Australia's new Research Reactor – OPAL

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ABSTRACT

Australia's new Research Reactor OPAL, which is the single biggest scientific investment made by the Australian Government, is operating safely and efficiently. Over the past year the planned availability of OPAL has reached 83%. This is a great tribute to our highly skilled operating, engineering, maintenance and utilisation teams.

As experience in operation is gained, the utilisation of OPAL is increasing. Neutrons for science users from across Australia and the globe are being utilised in purpose built neutron beam instruments for a variety of research projects. Medical isotopes used in diagnostic nuclear medicine are being produced after irradiation in the reactor facilities. Facilities allowing Neutron Activation Analysis for research and industry are both on-line, and irradiation of silicon ingots for Neutron Transmutation Doping has now entered the commercial supply phase.

This paper will address these achievements from the perspective of a journey through commissioning and early operation that has contained within it significant challenges as well as successes. That perspective will contain observations and lessons learned on the process of transitioning from an established reactor operating organisation to a new one, which should be helpful to those parts of the international community that are either embarking on, or planning, construction of a new research reactor.

The future for OPAL is bright, and we plan to build on this early experience to support programs in Australia and internationally in the realms of neutron-beam science, radio-pharmaceutical supply, research and industrial applications.

INTRODUCTION

The Australian Government made a commitment in 1997 to fund a Replacement Research Reactor for Australia. At that time it was recognised that the ageing HIFAR reactor was approaching the end of its useful life, and that if Australian science was to remain vibrant in neutron diffraction, then a replacement neutron source would be necessary. This, combined with a need to continue supply of neutron rich radio-isotopes to the Australian medical community, and a strategic choice to be remain engaged in nuclear science & technology, led to the decision to fund a modern multi-purpose research reactor. The process for site selection, tender evaluation, safety and design, construction and commissioning has been documented and reported at IGORR meetings and other conferences.

The reactor which was later named OPAL, attained first criticality in August 2006, reaching its nominal full operating power of 20 MW in November of that year. OPAL is a multi-purpose reactor, with the ability to deliver neutron beams across a broad range of energies, using modern neutron guide systems with instruments that are regarded as world-class. It has a number of irradiation facilities contained in a heavy-water reflector that surrounds the light-water cooled core. Those irradiation facilities allow irradiation of materials for radio-isotope production, Neutron Activation Analysis (NAA), Delayed Neutron Activation Analysis (DNAA), Neutron Transmutation Doping (NTD) of silicon, and materials testing.

PREPARATION FOR OPAL

Prior to the positive decision by the Australian Government, the commitment by ANSTO to the replacement of HIFAR was significant in terms of stakeholder engagement, funding analysis, technical needs and strategic direction. Much of this work had to be conducted by people at senior levels of the organisation, under confidential circumstances.

Following the decision, the amount of work and engagement by ANSTO staff grew to meet the requirements for reviews addressing environmental, safety and Parliamentary concerns. As each of those concerns were successfully addressed there was increased involvement from a range of stakeholders, including regulators, especially the nuclear regulator ARPANSA, and future users of the facility. In parallel more ANSTO staff became involved in the development of the technical specifications for the reactor.

ANSTO has extensive experience in reactor operation, maintenance and utilisation as well as reactor theory. These factors were advantageous in allowing the development of detailed, rigorous and while challenging, ultimately achievable reactor performance specifications. ANSTO was less experienced with the design, construction and commissioning of a research reactor as it had been more than a generation since HIFAR had been built. ANSTO also had little experience in large-scale project management. These strengths and weaknesses were assessed and then a strategy was developed for the reactor acquisition with the following elements:

- The supplier to deliver a “turn-key” reactor;
- The supplier to be experienced in research reactor design, construction and commissioning and to be responsible for those facets;
- The value of the facility to be assessed on technical performance and compliance to established international standards.
- ANSTO to be an informed, knowledgeable and engaged customer throughout the project life;
- Engage an experienced “large project manager” to lead the ANSTO team.

At the basis of the development of these technical specifications was the work conducted by the Nuclear Analysis Group, which by using computer codes and modelling techniques developed over many years was able to detail the neutronic and thermal-hydraulic specifications that set the goal for the performance of the reactor. This approach proved to be extremely valuable, as it allowed for deep understanding of what was achievable through tender bidding, and later ensured that ANSTO was an informed customer once the contract had been awarded. During the tender evaluation process proposed designs could be modelled quickly and accurately and this reduced the technical risk to the organisation.

DESIGN & SAFETY

The Contract for supply of the reactor was awarded to INVAP SE in July 2000 and the preliminary design commenced immediately based on the contract specifications, which in turn were based on the tender technical specifications. ANSTO seconded staff to INVAP’s headquarters in Argentina, and throughout the design phase many ANSTO staff attended design reviews, training and inspections, which was consistent with the established strategy for the project.

The reactor core comprises 16 fuel assemblies in a 4 x 4 array, cooled by up-flow of light water. The fuel assembly is a box-type design with 21 aluminium-clad fuel plates that contain Low Enriched Uranium (LEU) silicide dispersion fuel. The conventional assembly contains 484g U235 when fresh, and each assembly contains 20 natural cadmium wires used as a burnable poison. The core contains 5 Hafnium control rods which form part of the reactor control system, and part of the First Shutdown System (FSS). The reactor has two independent and diverse protection systems – the First Reactor Protection System (FRPS), which actuates the FSS, is based on digital technology, and the Second Reactor Protection System (SRPS) is based on hard-wired technology. The FSS shuts the reactor down in less than 0.5s by gravity assisted injection of the control rods, while the SRPS causes the Second Shutdown System (SSS) to achieve shutdown by partial drainage of the heavy water from the reflector vessel surrounding the core. As the reactor is under-moderated a small change in heavy water reflector height is all that is necessary to make the reactor sub-critical.

