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INVAP perspectives and initiatives for proliferation resistance as research reactor's designer

Alicia Doval, Eduardo Villarino
Nuclear Technology Department
INVAP S.E., Av. Cmte. Piedrabuena 4950, R8404, Bariloche, Argentina.

Daniel Hergenreder
Nuclear Engineering Department
INVAP S.E., Av. Cmte. Piedrabuena 4950, R8404, Bariloche, Argentina.

Diego Ferraro
Nuclear Engineering Department
INVAP S.E., Esmeralda 356, C1035 Buenos Aires, Argentina.

ABSTRACT

INVAP is an Argentine tech-company recognized as one of the leaders within the research reactor industry, with more than four decades in the field and several on-going projects worldwide. INVAP's projects portfolio covers not only research reactors but also associated facilities such as radioisotope production facilities, neutron science halls and fuel fabrication plants. In this line, the consideration of good practices from non-proliferation point of view represents a key factor within the design.

As a nuclear vendor INVAP has been developing special skills and capabilities to deal with diverse customers and regulatory bodies, even with different cultural features. These capabilities allow the customer to be integrated within the project, to develop core capabilities and to share a smooth but effective knowledge transfer in high-visibility projects.

This paper summarizes INVAP´s ongoing research reactor projects and its partnership to tailor the reactor design according to the customer´s objectives and capabilities, making emphasis in their key characteristics from the designer point of view that enhance the proliferation resistance

1 Introduction

Almost every research reactor is one of a kind, not only because of its specific utilization objectives and user requirements but also because of the background and motivation of the stakeholders involved in the development and construction of the facility. In general, three are the main actors in the project of a new research reactor and associated plants, the customer, the regulator and the nuclear vendor, all of them pursuing the same goal, crafting a machine that is safe and fulfills the user's requirements reducing proliferation risks. A variety of possibilities arise for the vendor's offer depending on the customer's background and on the trajectory of the Regulatory Body; it is the vendor's experience and flexibility that will allow these capabilities to be harmonized in ad-hoc schemes.

In this regard, INVAP, an Argentine tech-company recognized as one of the leaders in research reactor industry, has been developing special skills and capabilities to deal with diverse customers and regulatory bodies worldwide, each of them with their own approach and cultural background to handle these technological and organizational challenging projects. With more than four decades of experience in the design, analysis, optimization, upgrade, construction and commissioning of research reactors and associated facilities [1], [2], [8], [11], INVAP has successfully completed high-visibility projects worldwide. This fact allows INVAP to count with a mature designer point of view that considers all these involved aspects as a whole, formed through a long work path of challenging projects dealing with diverse design requirements, users, foreseen applications and driver intended uses. Nowadays, INVAP has on-going projects in Argentina, Brazil, The Netherlands, Saudi Arabia and Algeria, among others. In particular, having such diverse customers scattered worldwide, applicable legislation and foreseen application of the facilities requires a systematic and consistent approach.

As a vendor, INVAP focuses on the expected customer's performance goals, tailoring a facility design to match the client's and stakeholders' expectations. For such purpose, a high degree of versatility in the design and analysis process is commonly required, likewise a custom-oriented approach [3]. On top of that, the strict attention to nuclear safety shall be regarded from the early engineering design, ensuring the peaceful use of the involved technologies, even if it represents a trade-off with the global facility performance.

Furthermore, INVAP continuous developing capabilities allow customers to be part of the design teams of the projects, to develop core capabilities and to share a smooth but effective knowledge transfer.

2 Main grounds of INVAP's reactor designs

Regardless the conventional engineering involved in all technological facilities, the design process of a research reactor and its associated facilities represents a multidisciplinary challenge that involves key areas such as neutron physics, thermal-hydraulics, mechanical design, fuel assembly design, shielding dimensioning and radiological protection. This coordinated effort shall be developed taking into consideration not only the expected outcome (such as scientific or production goals) but also the good practices and international guidelines. In this sense, INVAP develops its designs in line with the global community approach regarding the use of Low Enriched Uranium (LEU), switching the design challenges to the conception of high-performance customized reactor cores and associated facilities that consider LEU in all the involved in-core and ex-core applications.

