrostatic pressure in two situations, namely:

- **Normal operation:** The pool is embedded and rigidly restricted at the base, stiffening rings, transfer canal, and penetrations.
- **Hydrostatic test:** The pool only rests on its base. Reinforcement structures were designed, as the transfer canal is an opening which had to be closed and reinforced throughout the test on account of its size. *Figure 13* shows the reinforcements of the already-built pool.

Figure 13: Reinforcements structures for the hydrostatic test

Thermal expansion

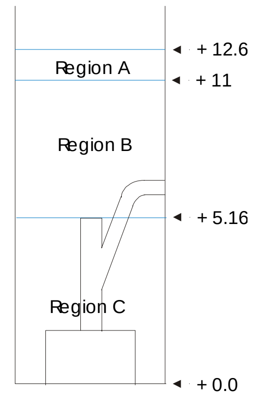
Table 2 shows the temperatures corresponding to the different load cases, known as “normal operation”, “anticipated operational transient”, and “accident condition”.

Stresses are registered in the pool in these cases, as the pool cannot expand freely since it is embedded in the reactor block. The thermal expansion coefficient of stainless steel is 1.55e-05 m/m°C, while that of concrete is 1.00e-05 m/m°C. Moreover, the block is connected to the rest of the building. In the event of a temperature rise, the pool expands more than the concrete, in light of which compressive stress will be registered on the shell.

The analysis also incorporates the expansion of the reactor block. A finite element model of the reactor block was built to consider its displacements.

Table 2: Thermal expansion load cases

Condition	Region A	Region B	Region C	Time
Assembly / Maintenance	20°C	20°C	20°C	Steady
1. Normal Operation	50°C	38°C	38°C	Steady
2. Anticipated Operational Transient (Loss of SCS with FSS)	50°C	45°C	40°C	0.5 h
3. Accident Condition (Loss of SCS with SSS)	90°C	90°C	60°C	30 h
4. Accident Condition (LOCA)	100°C (steam + air)	100°C (water level: +5.85 m)	60°C	5 h



5.5 RESULTS

The stresses obtained were compared with the allowable values required by the ASME Boiler and Pressure Vessel Code, considering the different service levels (A, B, C, and D).

Figure 14, *Figure 15*, and *Figure 16* provide stress and displacement (strain) graphic representation for different load states and combinations of them.

The design process was iterative and run in parallel with the analysis (manual and models). Therefore additional reinforcements were added in those sectors with high stresses and strain, specially at large openings and flat plates.

It is confirmed that maximum stresses fall below the allowable values required by the ASME Boiler and Pressure Vessel Code.

The criterion for the design of the inner pool supports was that of transferring the loads straight to the Reactor Block, so as to not stress the pool wall where the supports are welded. To meet this objective, structures were designed behind the pool wall in coincidence with the position of the supports. The structures remain embedded in the concrete.

A hydrostatic test was held to validate the design, and proved successful.

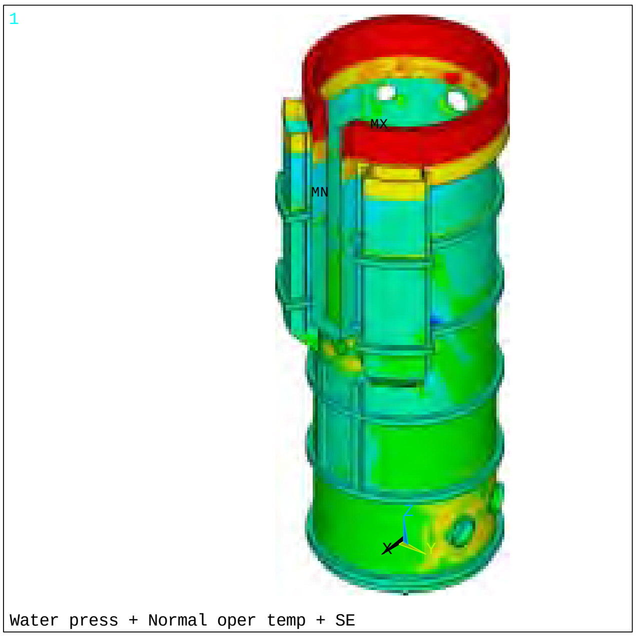


Figure 14: Combined load case: Hydrostatic pressure + thermal expansion + earthquake – Maximum principal stresses [Pa]

