OPAL, FROM IDEA TO REALITY

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ABSTRACT

In the late 90s, Australian scientists and technologists envisioned a future Replacement Research Reactor for the Australian Nuclear Science and Technology Organisation (ANSTO) to expand national capabilities in nuclear science and nuclear technology, and future sustainable supply of nuclear medicine.

INVAP, an Argentinean company eager, at that time, to consolidate its reputation as a Research Reactor supplier, was engaged to transition ANSTO's idea to reality through the design and construction of the OPAL Reactor.

Today, twenty years later, the OPAL Reactor symbolises the success achieved by two passionate organisations in developing and delivering a project to enhance and expand national capabilities. Today, the OPAL Reactor offers the foundation for a promising future for both ANSTO and INVAP.

This paper discusses the relevant activities developed throughout the project by both owner and supplier, each from their respective point of view, focussing on the successful implementation of different strategies and the lessons learnt in various areas such as:

- Identification and interaction with stakeholders
- Establishment of project roles and responsibilities
- Resolution of technical issues
- Management of a seamless transition between commissioning and routine operation

The paper offers a review of OPAL operational performance over the past 10 years.

Finally, the ambitious future envisaged by both institutions, each in their own niche, are depicted and correlated with the activities being developed presently.

1 Introduction

1.1 ANSTO´s search for the HIFAR heir

By the end of the last century, ANSTO determined that its HIFAR reactor was unlikely to be fully capable of satisfying the expected increase in demand for medical radiopharmaceuticals and the radial configuration of the beam tubes severely restricts the scope and efficiency of neutron beam research.

As a result, in 1992, the Minister for Science and Technology set up a review of Australia's needs for a new nuclear research reactor to replace HIFAR. The Research Reactor Review was to assess the benefits and costs of HIFAR operations, its remaining useful life and its eventual closure and decommissioning. It was also to consider possible locations for a new reactor, environmental impacts at alternative locations, a recommended preferred location and regulatory and organisational arrangements for reactor based research. The outcome of the review was a series of recommendations as follow:

- Keep HIFAR going;
- Commission a probabilistic risk assessment to ascertain HIFAR's remaining life and refurbishment possibilities;
- Accept the financial implications of the fact that neither the current nor any new reactor can be completely commercial;
- Accept in consequence that any decision on a new reactor or other neutron source must rest primarily on the assessed benefits to science and Australia's national interest; and

- Make a decision on a new neutron source in about 5 years' time when the relative arguments relating to spallation sources, cyclotrons and reactors might be clearer and when Australia's scientific neutron scattering performance is more evident."

In 1994, as part of an ANSTO strategy review, four neutron source options were examined;

- Closing down HIFAR
- Upgrading HIFAR
- Building a replacement reactor
- Building a spallation neutron source

The preferred option was identified as the construction of a replacement multi-purpose research reactor, considered to satisfy the wide range of Australia's nuclear requirements.

Therefore, in 1997, the Australian Government decided that a replacement research reactor should be built at Lucas Heights subject to favourable results of an Environmental Impact Study (EIS). The EIS identified no reasons on the grounds of safety, health, hazard or risk to the environment to prevent construction and operation of a replacement reactor at Lucas Heights.

As such, at the end of March 1999, the Minister for the Environment recommended that the proposal be implemented subject to 29 specified conditions.

The conditions were imposed to ensure that the reactor is built and operated in accordance with best international practice in respect to:

- Construction and operation
- Management of wastes
- Monitoring and containment of emissions
- Management of hazards and risks
- Emergency management plans; and
- Community consultation

A project manager with extensive experience in the setting up project teams and the evaluation of complex tenders for major defence projects was contracted and a team of technical and contracts specialists prepared a set documentation that was issued as a Request for Tender to four pre-qualified reactor vendors (Atomic Energy of Canada Ltd.¸ INVAP of Argentina¸ Siemens AG of Germany and Technicatome of France). The four vendors were selected as a result of an evaluation of the responses to a worldwide invitation for expressions of interest issued in mid-1998.

