OPAL: Commissioning a New Research Reactor

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Abstract. OPAL is a new 20MW multipurpose research reactor owned by the Australian Nuclear Science and Technology Organisation (ANSTO) and located at Lucas Heights near Sydney, Australia. Construction commenced in 2002 and commissioning was completed in 2007. Commissioning a new research reactor is not a common event worldwide and the lessons learnt during the commissioning of OPAL may be of benefit to other reactor operators. Safety is of primary importance and ANSTO and the principal contractor (INVAP) worked closely together to establish a good safety culture enabling an excellent safety record to be maintained throughout commissioning.

1. Introduction

In 1997, The Australian Government announced that a new research reactor (OPAL) would be built at ANSTO's Lucas Heights site to replace the High Flux Australian Reactor (HIFAR), a 10 MW DIDO type reactor that had been operating since 1958. OPAL is a 20 MW multipurpose facility designed for neutron beam research, radioisotope production and irradiation services. The principal contractor (INVAP) and ANSTO established effective organisations, good communications and an efficient and flexible planning process and these were key to the success of the project.

2. Project Timeline

September 1997	Australian Government announced that a replacement reactor for HIFAR would be built
September 1999	Site preparation licence issued
July 2000	INVAP SE (Argentina) appointed as principal contractor.
April 2002	Construction licence issued
Feb – May 2006	Cold commissioning
July 2006	Operating licence issued
12 August 2006	Reactor taken critical
3 November 2006	Full power 20 MW achieved
May 2007	Commissioning completed

3. OPAL Reactor

OPAL is a pool type reactor with a thermal power of 20 MW. The reactor is cooled and moderated by light water with a heavy water reflector. The compact core has 16 LEU fuel assemblies in a 4x4 array and there are no irradiation facilities within the core itself. All irradiated facilities are located in the reflector vessel. Beam facilities include a cold neutron source (CNS).

Two completely independent and diverse protection systems plus a reactor containment are key safety features of the design.

4. Organisation

Under the contract, INVAP is responsible to ANSTO for most aspects of design, construction and commissioning. Design activities were based in Bariloche, Argentina, but INVAP established a substantial site organisation staffed by experienced Argentinean engineers and technicians. INVAP joined with two Australian companies – John Holland and Evans Deakin Industries for this project.

The project was divided into phases. Following construction and post installation tests, individual systems were proved in pre-commissioning tests. With all necessary plant pre-commissioned, systems were progressively integrated until the whole plant was operated without nuclear fuel in Stage A Cold Commissioning tests. Nucleonic signals were simulated to allow all sequences to be tested and all systems were verified to provide assurance that the plant was ready for fuel loading. Following the issue of the Operating Licence, hot commissioning began with Stage B fuel loading, initial criticality and low power tests. In Stage C, the reactor power was progressively increased in steps up to 100% (20 MW) and extensive testing carried out at full power.

The arrangements for commissioning were in accordance with IAEA guidelines [1]for research reactor commissioning. The commissioning organisational structure was based on the following groups, each having a clear function and responsibility:

A joint ANSTO/INVAP *Commissioning Management Group* (CMG) provided strategic oversight, ensured resources were available and authorised the start of each commissioning stage.

The three man *Commissioning Group* (CG) consisting of the INVAP Commissioning Manager, the ANSTO Commissioning Reactor Manager and the ANSTO Project Engineering Manager was responsible for the organisation of testing. The CG met daily to review and approve the test schedule, procedures, test personnel and start of each test. Commissioning progress was monitored and reports provided to the CMG. The CG produced a detailed rolling 2 week schedule of testing. This testing schedule was provided to the nuclear regulator (ARPANSA).

The *Commissioning Teams* for individual tests were drawn from INVAP and ANSTO staff. For each test INVAP nominated a Test Responsible and ANSTO nominated a Test Lead. Before the start of every test there was a test team briefing where the test procedure was reviewed in detail, timing agreed, safety precautions and hazards identified and individual responsibilities allocated.

The *Commissioning Safety Review Committee* (CSRC) had experts drawn from ANSTO and INVAP and was responsible for reviewing the safety implications of hot commissioning tests and reviewing modifications found necessary during commissioning. This group had more specific expertise than the general ANSTO Safety Assessment Committee and because the committee was dedicated to OPAL, the CSRC could react in a timely manner to the issues encountered during commissioning.

