RA-10 Design Management: Strategic Objectives and Specific Actions

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Abstract. Procurement of a research reactor requires a high degree of expertise about management of engineering design. The owner/operating organization has to respond to the technical and programmatic aspects of the modern research reactor projects, and needs to validate that all design decisions are appropriate and safe, in order to accept the prime responsibility for safety when the research reactor is commissioned.

A key factor in the RA10 project is the clear identification of the role that must be undertaken by CNEA from the beginning, in relation to its deep involvement on specific and diverse technical aspects such as site evaluation, design, construction, licensing, and commissioning and performance demonstration of the Reactor Facility. In this way CNEA, as the ultimate Operator of the Reactor Facility, would be in a better position to run the plant in a safe, sustainable and efficient manner. Accordingly, in order to properly accomplish this strategic objective and to ensure specific knowledge transfer in some technical issues from the external engineering suppliers, a dedicated Design Management Team was established. This paper presents examples of the specific actions developed in this regard, namely:

- Consolidate the technical requirements of its experimental users and the product specifications of the medical and industrial customers.
- Participate in site evaluation issues, analysis of particular environmental constraints, the assessment of external hazards design base, etc.
- Understand the regulatory framework: the appropriate codes and standards that should be applied.
- Supervise the progress of the design at the engineering stages, and coordinate the feedback between diverse thematic areas.
- Implement a Control Procedure to review and approve technical documents.
- Execute an Organizational Design Review Process to ensure that all the specific design criteria have been considered and they are in compliance with the mandatory requirements.
- Assist in procurement issues: domestic industrial capabilities evaluation, technical specification preparation for bidding process, etc.
- Develop methodologies for Safety-Seismic-Quality classifications of systems, structures and components.
- etc;

Moreover, CNEA has subscribed an agreement (contract) with INVAP for the execution of engineering tasks, covering from the preliminary design up to the detailed design stages. Design Management Teams, from CNEA and INVAP, have interacted in a coordinated manner in order to fulfil the project timeline. In this sense, this paper presents indicators developed to monitoring the progress of engineering work packages. (Man-hours by thematic areas and by engineering stages, additional engineering hours caused by design changes, work package delivery delays, etc.). Additionally, the procedure to carry out the Design Review Technical Meetings is presented.

Finally, experience has shown that nuclear projects must face challenges similar to other complex mega projects with additional specific issues. Some lessons learned are discussed and a concluding remark on the inescapable need of establish a high qualified team, from the very beginning, to manage the diverse and complex technical aspects converging in modern RR projects.

1. Organization for RA-10 Design Management

Significant challenges have arisen from the diversity of customer requirements which have to be managed by CNEA as responsible for the design, construction, licensing, commissioning and operation of this large multipurpose research reactor named RA-10. These customers range from technical industries, educational institutions, national and international research organizations and even nuclear power plant testing programmes.

RA-10 Project includes main and support processes (*See Figure 1*). One of the main processes comprises the design (conceptual, preliminary and detailed stages), the manufacturing, construction and commissioning. The utilization devices development and the safety and licensing management are also main processes.