The Request for Tender itself was a performance-based specification with minimal specifications relating to specific design features. Typical performance-based requirements included:

- A peak thermal neutron flux of no less than 3*1014 n.cm2.sec-1
- Reactor operating power shall not exceed 20 MW.
- The power coefficient of reactivity and the temperature and void coefficients of reactivity should be negative.
- At least one automatic fast-acting shutdown system and a second independent system will keep the reactor in a safe shutdown state with a shutdown reactivity margin of at least 1%.
- An operating cycle providing maximum availability, having routine shutdowns no longer than 4 days and at a frequency of no more than once in four weeks.

However, among the specific design requirements was that the replacement reactor must be a pool type having cleaner and higher intensity tangential neutron beams of wider energy range than those available from HIFAR. In addition, there was a requirement that the facility include a neutron beam hall within the reactor building to accommodate beam instruments that need to be located close to the reactor and a neutron guide hall adjacent to the reactor building that will accommodate most of the beam instruments.

1.2 Expanding INVAP business frontiers

By the end of the last century, INVAP was already acknowledged as a world-class reactor vendor after its successful participation in international bids, rivalling against vendors with a large history and exemplary precedents in the Research Reactor Market.

Therefore, the participation in the ANSTO call for tenders was a natural step forward for INVAP which was, at that time, just finishing the deployment of the 22 MW ETRR-2 Reactor in the outskirts of Cairo, Egypt.
The ETRR-2 was the second research reactor exported by INVAP to Africa. It is a multipurpose reactor completely designed and constructed by INVAP and featuring characteristics appropriate for satisfying the ANSTO requirements for OPAL such as:

- A compact core constituted by MTR type fuel assemblies surrounded by a beryllium reflector for housing irradiation facilities.
- Two completely independent and diverse shutdown systems.
- Beam ports for research.
- Pneumatic transfer systems and large volume irradiation positions.

Therefore, the ETRR-2 represented a good starting point for the design of the OPAL from the conceptual viewpoint. Nevertheless, due to some of ANSTO requirements such as the cold neutron source and the multiple neutron guides, INVAP was aware of the fact that engagement of extra resources was required for participating in the bidding.
A tender of such magnitude implies an expensive process for the tenderer, requiring the investment of a significant number of man-hour of senior staff members analysing the requirements and preparing a sound proposal both from the technical and economical viewpoints.
It also requires the identification of the knowledge required to be integrated into the design team and the logistics required for securing the design team participation, well before preparing the offer to be submitted.
Therefore, the decision to compete in the tender required the implementation by INVAP of a multidisciplinary task force deployed worldwide for identifying partners and subcontractors while in Headquarters in Bariloche the conceptual engineering of the OPAL was being conceived.

2 The bidding process

2.1 ANSTO perspective

The tender process was a “two envelope” system whereby the tenderers are required to submit in one “envelope” the technical and contractual details of their bid whilst submitting the pricing details in the other “envelope”. In practice, the tenders were significant packages of documentation that in the case of INVAP was contained in 10 volumes and included:

- Numerous plans, including project management, design management and construction management plans, a preliminary commissioning plan and a technology transfer plan.
- A Safety Statement that formed a precursor to the Preliminary Safety Analysis Report (PSAR).
- Documentation demonstrating the qualification of INVAP, the main sub-contractors and the main consultants.
- A detailed tender specification of the proposal.

The tenders from the other vendors were of similar size and this meant that the tender evaluation by ANSTO was a significant activity in its own right that was undertaken by many of the same team as that which prepared the Request for Tender. The tender evaluation process was quantitative in nature and included a clarification stage through which the vendors were able to provide additional information and modify their tenders where a shortcoming against the ANSTO performance requirements had been identified by the evaluation team. The tender evaluation was also subject to independent review and audit by the Australian National Audit Office (ANAO) to verify that appropriate probity was maintained throughout the evaluation process.
In July 2000, the tender evaluation process determined that the INVAP proposal was the best of the four tenders received and ANSTO contracted INVAP to provide the Replacement Research Reactor (RRR). INVAP subcontracted an Australian entity, a joint venture between John Holland and Evans Deakin Industries (JHEDI), to provide resources in Australia. There is an international network of over 100 subcontractors providing services, products and

materials to INVAP and JHEDI and a significant number of contractors providing project support services to ANSTO.

