THE UTILISATION OF AUSTRALIA'S RESEARCH REACTOR, OPAL

KITH MENDIS, JOHN W. BENNETT, JAMIE SCHULZ
Australian Nuclear Science & Technology Organisation (ANSTO),
Kirrawee DC, New South Wales,
Australia
kith.mendis@ansto.gov.au

1. INTRODUCTION

The construction of the OPAL reactor commenced in 2002 and cold testing of the reactor systems as part of commissioning commenced in 2005. OPAL reached criticality in August 2006 which was followed by full power testing and performance demonstration tests.

Commissioning of irradiation and beam facilities progressed in parallel together with other reactor systems. On successful completion of hot commissioning, irradiations for the production of medical isotopes and other commercial irradiations commenced in mid-2007.

2. IRRADIATION FACILITIES

Radioisotopes are produced by introducing targets into dedicated irradiation positions in the reflector vessel.

The following irradiation facilities are described below (Figure 1):

- General purpose irradiation facilities;
- Bulk production irradiation facilities;
- Large volume irradiation facilities;
- Neutron activation analysis facility;
- Delayed neutron activation analysis facility; and
- Shielded hot cells for target loading, unloading and transfer to the radioisotope production plant.

The general purpose irradiation facilities comprise 55 tubes that run from two pneumatic transfer hot cells to locations in the reflector vessel having neutron fluxes ranging from 2.4×10^{12} to 1.0×10^{14} $cm^{-2}s^{-1}$.

Target materials are loaded into aluminium containers 25 mm in diameter and 70 mm long, and are transferred to the irradiation positions in the reflector by nitrogen. They can remain there for periods ranging from seconds to several weeks. The nitrogen gas is used both for transport and cooling and consequently targets are limited to those that can be adequately cooled by the gas flow.

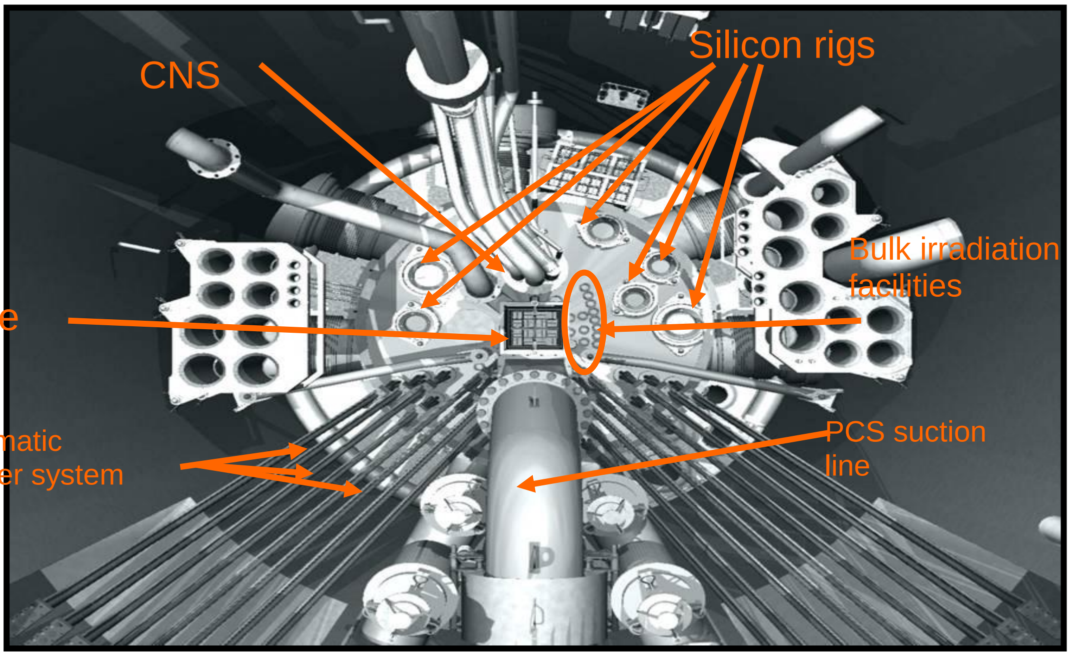

Fig. 1. Irradiation facilities.

The bulk production irradiation facilities comprise 17 irradiation tubes running vertically through the reflector vessel. The tubes are 50 mm in diameter and are water-cooled. Irradiation rigs, which can be removed while the reactor is at power, can accommodate up to 5 target cans and have a cooling capacity of 125 kW.

They are used primarily for the irradiation of low enriched uranium for the production of Mo-99 and tellurium dioxide for the production of I-131.

A total of six large volume irradiation facilities are available. They are used primarily for the neutron transmutation doping of single crystal silicon ingots for the electronics industry.