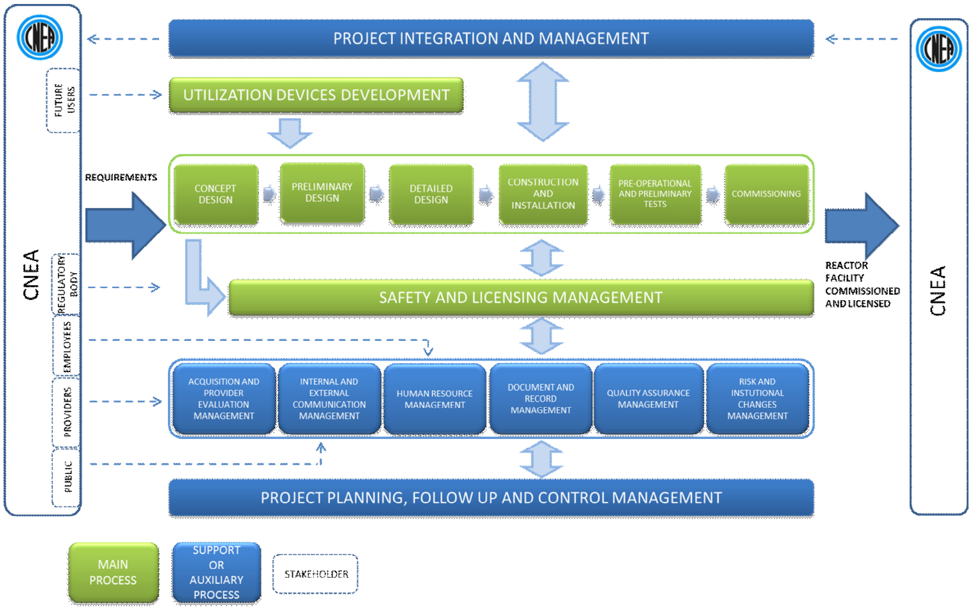

Figure 1. RA-10 Project Processes.

Main processes are those where the core project activities are conducted and whose successful completion leads to the direct accomplishment of the project objectives and compliance of the requirements. Support or auxiliary processes provide services to ensure the successful development of main processes.

Conceptual, Preliminary and Detailed design stages, as part of the main process, are carried out in accordance with the RA-10 Reactor Design Plan. Moreover, CNEA has subscribed an agreement (contract) with INVAP for the execution of most engineering tasks, covering from the preliminary design up to the detailed design stages. A key factor is the clear identification of the role that must be undertaken by CNEA from the beginning, in relation to its deep involvement on diverse technical aspects.

In order to properly accomplish this strategic objective within CNEA, a dedicated Design Management Team (DMT) was established by the RA-10 Project Direction, whose main functions are:

a) monitoring the design progress at the engineering stages.
b) coordinate feedback between working groups.
c) supervise the design review process.
d) implement an Administrative Control Procedure of technical documents

By the other hand, INVAP have designated its own Design Management Team, to coordinate the engineering work to and from its working groups (and from some external specialist consultants or subcontractors when necessary).

Both DMTs have interacted closely in a planned and systematic manner to fulfill the project timeline. In this regard, DMT's meetings are regularly held, on a weekly basis, in which the overall design status is reviewed and current specific technical issues are discussed.

Furthermore, thematic coordinators both in CNEA as in INVAP, were designated for each one of the following areas:

Neutronic
Thermal-hydraulic
Radiological Safety
Nuclear Safety
Mechanical Design
Process Systems
I&C
Civil / Architecture Design
LayOut / Integration
Electrical Systems
Licensing / Safety Assessment

Table 1. Thematic Areas

A brief summary of the main tasks developed by each thematic area can be consulted in the final appendix.

2. Work packages as a design management tool

The design work is assigned to the working groups in manageable portions called work packages (WP). The work packages are a type of subcontract and are identified by discrete Work Package ID numbers, at each engineering stage. A document known as Design Plan is the first deliverable document of each WP and typically contains the following information:

a) The scope and description of work to be done.
b) Responsibilities
c) Interfaces with other thematic areas
d) Input data required to the design
e) Applicable codes and standards
f) Design criteria
g) SSC´s safety, seismic and quality classification

h) V&V methodology to be followed.
i) A list of the documents to be delivered
j) The scheduled dates for commencement and completion of each task.

Planned design effort (man-hours) by Thematic Area and by Design Stage can be seen in Section 8- Table III & Fig 2. It is shown, for instance, that hours for Mechanical Design are seven times the hours for Neutronic Design.

Planned Design Effort (man-hours) can be seen in Section 8 - Table VI Fig3. Thematic Areas are grouped by related disciplines.