2.2 INVAP perspective

With the possible partners and subcontractors identified, a selection process started aimed at identifying the most suitable solutions to be implemented by the conceptual design being developed.

In the selection of partners and subcontractors, issues such as the quality of the product or services offered were considered as well as commercial issues such as:

- Customisation of the products to the Australian industrial practices and the particular OPAL design
- Application of Australian Standards
- Local representation in Australia
- Long term support and warranties to be offered to ANSTO

Next, the preparation of INVAP proposal started with the induction of INVAP selected partners and subcontractors into the leading requirements of the OPAL project as well as into the quality and safety requirements applicable to nuclear projects.

The need to ensure high availability and reliability of the OPAL SSC as well as the need to develop and deliver the support items for ensuring a safe and efficient utilisation of the facility required a thorough couching of those subcontractors lacking background in nuclear projects.

INVAP teams of experts travelled to the location of the partners and subcontractors during the tender preparation to assist them in developing their contribution to the proposal in total alignment with INVAP directives.

Being the "design of the core" the kernel of INVAP proposal, a large amount of resources was assigned to a design that would provide the expected neutron fluxes both in the research and production facilities at the minimum possible power level.

After very detailed calculations performed with the validated computational line developed by INVAP, a 20 MW power was defined as the appropriate range for satisfying the very demanding OPAL specs. Process systems developed for the ETRR-2 were adjusted to this power level and state of the art solutions were introduced for ensuring a proposal aligned with the latest requirements and practices.

3 Project development

3.1 ANSTO perspective

3.1.1 Project activities and responsibilities sharing

The ANSTO/INVAP contract was for design, construction, commissioning and performance demonstration of the RRR. In this way, the ANSTO responsibility and risk were minimised with the emphasis being put on INVAP to demonstrate that the RRR fulfilled the performance requirements as detailed in the contract. However, there was still a significant effort required from within ANSTO in relation to project oversight and verification, licensing and regulatory interface, coordination of ANSTO activities and preparation for the eventual handover of the RRR to the operating organisation. This effort was managed by a dedicated ANSTO Project Management Team under a contracted Project Manager who reported directly to the ANSTO Executive. Regular reporting was also required to other stakeholders, including the ANSTO Board, the Minister responsible, other Government departments, various advisory and user groups and others.

3.1.2 Project Progress

The Preliminary Safety Assessment Report (PSAR) was prepared and submitted as part of ANSTO's application to ARPANSA for a Construction Licence on schedule in May 2001. The PSAR was developed from the safety Statement provided as part of the tender package and based on the basic or conceptual system design. Detailed engineering commenced in February 2001 and continued in parallel with the evaluation of the Construction Licence application. This application was not only subject to detailed review by ARPANSA but also public review and a peer review by a team of international nuclear experts. All these reviews were completed satisfactory and a Construction Licence was issued in early April 2002, although there was a 2-month delay to examine the security implications of the events of 11 September 2001.

Following the issue of the Construction Licence, excavations for the reactor building were immediately commenced onsite. However, a geological fault was identified in the excavated site and construction was suspended to carry out a detailed investigation of the fault's capability (i.e. was it still active). The geological fault investigation determined that the fault was not capable having not moved for 9 million years ± 4.5 million years and ARPANSA approval to resume construction was received in October 2002. Concrete pouring commenced in November 2002 with the first major concrete pour in mid-December, with almost 1,000 cubic metres poured in one day.

The delays caused by the events of 11 September 2001 and the discovery of the geological fault during excavations for the reactor building were generally recovered and overall, the completion of commissioning was achieved only three months late compared with the original project schedule. Furthermore, although there were some deviations that resulted in additional costs to the project, there were no significant cost overruns. For a project of this size, complexity and duration, this is considered to be a significant achievement.

3.2 INVAP perspective

The construction phase would encompass activities in the construction site as well as in several specialised workshops worldwide, thus requiring a detailed coordination of these activities in order not to produce delays in the very tight scheduled being arranged.