2.1 The philosophy behind INVAP's reactor designs

As a general rule, and within the nuclear safety culture framework, INVAP approach in the design is based on a series of principles, namely:

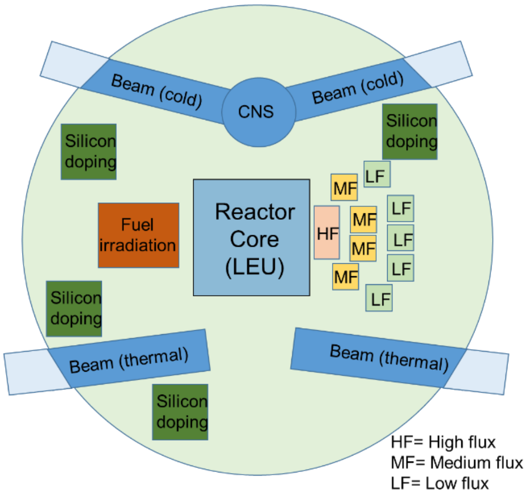
i. Always consider Safety as priority.
ii. Develop a customized design, tailored to client's requirements and capabilities.
iii. Involve peer-review and international experts from early engineering stages (e.g. IAEA, regulatory bodies, Technical Support Officers, ad-hoc consultants, etc.).
iv. Enhance visibility and integration with research reactors community.

As a consequence, INVAP designs for research reactors lead to a series of characteristics [3], [8], [11], which are observed regardless of the specific facility technological aspects (see Section 3):

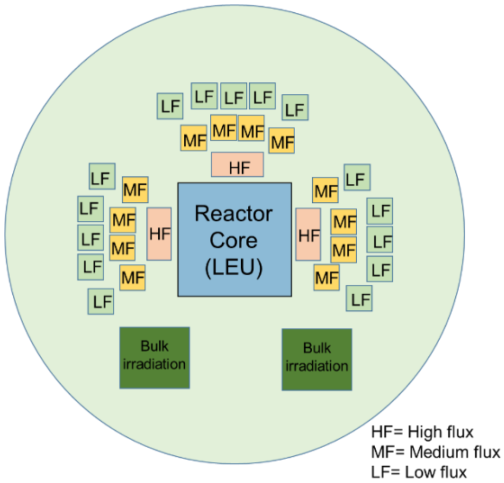
a. <u>Safety-oriented designs:</u> High safety-margins, with a mandatory fast First Shutdown System (usually composed by absorber plates) plus a Second Shutdown System (mandatory for high-power research reactors, diverse and redundant, usually not as fast as the First Shutdown System).
b. <u>Utilization of (LEU) fuels:</u> Mostly through plate-type U_3Si_2 (dispersed) designs, but also rodded-type (UO_2), with enrichment lower than 20%wgt for all cases. Alternative compounds such as UMo_x (dispersed or monolithic) are sometimes considered.
c. <u>Optimization of core performance and safety margins using tailored fuel managements and LEU fuel assemblies with burnable poisons:</u> To improve global performance of the shutdown systems and to improve power distributions each design counts with a tailored refueling strategy intended to maximize the foreseen applications and fuel burnup. For high-power research reactor reactors, it is a common approach to include burnable poisons, where the incorporation of cadmium wires within the fuel frames is the preferred solution by INVAP (for MTR-type fuels). The optimization of burnup (i.e. extraction burnup above 40% of the initial load) provides an isotopic barrier that enhances non-proliferation.
d. <u>Consideration of LEU targets:</u> Regarding ^{99}Mo production the consideration of LEU targets (usually $U\text{-}Al_x$) is nowadays a standard approach.
e. <u>High availability designs:</u> State-of-the-art designs are oriented to provide an availability of more than 300 FPD per year.
f. <u>Provide versatile design solutions:</u> Core and out-of-core devices are customized to customer's and stakeholders' goals, but also enough room to optimization/upgrade/reformulation of applications is considered by design, thus enhancing the interaction with future users, experts and research reactor's community world-wide.
g. <u>Continuous improvement of computational tools:</u> Neutronic and thermal-hydraulic computer codes are continuously improved for a better modeling of the core and out-of core irradiation devices, aiming to get the best achievable performance while keeping in mind the safety aspects as the main goal.