Planned Design Effort (man-years) can be seen in Section 8 - Table VI. Thematic Areas are grouped by related disciplines. It is shown that an average of 80 persons working full time during 5 years would be necessary to complete the design stage of RA10 reactor.

As a reference, total number of WP by stage and by thematic area, can be seen in Section 8- Table IV.

3. Design Review Process

INVAP is required to prepare all design documentation in sufficient detail and in a form which meets all the codes, standards and recommendations necessary to satisfy both the facility's performance specified by CNEA as the regulatory requirements established by the Regulator.

On the other side, CNEA is required to review and accept the design deliverables produced by INVAP verifying that safety and licensing requirements are satisfied.

The procedure to be followed for the review, verification and acceptance of the design deliverables provided by INVAP, is summarised hereunder.

Design deliverables are sent to CNEA for review and verification.

Within 15 working days of receipt, CNEA should undertake a thorough review of each design deliverable, and where necessary, may undertake additional analysis to verify the correctness of each design deliverable provided by INVAP.

In the event that some deliverables are considered to be deficient, INVAP will make the appropriate changes and these documents will be submitted again to further reviews, until such time as they fully comply with CNEA requirements.

Anyway, acceptance by CNEA of these design deliverables will not relieve INVAP of its responsibilities in relation to the achievement of the performance of the design as was contracted.

4. Design Review meetings

Throughout the preliminary and detailed design stages, INVAP is subjected to planned reviews of the developing details of the design, by CNEA staff and consultants. This process involves the conduct of a series of formal design review meetings.

Preliminary Design review meetings (PDR) are conducted when the design reached 30% of completion, whilst Critical Design review meetings (CDR) are conducted when the design reach 85% of completion.

PDR are aimed to ensure that all general and specific design requirements have been adequately addressed by each thematic area. CDR are aimed to ensure that the design solutions are adequate and the interfaces between thematic areas have been addressed, so that the design can be completed with no significant changes from that point on.

Both instances consist of meetings that may last up to one week, covering several Work Packages throughout a planned agenda, and they permit a thorough review of the design to detect inconsistencies and to provide feedback information between the working groups in a timely manner.

5. Design Change Management

Design change control is a very important aspect within design management. It should set up an effective design changes control process to verify the safety, functionality and reliability of items different from the reference design.

Design change may be made at the system level such as changes in performance, function, operating modes, control methods, or at the component level such as changes to service conditions, structures, materials, manufacturing methods and so on.

Therefore, design change control submissions for approval should include not only the design items themselves, but also changes to operating, environmental, interface conditions, and so on. Secondly, design changes need to be graded and reviewed based on their potential significance to safety and reliability. On the other hand, each thematic area must to assess the additional engineering hours and work package delivery delays caused by the design changes. Finally, design changes should be minimized because they usually cause schedule delays and cost increases.

All the design changes up to date were documented, and a suitable indicator can be seen in Section 8 – Table VII.

6. Document Control Procedures

During the design development, information is created, accumulated, classified, stored, and transferred to the relevant parties, distributed and when necessary destroyed. It can be technical and project information (drawings, diagrams, tables, 3D models, descriptions, analysis reports, bill of materials, etc.). It is important that these technical documents be accessible to all the working groups, with a controlled status of validity. In order to accomplish this, a centralized database was implemented, where all designers can access to the valid design documentation.

Total number of engineering documents by stage, emitted up to date can be seen in Section 8 – Table V.

7. Safety and Licensing Management

The safety and licensing process was started from the very beginning of the project together with the conceptual design stage in order to ensure that safety and licensing activities are an integral part of the development of the reactor design.

The main management tool for this process is the RA-10 Licensing Plan, which is aimed to coordinate the safety assessment and licensing activities to ensure that the established regulatory criteria are met. The licensing plan included the preparation of the safety assessments necessary for licensing purposes and the licensing documents, mainly the Preliminary Safety Analysis Report.