The *Commissioning Quality Assurance Group* (CQAG) was responsible for the QA plan, maintaining records and auditing commissioning activities. Both ANSTO and INVAP hold ISO 9001 accreditation.

ANSTO established a *Replacement Research Reactor Project Group (RRRP)* to manage the new reactor project. This group was responsible for all contractual issues, overseeing the construction and acting as the focus for the licensing work.

ANSTO also established a *Commissioning Operations Group (COG*) to take an active part in commissioning. This group formed the nucleus of the OPAL Reactor Operations organisation.

A Conduct of Testing protocol was agreed between INVAP and ANSTO. Key points were:

- Safety is emphasised to be of primary importance. A safety culture where management demonstrates commitment to safety and individuals show a careful, responsible attitude to operating the plant is essential

- Testing hours are defined as 08:00 to 20:00 with a possible extension to 22:00 to complete an ongoing test.

- Early each morning, a meeting will be held in the meeting room adjacent to the MCR to brief everybody involved in the testing planned for the day. The number of persons in the MCR is strictly limited and no meetings were to be held in the MCR

- Every afternoon the *Commissioning Group* will meet to review the testing and agree the scheduled program

To ensure that staff worked reasonable hours, the ANSTO commissioning operations group was organised into three teams to provide extended day working from the start of Stage A commissioning. Before the start of fuel loading, full 24/7 shift cover was in place with five shift teams. The minimum ANSTO operations shift staffing was normally one Shift Manager (professional engineer), one Reactor Operator and one Plant Operator. The Reactor Operator is responsible for the control of reactor operations from the Main Control Room (MCR). The MCR has a comprehensive Reactor Control and Monitoring System (RCMS) and most operations can be carried out from the MCR.

4.1. Reactor Operations Staffing and Training

The functional responsibility of staff to operate a research reactor depends upon many factors, most notably the nature of how the facility is used. Both the HIFAR reactor and the new OPAL reactor are designed for 24/7 operations with short planned shutdowns about every month for refuelling and maintenance. Both reactors require a full time operating staff.

There was not sufficient existing staff to operate two reactors, but some experienced operations staff were able to be released from HIFAR to join the new Commissioning Operations Group for the OPAL reactor.

An initiative that proved very successful was to recruit 10 recent engineering/science graduates as reactor engineers. Following a period of familiarisation with nuclear engineering on a variety of projects, these engineers and eight other staff from HIFAR and other divisions within ANSTO attended a five month training course. The course, led by an experienced HIFAR Reactor Shift Supervisor and based on IAEA guidelines, covered reactor engineering fundamentals, reactor principles and OPAL design and operation. An important aspect of training was regular toolboxes to discuss ANSTO policies and procedures, safety culture and conduct of operations topics such as control room techniques, shift handover and shift logging. Additional training also included five weeks with system designers in INVAP's headquarters in Bariloche, Argentina and hands-on sessions on the Argentinian pool reactor RA 6. INVAP's Integrated Logistics Group provided Power Point presentations and videos taken on mock-ups in additional to more conventional training material.

Unusually for a research reactor, the specification for the OPAL reactor included the provision of a reactor simulator. This has enabled all operations staff, but particularly the recent graduates, to practise reactor operations and gain a better understanding of reactor dynamics. Use of the STAR (Stop – Think – Act – Review) technique for operations was emphasised.

5. Documentation

The *Commissioning Plan* describes the objectives, organisation, responsibilities, outline of stage tests and all associated activities during commissioning. Specific commissioning plans for each commissioning stage were also produced containing the objectives and methodology for each test.

Each commissioning test was carried out to a written procedure, produced by INVAP and formally reviewed and accepted by ANSTO. It was important that the facility was tested by operating in accordance with the Plant Operating Procedures. When a deviation from these procedures was required for the particular test, detailed step-by-step instructions were included in the test procedure. A total of 108 commissioning test procedures were produced, 47 for Stage A testing, 39 for Stage B and 22 for Stage C. The test procedures included prerequisites, responsibilities, objectives, acceptance criteria, step-by-step instructions and record forms. Clear un-ambiguous acceptance criteria are essential and where calculations were required, the detailed calculation method was included in the test procedure. Test results were recorded on the record forms signed by INVAP and ANSTO representatives and outstanding issues were noted. Following completion of a commissioning test and the resolution of any outstanding issues, the INVAP Commissioning Manager issued a Test Approval Sheet providing an overall evaluation of the test results and a statement of whether the acceptance criteria had been met. ANSTO reviewed and accepted each Test Approval Sheet.