In particular, within INVAP's designs, such features are tailored depending on the main application both for the core and out-of-core devices [11], where this customization process is reflected into the global layout. As a general rule, multipurpose reactors (such as OPAL or RA-10, see Section 3) are oriented to a combination of scientific and radioisotope production, whereas dedicated facilities (such as PALLAS [4] or COQUI designs [15], [17]) are oriented to produce large amount of valuable radioisotopes (mostly for medical applications, but also industrial ones). These are schematically shown in Fig 1, where is key to note that INVAP designs consider the use optimization from early engineering stages, where the use of LEU for in-core and out-of-core devices remains as mandatory and states a strong constrain within the design process [3].

Fig 1. Scheme of the core and out-of-core design for multipurpose or radioisotope production dedicated reactors. Both core and out-of-core positions are designed to use LEU [3].



a) Schematic neutronic layout of a Multipurpose Research Reactor, where a crowded out-of-core layout arises from the diversity of foreseen outcomes.



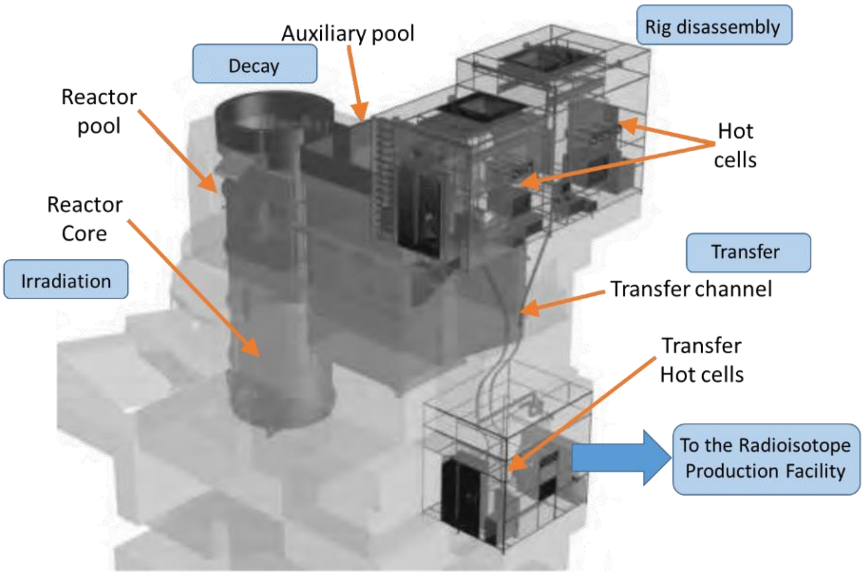
b) Schematic neutronic layout of a Radioisotope Dedicated Research Reactor, where larger amount of bulk facilities with a wide range of neutronic flux levels are usually available.

2.2 The irradiation in the research reactor of LEU and other materials

As mentioned in the former section, within INVAP's research reactor designs, only LEU is considered for both the fuel assembly and irradiation facilities. The preferred technology choice for the massive production of ^{99}Mo is the mini-plate fission, due to its proven scalability and high performance shown in the last decade. In particular, the potential proliferation concerns of this approach are handled by the use of LEU UAl_x targets, successfully developed by the National Atomic Energy Commission of Argentina, (CNEA) in 2002, likewise through the definition within early design stages of the layout the work path for the irradiation and processing of materials [17].

As an example of the impact of this approach from early design stages, Fig 2 presents an sketch of the work path for the LEU mini-plate targets for ^{99}Mo production for the on-going RA-10 project [8], [17], where the irradiation in the reactor core and the transfer up to the radioisotope production facility is schematically shown. This scheme thus represents an easy-to-follow and transparent path, where only LEU material is involved. This approach is considered from early layout design stages and it is also replicated in other INVAP's successful and on-going projects, such as OPAL, RMB or PALLAS. (see Section 3).

Fig 2. Scheme of the transfer of LEU targets from core for RA-10 reactor [17].