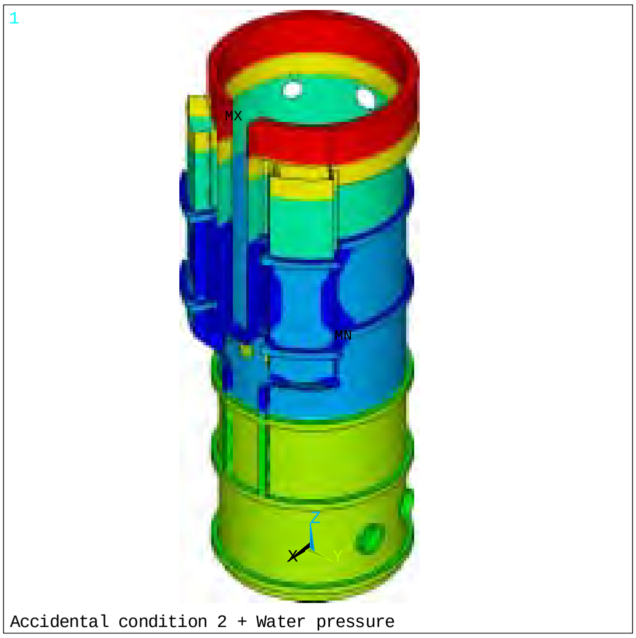


Figure 15: Combined load case: Hydrostatic pressure + thermal expansion + LOCA – Maximum principal stresses [Pa]