In addition to producing the thousands of project documents, INVAP was responsible for writing the Design, Operations and Maintenance manuals. Each manual was reviewed and approved by ANSTO and revised to incorporate commissioning experience.

In parallel with this process, ANSTO had to establish the OPAL Business Management System (BMS) and obtain ISO 9001/ISO 14001 accreditation. The ANSTO site has an existing high level accredited BMS system and an OPAL specific suite of documents was produced. This included Process Procedures for the Operating Organisation; Safety Management; Modification Management etc and supporting instructions and forms. In order to complete this task to a tight timescale, an experienced contract Document Manager and a team of contract technical writers were employed.

The Operating Limits and Conditions (OLCs) are an important basis on which ANSTO is authorised to operate the facility by ARPANSA. The OLCs establish the boundary within which the operation of the reactor facility has been demonstrated by the Safety Analysis Report to be safe.

In drafting the OLCs, ANSTO used IAEA guidance [2] and for detailed format guidance the US Nuclear Regulatory Commission NUREG format designed for nuclear power plants was used [3]. This provides clear instructions to the operator for limiting conditions, applicability, required action, completion times and surveillance requirements. An IAEA Review Team examined the OLCs in detail. While the review team largely endorsed the OLCs, a small number of recommendations for improvement were made and these were incorporated into a revised document before the issue of the Operating Licence.

6. Regulator

The Australian federal nuclear regulator is the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Licensing of the OPAL reactor as a nuclear facility has proceeded in stages, beginning with the issue of a Siting Licence in 1999 and ending with the issue of the Operating licence on 14 July 2006 [4]. Facility licences are issued to ANSTO as the operator of the Nuclear Installation. The paper *Licensing of the OPAL Reactor During Construction and Commissioning* delivered at this conference provides details of the process [5]. ARPANSA officers regularly witnessed commissioning tests.

7. Commissioning

The participation of the Commissioning Operations Group (COG) staff in commissioning activities is an important part of the transfer of knowledge from the reactor designer (INVAP) to the operating staff. Following the construction and post-installation, COG staff participated with INVAP and RRRP engineers in pre-commissioning testing where each individual system was tested.

Following the issue of the Operating Licence on 14 July 2006 and the first loading of real fuel assemblies into the reactor, ANSTO was responsible for the safe operation of the reactor. INVAP continued to provide operational guidance and was responsible for the Hot Commissioning Program.

7.1. Stage A Commissioning

The Construction Licence issued by ARPANSA, the Australian nuclear regulator, allowed cold commissioning up to but not including fuel loading. Stage A cold commissioning tests (74 days), including full system tests with dummy fuel assemblies in the reactor core, were completed in May 2006. At this time, the Main Control Room (MCR) was operational and COG staff carried out all operations under the direction of INVAP. Most operations can be carried out from the MCR and an important part of this testing was to verify the MCR procedures for the various reactor transition, e.g from Shutdown to Power, or Restart after a Trip 1.

7.2. Stage B Commissioning

7.2.1. Stage B1 Commissioning

ARPANSA issued the Operating Licence in July 2006 allowing Stage B1 hot commissioning to commence. Three types of fuel assembly were loaded in order that the first core was similar to an equilibrium core:

- 212 g U^{235} without burnable poison (BP)
- 383 g U^{235} with BP
- 484 g U^{235} with BP (OPAL standard fuel)

Nine of the full core sixteen fuel assemblies were loaded initially and for each subsequent fuel assembly loaded the control rods were withdrawn and the sub-critical multiplication factor determined. The reactor was taken critical on 12 August 2006 with fourteen fuel assemblies loaded as predicted. The shutdown value of the First Shutdown System with single control rod failure was measured for this first critical core.

The main issue during this testing stage was spurious trips from the nucleonics instrumentation due to electronic noise. This was resolved by close attention to earthing, connections and cable screening.

Stage B1 was completed (5 days), the report issued and ARPANSA approval was received to commence Stage B2.

7.2.2. Stage B2 Commissioning

The full core was loaded and 22 low power tests (up to 400kW) were carried out over 25 days to measure key nuclear and reactivity parameters of the core. The calculated power peaking factor (2.42) was checked by gold wire irradiations and good agreement obtained (2.48 measured).