It should to ensure that each PSAR chapter is being properly elaborated in terms of structure and contents considering the regulatory requirements. Accordingly, a thorough review must be done to ensure consistency. To elaborate the first complete version of the PSAR, 9 months were required. The purpose of the PSAR is to report the results of the safety assessments. The safety assessments included:

- **Site Evaluation:**

To support the safety assessment it is necessary collecting all the relevant information regarding the site (geographical, demographic, meteorological, geological and hydrological data. External services supply. Nearby installations).Additionally, some site specific studies, which are requested to specialized organizations, have to be managed. Thus, it is necessary elaborate the specifications for these studies and coordinate the review of the final reports. Some of these specific studies for RA-10 project were: aircraft crash impact assessment, probabilistic seismic hazard assessment, hydrological studies, etc.

- **Nuclear Safety analyses:**

Both deterministic and probabilistic analyses are required for licensing purposes and to provide design feedback. Deterministic safety analyses are conducted to demonstrate that the design include the necessary provisions to cope with the anticipated operational occurrences or accidental conditions, derived from postulated initiating events, without surpassing the established acceptance criteria. Probabilistic safety analyses are required in order to demonstrate the fulfillment of regulatory criteria regarding safety systems reliability, derivation of core damage frequency, assessment of plant damage states, evaluation of source terms and consequence assessment. Thus, it is necessary elaborate the specifications for these analyses in order to fulfill national regulations and following international guidelines. These safety analyses were conducted by CNEA Nuclear Safety Department.

- **Design evaluation:**

A comprehensive design evaluation was conducted for all structures, systems and components important to safety as required by the applicable national regulations and international requirements. The evaluation includes, inter alia, SSC classification, internal and external hazard events (natural and man-made), etc. Aspects such as ageing and decommissioning were also assessed.

Finally, the results of the safety assessment were reported in the PSAR and were submitted to the Regulatory Body (ARN). The review process was completed on August 2014 and the regulatory body issued the construction license on October 2014.

8. Design Management Indicators

The design of a 30 MW Multipurpose Research Reactor is a major undertaking requiring a large investment in time, money, and human resources.

These indicators are intended to bring strategic information to national atomic energy organizations that are considering the construction of a high power research reactor. In this sense, the design of the RA10 Multipurpose Research Reactor is presented just as a case study.

Stage	Starting Date	Finish Date	Duration	% Completed
Conceptual Design	**4/2011**	**11/2011**	**8 months**	**100%**
Preliminary Design	**12/2011**	**7/2013**	**18 months**	**100%**
Detailed Design	**7/2013**	**7/2016**	**36 months**	**30%**

Table II. Status of the Design (November 2014)

	Planned Man-Hours	
Thematic Areas	Preliminary Stage (18 months)	Detailed Stage (36 months)
Neutronic	5782	17650
Thermal-hydraulic	3788	21715
Radiological Safety	3835	11900
Nuclear Safety	16000	32000
Mechanical	43507	122639
Process Systems	43584	93923
I&C Systems	16804	98000
Civil / Architecture	12700	51540
LayOut / Integration	9732	27008
Electrical Systems	5300	21300
Licensing / Safety Assessment	21332	20560
Design Management	23450	47001
	205814	**565236**
	771050	