A neutron activation analysis facility and a laboratory are available in the reactor building for the elemental analysis of samples that are irradiated in a dedicated large pneumatic conveyor irradiation tube for up to 15 minutes at a maximum neutron flux of 4×10^{13} cm^{-2} s^{-1}. The travel time from the reactor to the terminal station is around 3 seconds. Despite the need for manual retrieval and handling of the samples, short-lived activation products down to Al-28 (half life 2.24 minutes) can be measured using nearby gamma ray spectrometers.

Longer sample irradiations of up to 20 hours in the general purpose pneumatic tubes and subsequent gamma ray spectrometry in an automatic sample changer complete the suite of NAA facilities.

A delayed neutron activation analysis (DNAA) facility is available for the determination of uranium in ores and in samples produced during ore processing. The facility provides automated online counting of neutrons after sample irradiation using an array of BF_3 counters.

Two pneumatic conveyor hot cells within containment are provided for the transfer of targets from the irradiation tubes to remote hot cells. The transfer from the conveyor hot cells is achieved either via a further pneumatic conveyor system or via the transfer of the targets in shielded transport containers.

An additional isotope transfer hot cell is provided for the unloading of the bulk irradiation rigs and for the transfer of the targets removed to the loading hot cell.

The irradiation facilities have adequate production capability both in terms of the range of fluxes available and particularly in the total irradiation capacity of the reactor.

2.1. Existing capabilities

The existing capabilities of OPAL include:

- Education and training:
  - Public tours and visits;
  - Training on reactor operation;
  - Training on radiation protection;
- NAA for internal and university researchers, industry and government agencies;
- DNAA;
- Production of radioisotopes:
  - Medical radioisotopes for needs of Australia and other countries;
  - Range of isotopes for industrial purposes;
- Irradiations for geochronology:
  - Argon geochronology for dating of geological samples;
  - Fission track geochronology;
- Transmutation effects:
  - Neutron transmutation doping of silicon of up to 8” dia.;
  - Materials irradiation;
- Research in material structure studies are performed using the following neutron scattering experimental equipment:
  - High intensity powder diffractometer;
  - High resolution powder diffractometer;
  - Residual stress diffractometer;
  - Laue diffractometer;
  - Small angle neutron scattering;
  - Triple axis spectrometer;
  - Neutron reflectometer;
  - Time of flight/polarisation analysis spectrometer;
- Nuclear analysis capabilities in neutronics, criticality, thermal-hydraulics and shielding;
- Water tunnel for hydraulic testing and flow studies; and
- Cold neutron source for beam research.

2.2. Potential capabilities

- Education & training:
    - Teaching programs for physical/ biological science and nuclear engineering;
- Neutron radiography:
    - Static radiography;
    - Motion radiography;
    - Tomography;
- Prompt gamma NAA using cold and/or thermal neutron beams;
- Positron source;
- Testing:
    - Instrument testing and calibration using neutron beams;
    - Loops for testing nuclear fuel; and
- Hot neutron source for fast neutron beam research.

2.3. Irradiations currently performed

- Medical isotopes Mo-99, I-131, Sm-153, Cr-51, Y-90 and Lu-177;
- Long and short residence time NAA;
- Material irradiations for research and to determine neutron damage;
- DNAA for uranium analysis; and
- Neutron transmutation doping of silicon.

2.4. Planned irradiations

- Bulk production of Lu-177;
- Geochronology samples, fission track and argon dating;
- Radioactive tracers, Sc-46;
- Au-198 grains; and
- Brachytherapy sources, I-125 seeds.

3. NEUTRON BEAM FACILITIES

3.1. Heavy water reflector vessel

Neutron beam facilities have been incorporated into the heavy water reflector vessel (Figure 2) and include five neutron beam assemblies, a cold neutron source and provision for a future hot neutron source. All neutron assemblies are tangential to the core in order to minimise fast neutrons and gamma radiation from entering the assemblies and comprise of:

- Two thermal neutron beam assemblies that emerge from the reflector vessel in opposite directions, TNB-1 and TNB-4, respectively;
- Two cold neutron beam assemblies, CNB-2 and CNB-3; and
- An additional beam assembly HNB-5 for a possible hot neutron source in the future.