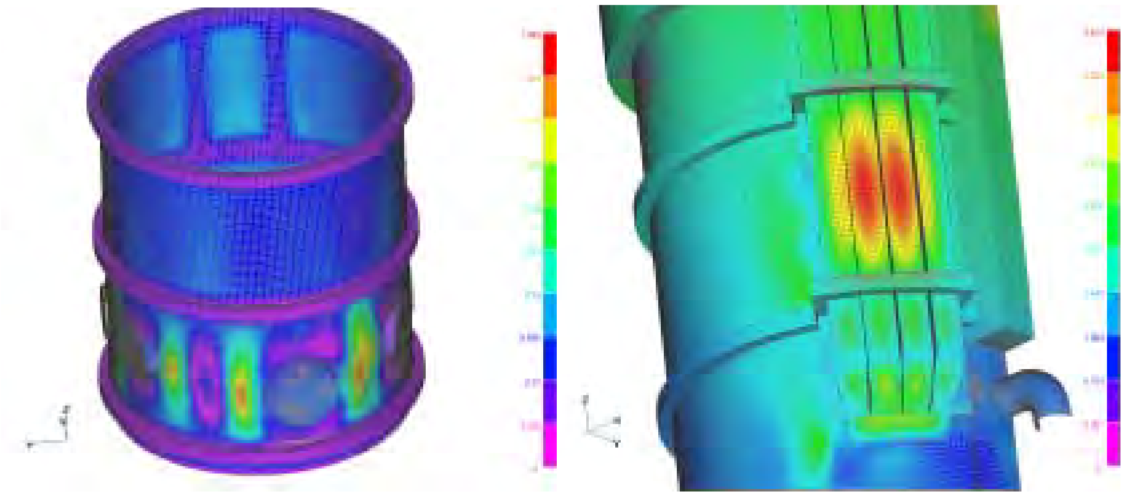


Figure 16: Hydrostatic pressure – Strains on beam and pneumatic system areas

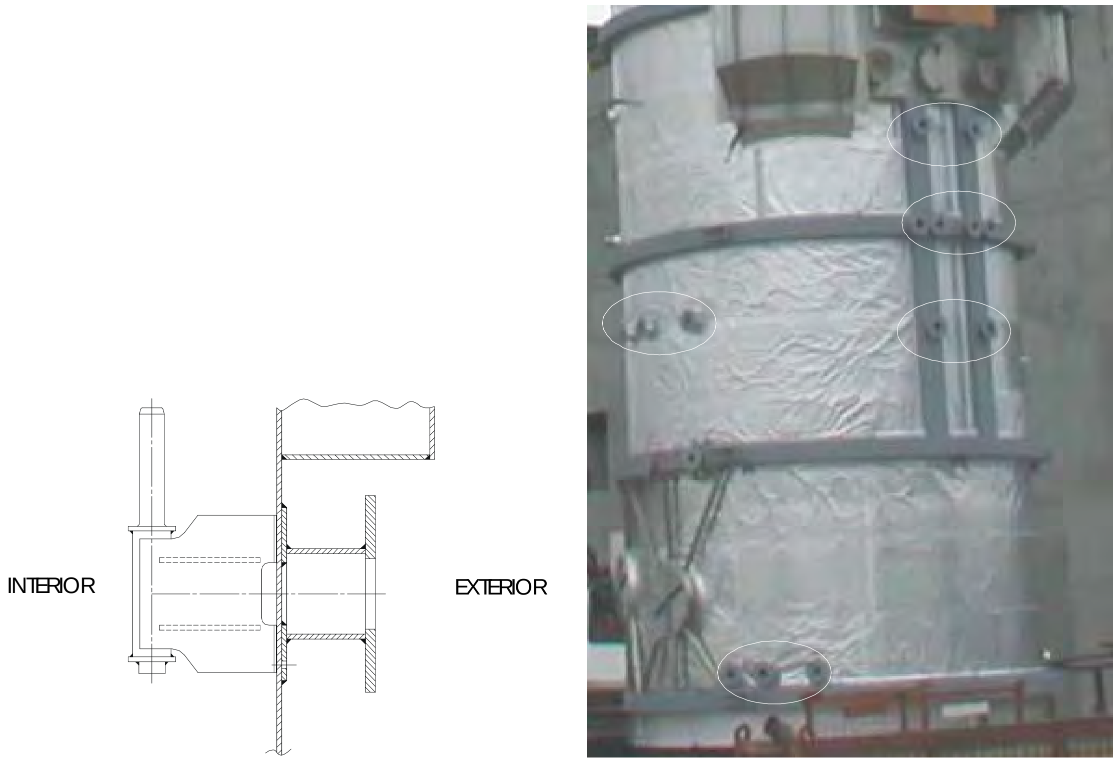


Figure 17: Structures behind the pool coinciding with the position of certain inner supports

6. FABRICATION AND INSTALLATION

The pool was manufactured following Code ASME III, Section ND (Pipelines were designed, manufactured, and inspected in accordance with Code ASME B31.1).

The pool construction is of the 100%-welded type.

ASTM-A240-304L stainless steel sheets were used for its construction. Penetrations were pre-marked on the sheets prior to rolling and welding the latter. *Figure 18* shows the area of the penetrations corresponding to the primary cooling circuit pipelines.

All welds that make up the pressure boundary were submitted to a 100% visual, penetrant dye, and X-ray inspection. The same inspection criterion was applied to all pipes.

Once the different pool sectors were manufactured, they were welded to make up two towers, a top and a bottom one. *Figure 19* shows the top tower. Stiffening rings were further welded to both towers, with their respective supporting sheets, pneumatic chambers, and inner supports.

Finally, both towers were joined, and the ventilation, instrumentation, and top overflow channel were added, together with penetration reinforcements (pads) and inner pipelines.

Once the reactor pool was built, all inner pipes and internal stiffener structures were placed for further hydraulic test, transportation, lifting, and installation purposes.

Pneumatic tests were held on the pipeline connections, as well as a hydraulic test on the pool, during which the said pool was filled with water up to the level established for normal operation.

The pool was shipped to the site (*Figure 4*) and further lifted by means of cranes to enter it through the top of the reactor building (*Figure 20*).

Once both pools (reactor pool and service pool) were installed in the Reactor Block, all block embedded elements were installed and the corresponding concreting works were carried out to complete the Reactor Block.

Figure 18 – Rolled and welded sheet

Figure 19 – Top tower

Figure 20 – Lifting and installing the reactor and service pool

7. CONCLUSIONS

The reactor pool (RPO) was designed, analysed, manufactured, and inspected in accordance with ASME Boiler and Pressure Vessel Code III, Section ND.

The construction of the RPO required the following:

- Proper conceptual structural design
- Adequate analyst - mechanical designer interaction
- Analysis and construction experience

The reactor pool was analysed through finite element models, used for design assistance and structural qualification of the pool.

The pool was numerically evaluated under seismic event, hydrostatic pressure, thermal expansion and transportation.

All load cases and their combinations are adequately withstood by the pool structure, in accordance with the allowable values required by the ASME Boiler and Pressure Vessel Code.

The hydrostatic test established by the Code was carried out to validate the design analysis and construction.