Other key safety features of the design are: a reactor containment; a rigs cooling system; the ability to cool the core by natural circulation during shutdown, a large liquid deuterium cold neutron source (CNS) which is contained within a thimble that would resist a Deuterium-Oxygen explosion, thus allowing the reactor and CNS safety cases to be de-coupled.

As part of the licensing requirements for operation, ANSTO provided information in 5 parts to address the total safety case. Those parts are:

- Part A: General information on the purpose and location of the Reactor
- Part B: The plans and arrangements for managing safety of the Reactor Facility, including, maintaining effective control, safety management, radiation protection, waste management, ultimate disposal, security and emergencies. An Environmental Management Plan was also provided.
- Part C: The Safety Analysis Report (SAR) for the Reactor
- Part D: The Operational Limits and Conditions (OLCs) for the Reactor
- Part E: The plans and arrangements for hot commissioning the Reactor

The Application was supported by further documentation, including operation and maintenance manuals and the OPAL Business Management System (BMS). The BMS is one of the major bases for the operating licence as it encapsulates the documentation required to operate the reactor safely, including design, processes, procedures, instructions, forms, and other supporting documents.

REACTOR 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.

Samples of results from commissioning are shown below:

Stage A - where integrated systems tests were undertaken, including testing with a complete core load of dummy fuel assemblies;

Stage B – 1st criticality, full core load and reactor physics tests at reactor powers less than 400 kW. Table 1 shows reactor physics parameters as measured during Stage B.

Variable	Value	Design Criteria
Isothermal Feedback Coefficient	-15.74 [pcm/ºC]	< 0
Void Feedback Coefficient	-222.89 [pcm/% Void]	< 0
Power Feedback Coefficient	-0.74 [pcm/kW]	< 0
Power Peaking Factor	2.48 [-]	< 3
SDM of the FSS	10067 [pcm]	> 3000
SDM (Single Failure) FSS	6276 [pcm]	> 1000
SDM of the SSS	10461 [pcm]	> 1000
Safety Factor of Reactivity	2.01 [-]	> 1.5
SDM of FSS at 0.5 sec	9966 [pcm]	> 2000
SSS Reactivity worth in 15 sec	8488 [pcm]	> 3000
CRP Reactivity Insertion Rate	19.6 [pcm/sec]	< 20

Table 1. Reactor physics performance compared to design criteria

Stage C – Full power achieved in November 2006.

The full program of flux measurements for the neutron beam instruments is continuing while the irradiation facilities measurements were completed in early 2009. The results of those tests indicate that the design has achieved the performance expected of the facility.

REACTOR OPERATION, SAFETY & CHALLENGES

OPAL is currently operating in program number 17, which is equivalent to nearly 18 months of full operation. There was a lengthy shutdown of the reactor between July 2007 and May 2008, due to the widely reported fuel fault, where several fuel plates were discovered vertically displaced from the fuel assemblies. Since the return to service in May 2008, the reactor has operated for lengthy periods. During the period 1 July 2008 to 30 June 2009 the planned availability of the reactor was 84%, which is an encouraging indicator toward our aim of becoming a world leader in research reactor operations and utilisation by the end of 2010.

We have developed a set of Safety Performance Indicators (SPIs) based on the WANO system. These SPIs are comprehensive and are divided into those related to Reactor Safety, Radiation Safety, Industrial Safety and Safety Management. A “traffic light” system is used with the performance indicators to allow a rapid assessment of areas that are performing adequately, below expectation, or require immediate attention. Some of the SPIs are noted below.

Reactor Safety

- Unplanned automatic trips per 7000 hrs critical (WANO)
- Number of spurious safety system actuations when critical
- Number of reportable events INES > level 0
- Number of events INES level 0
- Percentage of INES level 0 or > level 0 with a human factor root cause
- Number of OLC breaches
- Number of times a Limiting Condition entered
- Unavailability detected during OLC SR
- Number of failures of ESF components (not requiring reactor shutdown)
- Maximum PCS activity ALMO 1 (maximum monthly)
- Maximum PCS conductivity (maximum monthly)
- Number of standing alarm**s** when critical (end of each week)

Radiation Safety

- Maximum individual effective dose
- Number of staff with dose above 5 mSv/yr

- Number of staff with dose above 2 mSv/yr
- Number of dose investigations required
- Number of personal contamination events
- (all dose figures on a rolling basis)

Industrial Safety

- Number of actual fires
- Number of Lost Time Injuries

Safety Management

- Number of internal BMS audits not completed to schedule
- Number of corrective actions from external Quality/Environment audits outstanding
- Number of accredited operators
- Number of housekeeping tours completed to schedule
- Percentage of event reports open after 1 month

As with any new and complex endeavour there have been a number of challenges for the OPAL team. The most complex and performance oriented challenges have been, the previously mentioned fuel fault, and the degradation of isotopic purity of the heavy water contained in the reflector vessel. Both these challenges will be mentioned in more detail in the meeting presentation.

THE FUTURE

Over the next two years, we aim to to deliver value to our customers and stakeholders through safe and reliable reactor operation. We also aim to continue to build and develop effective teams and engender, and where necessary strengthen, safety culture and communications. As these factors become normalised we will oversee the development of more efficient systems, with the aim of realising the investment in the OPAL research reactor for the benefit of Australia.