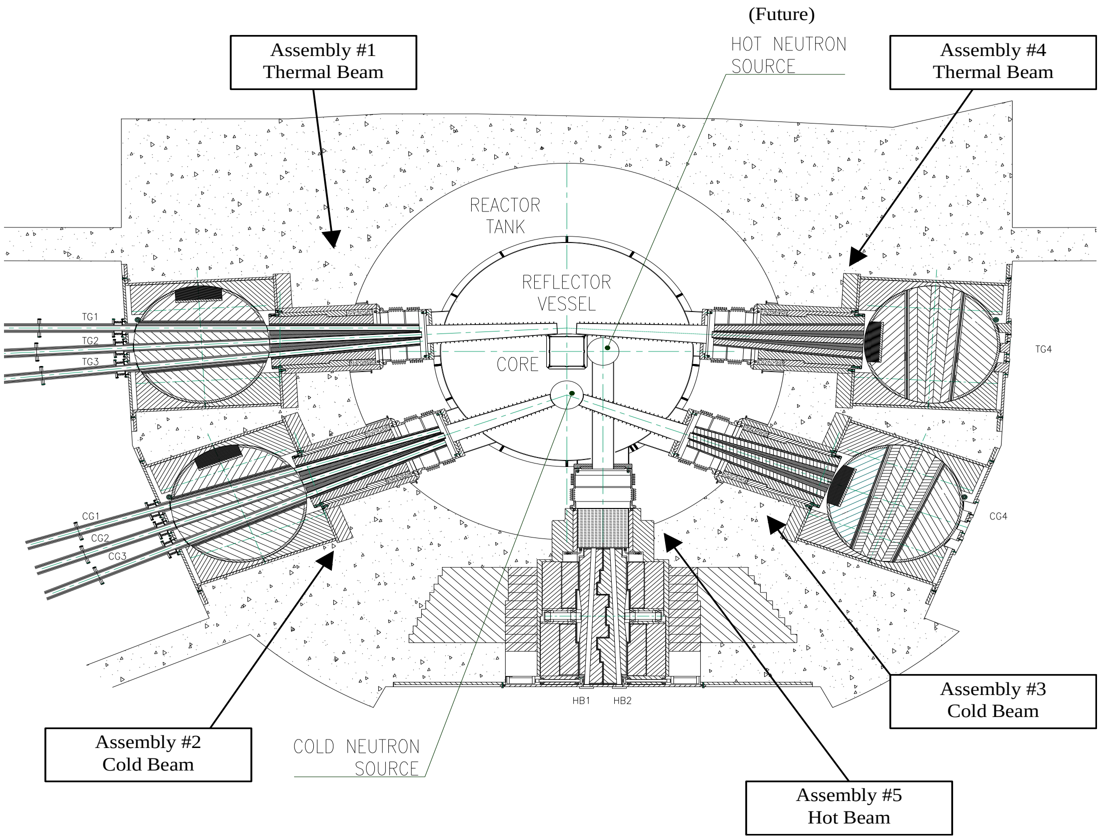

Fig. 2. Neutron beam arrangement.

3.2. Thermal neutron source

The thermal neutron source comprises a heavy water zone located close to the region of peak thermal flux in the reflector vessel. The nominal peak thermal neutron flux at the performance at the reactor face of the TNB-4 assembly is 3.7×10^{10} $cm^{-2}s^{-1}$. The neutron spectrum has a peak neutron yield at approximately 1.1 Å at an operating temperature above 40°C.

3.3. Cold neutron source

The cold neutron source is a vertical liquid deuterium thermo-syphon type cold neutron source and is located close to the peak in the thermal neutron flux in the reflector vessel. The nominal peak thermal neutron flux at the performance at the reactor face of the CNB-3 assembly is 3.6×10^{10} $cm^{-2}s^{-1}$. The neutron spectrum has a peak neutron yield at approximately 3 Å at an operating temperature below 25 K. OPAL is designed such that the reactor can operate with the cold source operating and in standby mode.

3.4. Hot neutron source

Provision for a future hot neutron source has been accommodated into the heavy water reflector vessel which would utilise a graphite moderator heated by gamma radiation and, to a small extent, by neutron radiation from the reactor to an approximate equilibrium temperature of 2400°C.

3.5. Neutron beam transport system

Super mirror neutron guides under vacuum are utilised to transport neutrons from the high density neutron areas located in the reflector vessel to the research instruments located in the reactor beam hall and the neutron guide hall. The thermal and cold neutron assemblies can feed up to 3 separate neutron guides. TNB-1 and CNB-2 each presently have 2 thermal guides installed, whereas TNB-4 and CNB-3 have only single guides installed.

The thermal neutron beam assembly TNB-1 has two thermal guides TG-1 and TG-3 in the same horizontal plane. The cold neutron beam assembly CNB-2 has in the same horizontal plane the guides CG-1 and CG-3. The neutron guides TG-1, TG-3, CG-1 and CG-3 all are curved between the reactor face and the exit of the neutron guide bunker to further remove fast neutrons and gamma radiation that have entered the neutron beam assemblies. There are minimal neutron flux losses though the neutron guide system.

3.6 Neutron beam instruments

The OPAL reactor has initial space for up to 18 instruments with provision for construction of a second neutron guide hall on the other side of the reactor which would be supplied neutrons by TNB-4 and CNB-3 neutron beam assemblies.