Table III. Planned Design Effort (man-hours) by Thematic Area and by Stage

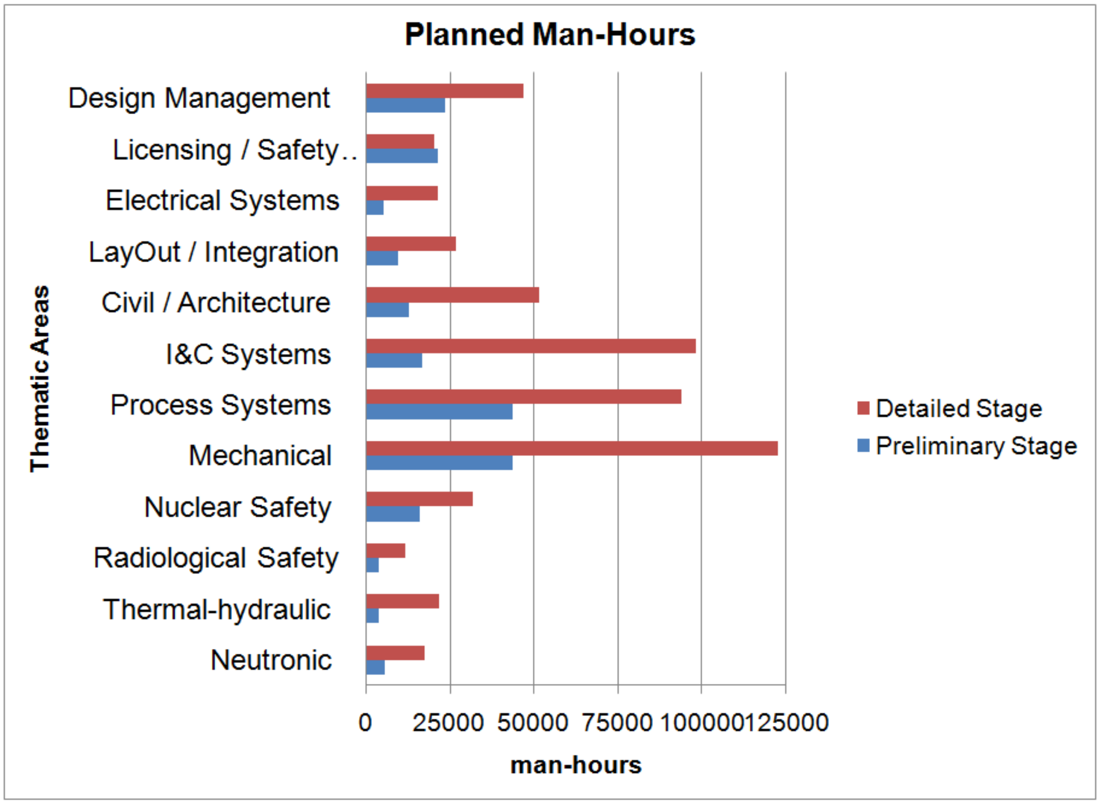

Figure 2: Planned Design Effort (man-hours) by Thematic Area and by Stage

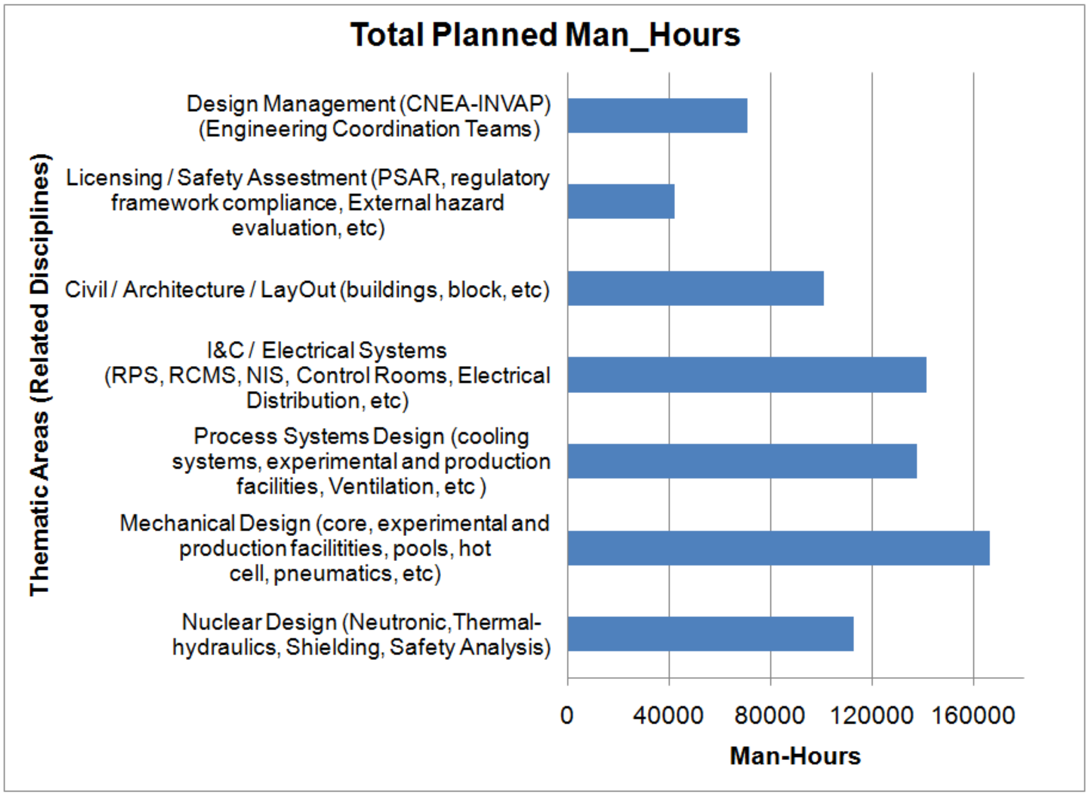

Figure 3. Planned Design Effort (man-hours). Thematic Areas are grouped by related disciplines

Nº Work Packages		Thematic Areas (related disciplines)
Preliminary Stage	Detailed Stage	
4	7	Nuclear Design (Neutronic,Thermal-hydraulics, Shielding, Nuclear Safety Analysis)
12	27	Mechanical Design (core, experimental facilitities, pools, hot cell, pneumatics, etc)
7	19	Process Systems Design (cooling systems, experimental facilities, Ventilation, etc)
8	9	I&C / Electrical Systems (RPS, RCMS, NIS, Control Rooms, Electrical System, etc)
8	12	Civil / Architecture / LayOut (buildings, block, etc)
39	74	

Table IV. Total number of Work Packages by Thematic Area and by Stage

	Documents Issued	**% Completed**
Conceptual Design	142	100%
Preliminary Design	1897	100%
Detailed Design	1308	30%

Table V. Total number of Documents Issued (November 2014)

[*] Type of Documents: descriptive memories, technical reports, P&I diagrams, plans and drawings, lists, etc.