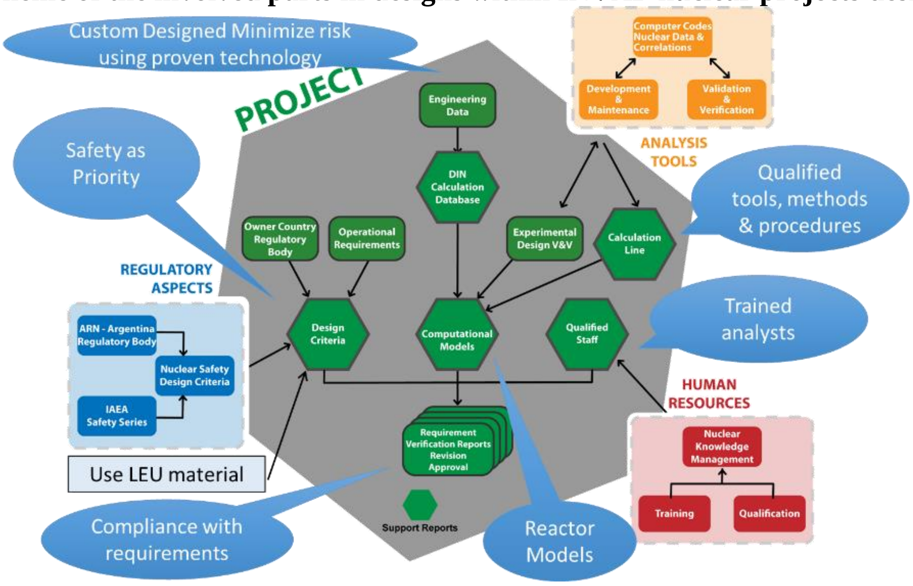


2.3 Involved aspects during INVAP's reactor design process

To handle all the aspects mentioned in former sections, INVAP's designs considers applicable regulatory aspects, international guides, Argentinian regulations, and project requirements as a whole, where the design is developed using validated analysis tools by highly qualified analysis.

All these sides interact during the diverse stages of a facility design, as shown in Fig 3, and have been successfully applied in several reactor designs and associated facilities, [2], [9], [13], [14], [15], [17].

Fig 3. Scheme of the involved parts in designs within INVAP nuclear projects design [10].



All these aspects within INVAP designs are also oriented to minimize operational costs and optimize the foreseen performance, which is also a requirement from the customers' point of view.

By this process, the total core power is always minimized through the optimization of the layout, and the fuel burnup is also optimized (thus providing an isotopic barrier regarding proliferation issues).

2.4 The importance of the training and knowledge transfer

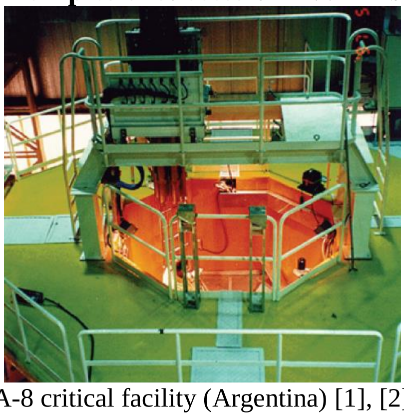
As reactor's designer with past and on-going projects within diverse cultures and legal frameworks, INVAP reinforces the importance of ensuring an appropriate training and knowledge transfer. Within this process, INVAP considers not only the owner and operator of the facility, but also other involved technical specialists and regulatory body if applicable. In this sense, the INVAP's approach is to ensure that the client and the involved stakeholders gain a deep understanding of the underlying technology, features, characteristics and limitations of the nuclear facility provided.

As a result, INVAP envisages the transference of know-how as part of the training activities, regularly developed during the diverse design and execution phases of the project. Depending on client´s capabilities and background, different approaches are implemented, aimed to ensure client's involvement in the design and enhance the operation of the provided facility. This approach was successfully applied in several projects (see next Section), where it is always oriented to enhance the safe and peaceful use of the nuclear energy.