The buildings that support the neutron beam instruments comprise:

- Reactor beam hall – an area in the reactor building that accommodates the neutron beam instruments that need to be as close to the reactor as practicable;
- Neutron guide hall – an area adjacent to the reactor building that accommodates the majority of the neutron beam instruments; and
- Workshops, laboratories, offices and a viewing gallery.

There are 7 neutron beam instruments that are currently operational which include:

- Wombat, a high intensity powder diffractometer;
- Echidna, a high resolution powder diffractometer;
- Kowari, a residual stress diffractometer;
- Koala, a Laue diffractometer;
- Quokka, a small angle neutron scattering instrument;
- Taipan, a triple axis spectrometer; and
- Platypus, a neutron reflectometer.

There are 6 additional neutron beam instruments are under construction:

- Pelican, a time of flight/polarisation analysis spectrometer;
- Sika, a cold triple axis spectrometer;
- Kookaburra, an ultra small angle neutron scattering instrument;
- Emu, a backscattering spectrometer;
- Bilby, a small angle neutron scattering instrument; and
- Dingo, a neutron radiography/imaging/tomography instrument.

The Sika instrument is funded and being constructed by the National Science Council of Taiwan. As part of the construction of the Bilby instrument, the CG-2 neutron guide will be installed in the CNB-2 cold neutron beam assembly.

4. INTERFACE WITH CUSTOMERS

Regular contact is maintained with all internal customers to ensure that their requirements are met in the delivery of medical isotopes and commercial irradiations. In addition:

- Monthly meetings are held with major internal customers at management level to assist in intermediate and long term planning;
- Weekly meetings are held with all internal customers to review irradiation schedules and to receive feedback on client satisfaction; and
- Continuous feedback is provided to customers when disruptions occur to reactor operations and irradiation schedules.

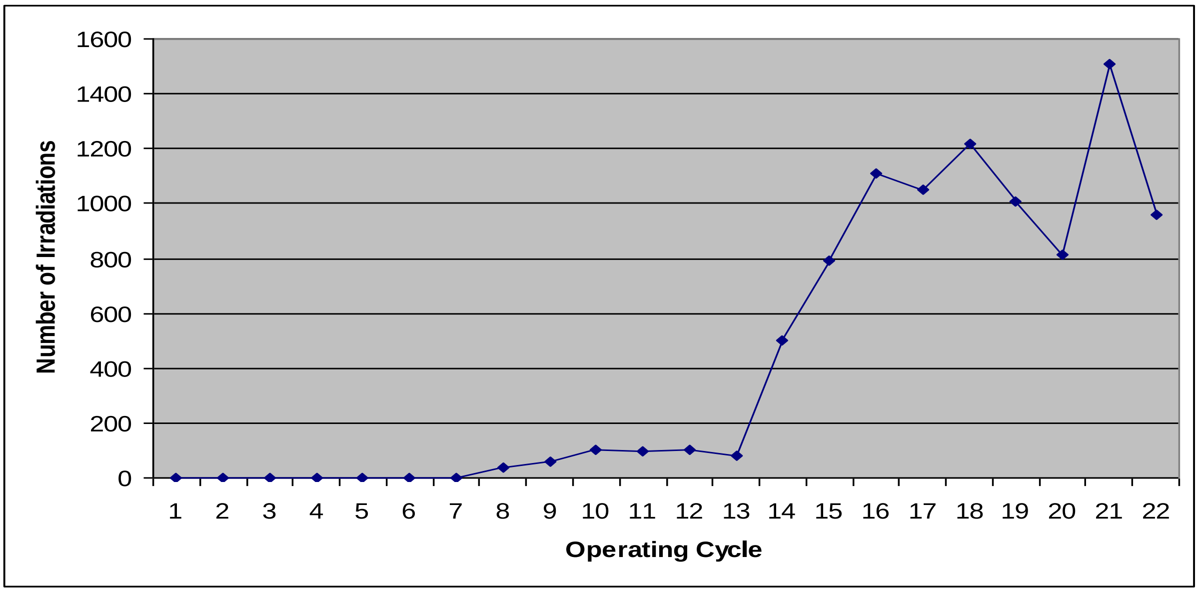

Fig. 3. Utilisation of OPAL facilities.

5. CONCLUSIONS

During the past four years there has been a significant increase in the utilisation of reactor facilities (Figure 3), and OPAL has been successful in delivering medical isotopes and other irradiated products to customers in time for processing.

Significant achievements have been gained in the areas of NAA and DNAA and also in utilising the neutron beam instruments for research over a wide range of applications.

A strategic plan is in place to further improve the use of OPAL towards achieving optimum utilisation of irradiation and beam facilities.

6. REFERENCES

[1] CAMERON, R.F., HORLOCK, K., "The replacement research reactor", Presented at Australian Nuclear Association National Conference, Sydney, 2001.