Man-Year (5 years)	Planned Man-Hours (Preliminary + Detailed)	Thematic Areas (related disciplines)
12	112670	Nuclear Design (Neutronic,Thermal-hydraulics, Shielding, Nuclear Safety Analysis)
17	166146	Mechanical Design (core, experimental and production facilitities, pools, hot cell, etc)
14	137507	Process Systems Design (cooling systems, experimental facilities, Ventilation, etc)
15	141404	I&C / Electrical Systems (RPS, RCMS, NIS, Control Rooms, Electrical Distribution, etc)
11	100980	Civil / Architecture / LayOut (buildings, block, etc)
4	41892	Licensing / Safety Assestment (PSAR, external hazard evaluation, site evaluation, etc)
7	70451	Design Management (CNEA-INVAP) (Engineering Coordination Teams)
80	**771050**	

Table VI. Planned Design Effort (man-years) and (man-hours).
Thematic Areas are grouped by related disciplines

Design Stages = Preliminary + Detailed = 18 months + 36 months = 5 years
It means an average of 80 persons working full time during 5 years

Man-Year: A method of describing the amount of work done by an individual throughout the entire year. The man-year takes the amount of hours worked by an individual during the week and multiplies it by the number of weeks worked in a year. The man-year calculated can be different for various industries.