Among the specialised workshops locations, the following may be mentioned:

- Russia: development and construction of the in-pile section of the cold neutron source
- Hungary: development and construction of the neutron guides
- Argentina: manufacturing of the pools' internal components including the zircalloy reflector vessel housing the heavy water and irradiation facilities
- France: manufacturing of the cryo generator for the CNS
- India: calibration of the core cooling system flow instrumentation

The manufacturing of several new features incorporated into the OPAL design required the construction of mock-ups and the performance of testing campaigns. One of the mock-ups developed was a 1 to 1 replica of the second shutdown system (SSS) for testing the dynamic behaviour of the heavy water dumping.

The logistics arrangements for the fabrication of components in locations close to the construction site required careful planning. An outstanding example of this type of coordination involves the reactor pool and the service pool: transportation of the pools from the manufacturing workshop to the construction site required coordination with road transit authorities as well as with the electric power companies.

Figure 1: SSS mock up and transportation of the Reactor Pool

In parallel with the procurement, manufacturing, construction and installation processes, INVAP started the development of those items that would be required to operate, maintain and utilise the reactor after its commissioning.
All these items were developed in a coordinated manner under the so-called ILS process. ILS stands for Integrated Logistics Support, a technique required by ANSTO in the original specifications developed for OPAL. The items covered by ILS ranged from the preparation of the spare list for ensuring the desired availability up to the operation and maintenance manuals and procedures.
The drafting of these manuals and procedures was primarily developed by the design teams which were familiar with the design and configuration of the OPAL; the framework was provided by the ILS group including:

- Comprehensive list of systems requiring manuals
- Comprehensive list of plant and systems procedures
- Plant configuration matrix defining systems operational states vis-a-vis reactor states
- Integration of INVAP produced manuals with COTS manuals
- Style Manual for writing manuals and procedures
- Structure of typical procedures
- Review process for ensuring accuracy, legibility and compatibility with other documents

The development of the training plan for the first operation team together with ANSTO specialists was performed during the construction phase and was a vital element for ensuring a smooth transition to future stages.

3.3 Commissioning

Reactor Commissioning was planned and executed in accordance with the guidelines established by the IAEA for research reactor commissioning. The commissioning organisational structure was based on the following groups:

- A joint ANSTO/INVAP Commissioning Management Group (CMG) – for oversight
- The Commissioning Group (CG) – day-to-day management of commissioning
- The Commissioning Teams - for individual tests
- The Commissioning Safety Review Committee (CSRC) – independent safety review
- The Commissioning Quality Assurance Group (CQAG) - QA, records and auditing
- The Commissioning Operations Group (COG) - formed the nucleus of the OPAL Reactor Operations organisation.

The Commissioning stages were:

- Stage A - where integrated systems tests were undertaken, including testing with a complete core load of dummy fuel assemblies;
- Stage B – 1st criticality (OPAL first went critical at 11.25 pm on 12 August 2006), full core load and reactor physics tests at reactor powers less than 400 kW.
- Stage C – Full power achieved in November 2006.

The full program of flux measurements for the neutron beam instruments was performed later while the irradiation facilities measurements were completed in early 2009. The results of those tests indicated that the design has achieved the performance requirements expected of the facility.

4 OPAL operational performance over the past 10 years

Below is a graph showing the number of OPAL operating days at power each calendar year since original criticality in 2016.