Stage B2 Design verification results

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

SDM Shutdown Margin

FSS First Shutdown System (Insert all 5 control plates)

SSS Second Shutdown System (Dump half the heavy water from the reflector vessel)

CRP Control Rod Plate

Issues during Stage B2 commissioning:

- Wide range nucleonics detectors discontinuity as detector changed from pulse to Campbell mode – offsets adjusted and okay.
- Wide range set point for rate enable occurred with detector in pulse mode where the signal is noisy. The rate enable setpoint was raised as this was still within the safety case.
- Failure of a diesel starter motor during a test run. Main cause was identified to be a faulty battery.

7.3. Stage C commissioning

Approval was received on 13 October 2006 to commence Stage C commissioning. During this stage the reactor power was increased in steps up to full load (20 MW) which was first achieved on 3 November 2006. Twenty four test procedures were used and more than seventy test records completed.

Issues during Stage C commissioning:

- The CNS turbine failed so only testing with the CNS in standby (warm) mode was completed in the original schedule. After the turbine was replaced, all the tests were successfully performed.

- The core outlet temperature sensors did not give a true indication of the core outlet temperature. The primary coolant flow path around these detectors was modified and the problem solved.
- Cooling tower performance allowed the operation of the reactor at full power, but extrapolation to the design basis conditions indicated that four of the five fans would not be sufficient for this heat load. The manufacturer has improved the fan performance and further tests were carried out.

The first reactor refuelling was completed in February. This core is calculated to have the highest PPF and the calculated value (2.49) was confirmed by gold wire measurements (2.48). The reactor was operated at full load 20 MW for testing of neutron beam instruments and commissioning of irradiation facilities. Following the PPF test, instrumentation showed a rise in activity levels in the primary coolant. The standard FA in core position A2 was identified as suspect by sip testing and replaced.

The replacement CNS turbine was installed and the CNS system successfully commissioned in March 2007. By May 2007 all outstanding reactor commissioning tests had been completed and the reactor was operating routinely at full load 20 MW. Commissioning of neutron beam and irradiation facilities continues.

8. Operational Experience

In early 2007, the isotopic purity of the heavy water in the reflector vessel was found to be slowly reducing due to a light water leak. The source of the leak was determined to be a non-structural seal weld associated with the neutron beam tube connections to the vessel, but the reactor continued to be operated at full power whilst different repair strategies were investigated. In September 2007 a solution of fine particles of alumina powder was injected into a collar positioned around the welded joint to seal the leaks. The results of this process are being assessed.

On 24 July 2007, during a routine video camera inspection of the core following refuelling, some fuel assemblies were observed to have displaced fuel plates. The primary cooling flow in the OPAL reactor is upwards and a total of 13 of the 336 plates were later confirmed to be vertically displaced by varying heights above their normal position in the fuel assembly. Fourteen of the 16 fuel assemblies were unloaded from the core and transferred to the adjacent service pool with the standard fuel handling tool. For two fuel assemblies with raised plates close to the fuel assembly lifting pin, the standard fuel handling tool could not be used and special handling devices were devised and, following approval from ARPANSA, these last two fuel assemblies were also removed. Unloading of the core was completed on 30 August. Investigation into the fault is in progress.

9. Conclusions

The main lessons from the commissioning of the OPAL reactor are that good organisation, communications, quick response to problems and the establishment of a good safety culture are essential for the success of the project. The IAEA guidance documents provided a suitable organisation structure for commissioning which was acceptable to the regulator.

A collaborative approach between the operating organisation (ANSTO) and the principal contractor (INVAP) enabled commissioning to be carried out efficiently to schedule.

The commissioning tests were comprehensive and demonstrated compliance with the safety case.

The early availability of trained staff, test procedures and management procedures is essential.

The early establishment of the ANSTO commissioning operations group enabled an efficient transfer of operational experience and responsibility from INVAP to ANSTO and a smooth transition to routine operations.

Commissioning a new research reactor is not a common event and every research reactor is different, but organisation and communications remain as key aspects.

REFERENCES

[1] IAEA Draft Safety Guide NS 259 Commissioning of Research Reactors.

[2] IAEA Draft Safety Guide NS 261 Operational Limits and Conditions for Research Reactors

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