Design Changes (DC)				
Preliminary Design (100%)		Detailed Design (30%)		
Total : 19 DC		Total : 17 DC		Thematic Areas (related disciplines)
WPD	AEH	WPD	AEH	
120 days	550 hs.	30 days	368 hs.	Nuclear Design (Neutronic,Thermal-hydraulics, Shielding)
30 days	800 hs.	150 days	1810 hs.	Mechanical Design (core, experimental and production facilitities, pools, hot cell, pneumatics, etc)
		90 days	2100 hs.	Process Systems Design (cooling systems, experimental and production facilities, Ventilation, etc)
		45 days	866 hs.	I&C / Electrical Systems (RPS, RCMS, NIS, Control Rooms, Electrical Distribution, etc)
		15 days	570 hs.	Civil / Architecture / LayOut (buildings, block, layout, integration etc)
	1350 hs.		**5714 hs.**	

Table VII - Design changes up to date (November 2014).
Thematic Areas are grouped by related disciplines

It is shown Additional Engineering Hours (AEH_hours) and Work Package Delays days (WPD_days) caused by design changes, presented by engineering stage and by thematic area (grouped by related disciplines).

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9. Conclusions and Lessons Learned

- Multipurpose Research Reactor projects require a high degree of expertise about management of engineering design.

- If design work is conducted by different organizations, good coordination and communication is essential for a successful outcome.

- It is mandatory assign high priority to safety and quality over cost and schedule;

- Design review meetings (PDR & CDR) have proved to be of strategic significance, in order to detect inconsistencies and to provide feedback information between the working groups in a timely manner.

- The systematic administration and preservation of technical documentation, in order to support the traceability of the design for future modifications, is of vital significance.

- Design changes entail additional engineering hours and project schedule delays therefore their control is a very important aspect within design management. An important lesson learned on this regard is that even minor changes may cause large cascading effects.

- Early definition and mutual agreement with the regulatory body, about the regulatory framework to be applied, about the scope and depth of safety assessment, and about structure and contents of PSAR, allows a straightforward licensing process, saving time and effort.

- Design solutions supported on proven technologies are less challenging, complex, and costly than innovative design solutions.

- CNEA, as the ultimate operator of the RA-10 reactor, have been deeply involved from the very beginning, on all technical aspects of the project such as site evaluation, design, engineering and licensing, and will continue in this way during construction, commissioning and performance demonstration of the reactor, in order to be in a better position to run the plant in a safe, sustainable and efficient manner.

10. References

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Specific Considerations And Milestones For A Research Reactor Project, IAEA Nuclear Energy Series NP-T-5.1, Vienna (2012)

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Implementation of a Management System For Operating Organizations Of Research Reactors, IAEA Safety Report 75, Vienna (2013)

[3] AUTORIDAD REGULATORIA NUCLEAR, Design of Nuclear Research Reactors, Regulatory Standard AR 4.2.2, Revision 1, Buenos Aires, Buenos Aires (2002).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Research Reactors, IAEA Safety Requirements No. NS-R-4, Vienna (2005).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Evaluation for Nuclear Installations, IAEA Safety Requirements No. NS-R-3, Vienna (2003).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report, IAEA Specific Safety Guide No. SSG-20, Vienna (2012).

11. Appendix: main tasks developed by each thematic area

Neutronic Design

- Core configuration, Reactivity and Power Peaking Factor
- Excess reactivity throughout the fuel cycle
- Reactivity Feedback Coefficients and Kinetic Parameters
- Neutron Flux Distribution, power densities and burnup.
- First Shutdown System Reactivity Worth
- Second Shutdown System Reactivity Worth

Thermal-hydraulic Design

- Power State and Shutdown State: Flows, Velocities, Pressure Drops, Wall Temperatures, etc.
- Thermal and Hydraulic Analysis of the Core
- Thermal and Hydraulic Analysis of the Control Rod Plates and Control Rod Guide Box
- Thermal and Hydraulic Analysis of the Irradiation Facilities
- Thermal-hydraulic Effects of Anticipated Operational Occurrences