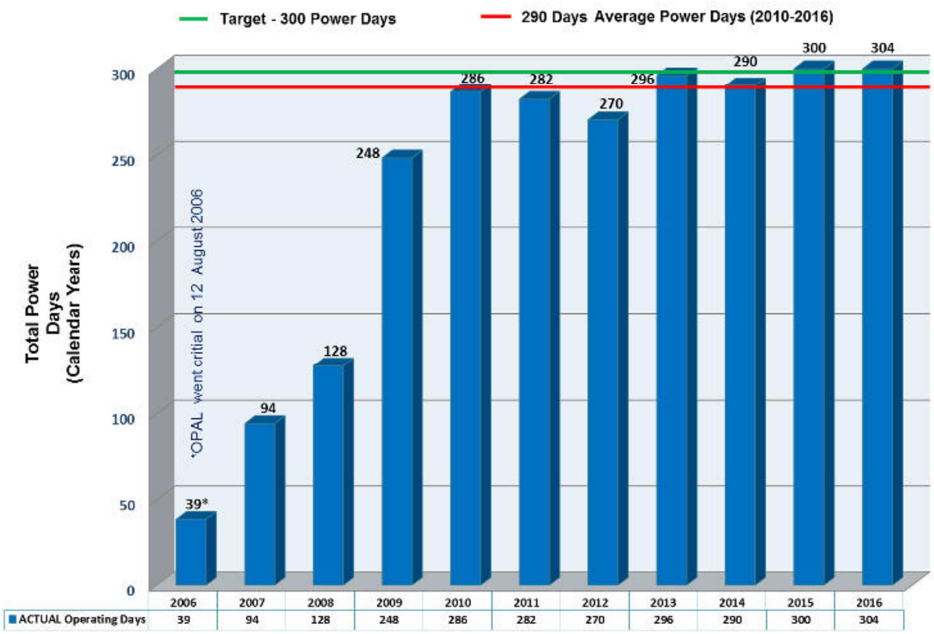

Figure 2: OPAL Operating Days at Power Calendar Years (2006 – 2016)

As can be seen, it took about four years before the OPAL reactor started achieving its full operational potential. This delay was mainly due to a problem encountered during early operation with the fuel assemblies that took 10 months to resolve, including the associated regulatory review and approval process. Since, 2010, the OPAL reactor has been averaging 290 days of full power operation each calendar year and the current business target is for 300+ days full power operation per year, which has been achieved for the last two years. The projected operating schedule means that this will continue to be achieved in the future, with the exception of 2019 when a major, long-term shutdown is scheduled and even then, we are still scheduling 210+ days of full power operation.

5 Lessons learnt

5.1 Lessons learned from ANSTO perspective

A number of lessons learned were identified by ANSTO from a project management perspective. In particular, ANSTO's recognised early on in the process of preparing for the RRR tender that it had a number of strengths and weaknesses in relation to the construction and operation of a RRR:

- Very experienced in reactor theory
- Very experienced in operation, maintenance, utilisation and modification of research reactor, specifically HIFAR
- Little experience at design, construction or commissioning of research reactors
- Little experience at management of major projects

As a result, a number of strategic decisions were made, including

- Utilise a turnkey contract with an experienced research reactor vendor.
- Prepare a performance-based tender that maximises the vendors' freedom to develop appropriate design solutions that meet ANSTO's requirements.
- Require the reactor vendor to maximise Australian content.
- Bring in an experienced project manager to lead the ANSTO team.
- Clearly specify that it is the Contractor's responsibility to prepare and to drive the schedule but that this would be controlled by ANSTO through liquidated damages provisions

The ANSTO project team also took into consideration team building, development and redeployment. This was particularly relevant as the team make-up varied dramatically through the stages of the project. As a result, it was necessary to choose the team carefully,

nurture the team through growth and development and assist in the redeployment of team members during the project's final stages.
A number of specific lessons learned were identified in relation to the licensing and regulatory aspects as follows:
Nothing helps the licensing process more than well-organised and clear submissions and approval process.

- A single working level point of contact facilitated the licensing process and minimised potential misunderstandings.
- Frequent, periodic meetings, even when there were no issues on the table, proved to be extremely valuable to build relationships.
- Top and middle management involvement in the licensing process is essential.
- Coordination between different regulatory bodies (e.g. nuclear safety and security) is essential to ensure clarity as to who approves what.
- Safety and Licensing has been integrated into the whole of the RRR project from preparation of the RFT onwards.

Overall, the single major lesson learned from the RRR project is that the clear identification of roles and responsibilities is fundamental to success closely flowed by the need to work as a team with a common objective.