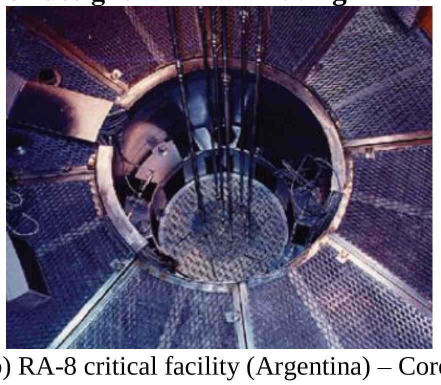
3 Examples of INVAP's reactor and associated facilities designs

The design aspects mentioned in former sections were successfully applied during the last 40 years within INVAP projects worldwide. Fig 4 shows examples for diverse reactor designs, in a broad range of powers. Examples of INVAP high-power multipurpose reactor designs such as OPAL (Australia, in operation since 2006 [12]), the ETRR-2 (Egypt, in operation since 1998 [9]), the RA-10 (Argentina, under construction [8],[9]), and the RMB (Brazil, end of detail design [6], [9]) are presented, likewise high-power dedicated radioisotope production reactors such as Coqui (USA, end of conceptual design [15]) or PALLAS (The Netherlands, currently detail design stage [7], [9], [16]). On top of that, low-power multipurpose reactors such as NUR (Algeria, to be upgraded [2]), RA-6 (Argentina [9], upgraded in 2008 and converted to LEU by the facility owner [19]) and LPRR (Saudi Arabia, under construction, [2], [5]) are also provided, likewise critical facilities as RA-8 (Argentina [9]).

Fig 4. Examples of successful INVAP's research reactor designs worldwide using LEU.

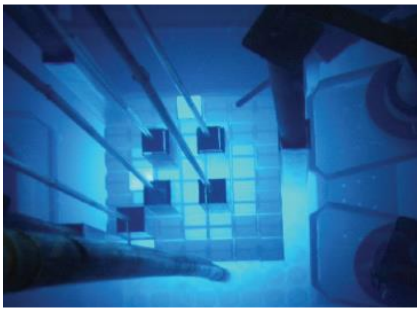


a) RA-8 critical facility (Argentina) [1], [2], [9].



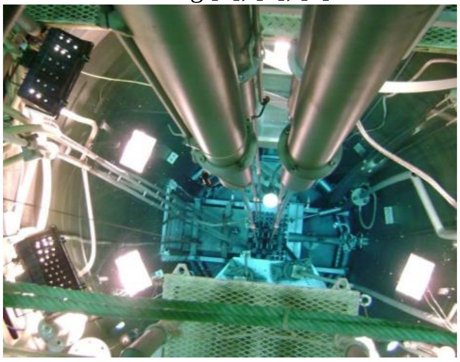
b) RA-8 critical facility (Argentina) – Core detail – Fuel rod array. Natural circulation [1], [2], [9], [8].

b) RA-6 reactor (Argentina) [1], [2], [9] – Upgraded to 1 MWth and converted to U_3Si_2 LEU [19].



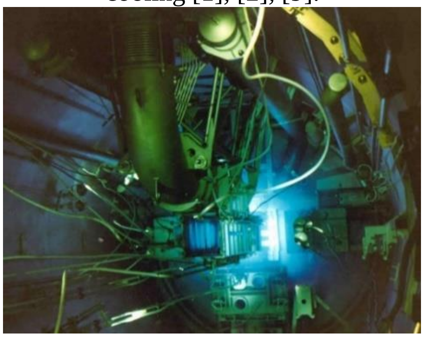
b) RA-6 reactor (Argentina). Core at full power (MTR-type). Downwards forced cooling [1], [2], [9].

c) NUR reactor (Algeria). To be upgraded to 3.5 MWth [1], [2], [9].



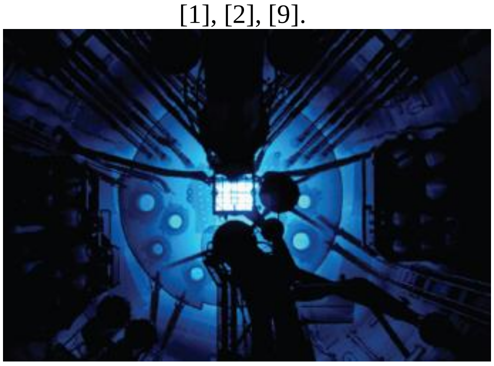
d) NUR reactor (Algeria). Core at full power (MTR-type). Downwards forced cooling [1], [2], [9].

e) ETRR-2 reactor (Egypt) - 22 MWth [1], [2], [9].