Shielding / Activation Calculation

- Determination of radiation source parameters, intensity, activity, isotopic composition, etc.
- Transport calculations through the proposed shielding and evaluation of the desired response (dose, energy deposition, etc.) at points of interest.
- Bunker and Associated Shielding

Nuclear Safety Analysis

- Identification of design basis initiating events
- Radiological consequence analysis
- Event sequence analysis (RIA, LOFA, LOCA, etc)
- Transient analysis
- Beyond design basis accident
- Probabilistic safety analysis
- Safety System Reliability calculations and failure frequency determination

Mechanical Design

- Verification of stresses and displacements of the reactor mechanical components
- Structural and seismic analysis, Thermal Stress Calculation, Stress due to Pressure Difference, Critical Buckling Stress, Fluid–Structure interaction, etc
- Design of Reactivity Control Rod mechanisms
- In-Core and Out-of-Core Irradiation Facilities
- Radioisotope Handling Facilities, Hot Cell
- Neutron Beam Facilities
- Pneumatic Transfer System
- Reactor and Service Pools, Reactor Bridge, Flap Valves and Siphon Breakers
- Core Grid, Control Rod Guide Box, Fuel Clamps, Reflector Vessel, Core Chimney
- Decay Tank
- Instrumentation Support Structures

- Mechanical Design of Cold Neutron Source
- Cranes - Hoists and Lifting Devices

Process Systems Design

- Selection of components (Pumps, Heat Exchanger, Valves, cooling towers, etc)
- Calculation of the piping circuits.
- Chemistry of Reactor Coolant: Purification System, Ion Exchange Columns, Resins
- Primary Cooling System
- Reactor and Service Pools Cooling System
- Deuterium Cooling and Purification System - Deuterium Recombination System
- Secondary Cooling System
- Confinement Ventilation Systems: ducts, dampers, filters, ventilators including motors, etc
- Heating, Ventilation and Air Conditioning Systems
- Process System of Facilities (Cold Neutron Source - Helium Compressors Circuit)

I**&C Systems Design**

- Reactor Protection System
- Reactor Control and Monitoring System
- Post Accident Monitoring System
- Nucleonic instrumentation (Fission Chambers, Compensated Ionisation Chambers
- Radiation Monitoring System
- Process Systems Instrumentation
- Control Room Design Human Machine Interface
- Comunications

Civil / Architecture Design

- Architectural Design, Structural Design, Footings Design, Site Foundations analysis, etc.
- Earthquake, Aircraft Impact, Wind and associated missiles, Floods and water penetration, etc.
- Reactor Building, Reactor Block
- Auxiliary Building, Offices, Main Entrance
- Neutron Guide Hall
- Services Building - Facility Substation Electrical

Layout / Integration

- Equipment layout
- Routing: process pipe, ventilation ducts, cable trays. Check for interferences.
- Logistical issues
- Circulation of Personnel and Equipment
- Emergency Exits and Access, Air-locks, Hatches and Penetrations
  .

Electrical Systems

- System design, equipment procurement specifications, diagrams and load summaries. Cable sizing calculations. Grounding, Lightning Protection.

- Normal Power System: High Voltage Switchgear, Transformers, Distribution Switchboards, Motor Control Centres, distribution panels, cabinets, electrical components; cable trays, conduits;
- Standby Power System: Diesel Generators, Uninterruptible Power Supplies.

Licensing / Site Evaluation

- Safety assessments
- Preparation and submission of license documents, mainly the Preliminary Safety Analysis Report PSAR
- Assessment of regulatory framework compliance
- Site evaluation issues, analysis of particular environmental constraints, the assessment of external hazards design base
- Methodologies for Safety-Seismic-Quality classifications of systems, structures and component.
- Design evaluation for all structures, systems and components important to safety as required by the applicable national regulations and international requirements.