5.2 Establishment of project roles and responsibilities

Project roles and responsibilities were clearly stated from the very beginning and maintained along the different project stages.
A full visibility of the actions being performed by each party (ANSTO, INVAP and subcontractors) was a key factor in the process by providing certainness and confidence that all the required actions were being taken in a professional and organised manner.
Periodic major reviews of the project's progress made by top representatives from the parties were also relevant for controlling that each of the counterparts interacting in the daily performance of the works behaves as expected in this allocation of roles and responsibilities.
Among the relevant roles, the following are to be mentioned:

- Development of the engineering
- Approval of the design
- Approval of design modifications
- Approval of test results
- Approval of deviations from the design targets.

5.3 Resolution of technical issues

Numerous technical issues emerged during the development of the project and these were resolved by a common resolution method agreed between ANSTO and INVAP.
A pillar for resolving these issues was the Detailed Engineering review process that meant each and every technical document prepared by INVAP or its subcontractors was subject to review, verification and acceptance by ANSTO. ANSTO comments were submitted to INVAP in the form of a Review Transmittal with the comments therein organised in a comprehensive and detailed list. INVAP then provided dispositions to the comments and subsequently provided revised versions of the technical documents where appropriate.
This review process was under the control of ANSTO and INVAP design managers with the resolution of comments identified in the Review Transmittals being undertaken by the specialists of the respective area. When required, design review meetings were organised to resolve outstanding issues in a multidisciplinary environment. The comments and associated dispositions identified at such meetings were included in the Review Transmittals. In few cases, the unresolved comments required the performance of additional assessments aimed at addressing particular issues.
The successful implementation of this process during the Detailed Engineering phase encouraged its continuation into the construction, system testing and commissioning phases, in which non-conformities were properly documented and Review Transmittals were

generated including, in some cases, the production of a Punch List that clearly detailed the issues to be resolved.

5.4 Management of a seamless transition between commissioning and routine operation

After the conclusion of the construction phase, a facility cold run was performed with the operational and logistic arrangements to be used in routine operation totally in place and enforced.

For this cold run, the reactor core was loaded with dummy fuel assemblies; the rest of the SSC were set up as per the operating conditions. The first operating team was also prepared and in condition to operate the plant following the manuals and procedures developed during the design stage and validated during the preoperational tests.

The end of the cold run confirmed to IN VAP that the construction works were finished and that the relevant issues listed in the few remaining Punch Lists were closed. The successful participation of the FOT in this cold run also ensured that ANSTO was in condition to assume the operational role as soon as the nuclear fuel was loaded into the core.

In support of this transition, INVAP arranged a team constituted by:

- Selected members from the Construction Group
- Selected members from the Design Group
- Senior operators from currently operating facilities in Argentina

6 The future ahead

6.1 ANSTO expectations

In accordance with ANSTO policy, Reactor Operations prepares a 5-year plan that identifies key performance indicators that are to be met. These include an OPAL reliability target of 98% (i.e. being at power when we say we will be at power), which from feedback from customers and stakeholders, is more significant than a pure availability target. However, it is recognised that a key aspect to achieving any performance targets is investment in our personnel as without this, all other targets become meaningless.

With respect to our customers and stakeholders, our objective is to operate a high reliability multi-purpose research reactor that provides on-time delivery of irradiation products and neutrons for research. In particular, it is our intention to grow our irradiation capability, increase user accessibility and maintain high NTD silicon production.

6.2 INVAP expectations

Since the completion of the OPAL project, INVAP has been involved in several research reactor tender processes, some of them closely related to OPAL.

As a result, two on-going projects are to be mentioned:

- RA10 reactor requested by the Argentinean Atomic Energy Agency (CNEA)
- RMB reactor requested by the Brazilian Nuclear Energy Agency (CNEN)

The specifications for these two facilities are based on the ones developed by ANSTO for OPAL. Some particular requirements required redefinitions and redesign: the most important being the increase in the reactor power for both projects, up to 30 MW, and the incorporation of in-core irradiation facilities.

In addition to these on-going projects, in several instances INVAP has been approached by operating organisations or newcomers into the research reactor arena, requesting quotations for developing OPAL like facilities.

7 Conclusions

The OPAL project represents an outstanding example on how two committed, matured and knowledgeable organisations may transform an idea into reality fulfilling all the expectations on schedule, budget and performance and developing a lasting framework of trust and friendship.