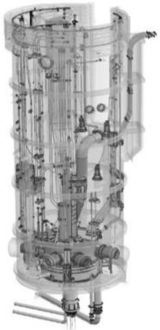
f) ETRR-2 reactor (Egypt). Core at full power (MTR-type). Upwards forced cooling [1], [2], [9].

g) OPAL reactor (Australia) - 20 MWth [1], [2], [9], [12].



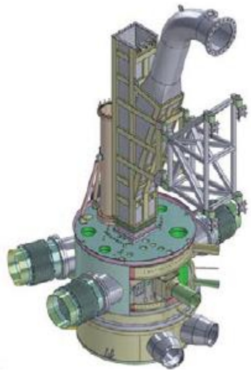
h) OPAL reactor (Australia). Core at full power (MTR-type). Upwards forced cooling [1], [2], [9], [12].

i) Scheme of the RMB reactor (Brazil) and associated facilities (detail design ended) - 30 MWth [2], [6].



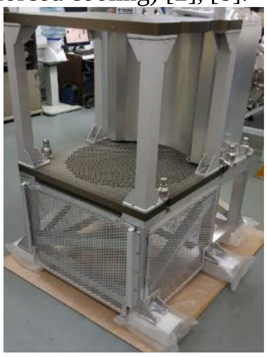
j) RMB reactor (Brazil). Sketch of the reactor pool [6].

j) RA-10 reactor (Argentina) and associated facilities (under construction) - 30 MWth [2], [8].



k) RA-10 reactor (Argentina). Sketch of the reflector vessel and primary circuit (upwards forced cooling) [2], [8].

l) LPRR (Saudi Arabia). Full model of the facility (under construction). Low power, natural circulation, rod type - 70 kWth [2], [5].



m) LPRR (Saudi Arabia). Core grid (to be installed) [2], [5].

n) PALLAS reactor (The Netherlands). Full model of reactor and associated facilities (PSAR presented, detail design started) - 25 MWth [2], [4], [7].

Regarding the associated facilities, examples of INVAP designs are presented in Fig 5 for radioisotope production plants and Fig 6 for fuel assembly manufacturing. As already mentioned, for both cases, only LEU material is considered, using processes that were fully developed and validated in Argentina, involving international peer-reviewers and independent experts.

Fig 5. Example of INVAP's LEU radioisotope production facility designs [1].

a) Radioisotope Production Facility (Egypt).

b) Front of the hot-cells.

c) Example of the hot-cells' equipment.

Fig 6. Example of INVAP's LEU FA production facilities and associated equipment [1].

a) Fuel Production Facility (Egypt).

b) Examples of provided equipment.

Last but not least, depending on the customer background, capabilities and objective and in compliance with nuclear regulations, INVAP harmonizes all these aspects in ad-hoc schemes. These schemes are focused on supporting an Intelligent Customer and on developing the core capabilities required to perform the role of Design Authority, as needed, in a responsible way.
The involvement and commitment of customers in the design teams at early engineering stages enhance not only the knowledge transfer but they are a key issue to smooth the licensing processes.
At the end of the day, supporting customers during the development of their projects to achieve their goals, ensures the peaceful and safe use of research reactors.

4 Conclusions

INVAP's projects portfolio covers not only the research reactors but also the associated facilities both regarding neutron science, massive radioisotope production and fuel fabrication plants. These are tailored and custom-oriented solutions successfully applied worldwide, where diverse regulatory frameworks apply. As a general rule, it was reinforced that all INVAP designs are focused in the optimization of the reactor core and associated facilities, preserving safety as a priority and following all international good practices from early design stages.

Most relevant aspects and approaches were presented from a designer's point of view keeping in mind that ad-hoc schemes are developed according to customers' capabilities and background. Besides that, a summary of completed and ongoing research reactor projects is provided, making emphasis in the full-scope use of LEU.

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