〈Technical Note〉

THE OPAL (OPEN POOL AUSTRALIAN LIGHT-WATER) REACTOR IN AUSTRALIA

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Received August 31, 2005

The OPAL (Open Pool Australian Light-water) reactor is currently being constructed to replace HIFAR (HI-Flux Australian Reactor, commissioned in 1958) in mid-2006. HIFAR will be shutdown for decommissioning after several months of simultaneous operation with OPAL for smooth transition of operating systems and business. OPAL is a 20 MW multipurpose research reactor for radioisotope production, irradiation services and neutron beam research. The OPAL reactor uses low enriched uranium fuel in a compact core, cooled by light water and moderated by heavy water, yielding maximum thermal flux not less than 4×10^{14} n cm^{-2} s^{-1}. The reactor containment building is constructed of reinforced concrete and has been designed to protect the reactor from all external events such as seismic occurrences and impact from a hypothetical light aircraft crash. This paper describes the main elements of the reactor design and its applications.

KEYWORDS : ANSTO Opal Research Reactor

1. INTRODUCTION

In 1997, a decision was made to construct a replacement research reactor at ANSTO to replace the then 40 year old HIFAR which is expected to reach the end of its useful operational life around 2006. Since then, the project has progressed through a number of stages, including:

- Environmental Impact Statement;
- Public Works Committee process;
- Site licensing, August 1999;
- Request for tender, August 1999;
- Contract to INVAP, July 2000;
- Preliminary engineering process;
- Construction licence application, May 2001;
- Reactor construction started in April 2002.

The OPAL reactor is currently under construction and scheduled to be commissioned in mid 2006. See Figures 1 and 2 below.

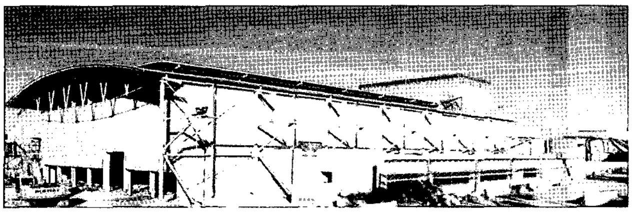

Fig. 1. Construction: Neutron Guide Hall

Fig. 2. Construction: Reactor Building

2. OPAL REACTOR - DESCRIPTION

The reactor is of open-pool design, i.e. the core is contained inside an open pool of light water which provides both cooling and protection against radiation from the core. The core itself is surrounded by a Reflector Vessel containing heavy water which reflects neutrons back into the core and maintain the nuclear reaction.

The design of the reactor has been optimised to satisfy the radioisotope production requirements and to supply high flux neutron beams for researchers and future expansion for development and application in such vital areas as agriculture, industry and manufacturing, minerals and energy, human health and the environment.

The main technical data is shown below and the detail expanded in the following sections.

Reactor :
- Open pool type
- Demineralised water cooling
- Heavy water reflector
- Separate/diverse reactor protection systems
- Separate/diverse shutdown systems
- Low Enriched Uranium (LEU) fuel
- 14m deep stainless steel reactor tank

Industrial – Irradiation Facilities :
- 55 general purpose positions (pneumatic)
- 2 positions for Neutron Activation Analysis
- 17 rigs for bulk production
- 6 rigs for Neutron Transmutation Doping

Fig. 3. OPAL Against Setting Sun

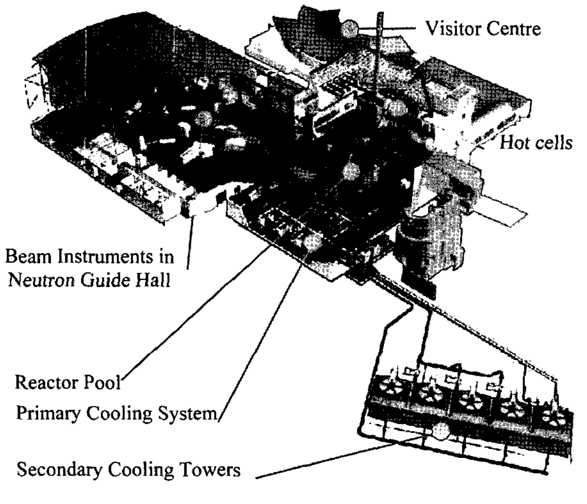

Fig. 4. OPAL - Sections

Research – Neutron Beam Facilities :
- Neutron Sources : Thermal and Cold
- Provision for Hot Neutron Source
- Super-mirror neutron guides
- Neutron Guide Hall & Reactor Hall designed for 18 neutron beam instruments
- A suite of the first 8 instruments by 2006

Images of OPAL and cut-away sections are shown in Figures 3, 4 and 5.

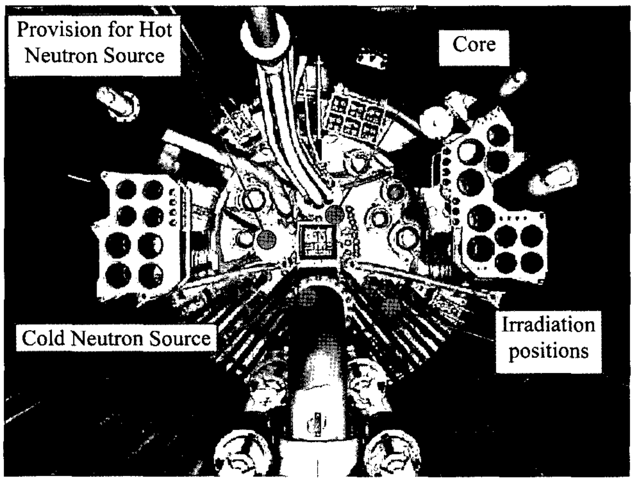

Fig. 5. Reactor Pool – Plan View

2.1 Reactor Safety Systems

The reactor design and construction features ensure an effective protection for individuals, the general public and the environment against radiological hazards. Engineered Safety Features at OPAL comply with fail-safe and reliability safety criteria and are capable of maintaining the reactor in a safe condition under all anticipated operational and abnormal conditions. The 'defence-in-depth' and As Low As Reasonably Achievable (ALARA) principles have been applied in the design, with multiple levels of protection and physical barriers to prevent radioactive releases. All reactor systems are designed with adequate safety margins to ensure they will behave in a known manner under anticipated operational occurrences.

Engineered Safety Features are:
a) Reactor Protection Systems
b) First Shutdown System (Fail-safe)
c) Second Shutdown System (Fail-safe)
d) Reactor Pool Coolant Boundary
e) Core/Rig Cooling by Natural Circulation
f) Reactor Containment System

g) Post Accident Monitoring System
h) Standby Power System
i) Emergency Control Centre Ventilation and Pressurisation System

2.2 The Core

The core measures 350mm x 350mm x 615mm and is located inside the reactor pool at 10m below water surface level. The core consists of 16 Fuel Assemblies made of low-enriched uranium silicide fuel plates with aluminium cladding. Fission heat is removed by water circulating through coolant channels between the fuel plates. After shutdown, and in the event of power failure, decay heat is removed by natural convection of water in the reactor pool.

Reactivity is controlled by 5 independent control blades driven from underneath, 4 of which have hafnium plates and the fifth has a central cruciform shaped plate. The core, thus, forms into a 4 x 4 format. (Figures 6 and 7). During normal operation the central control blade is used for reactivity regulation and the other four are used for coarse reactivity compensation, commanded by the Reactor Control and Monitoring System.

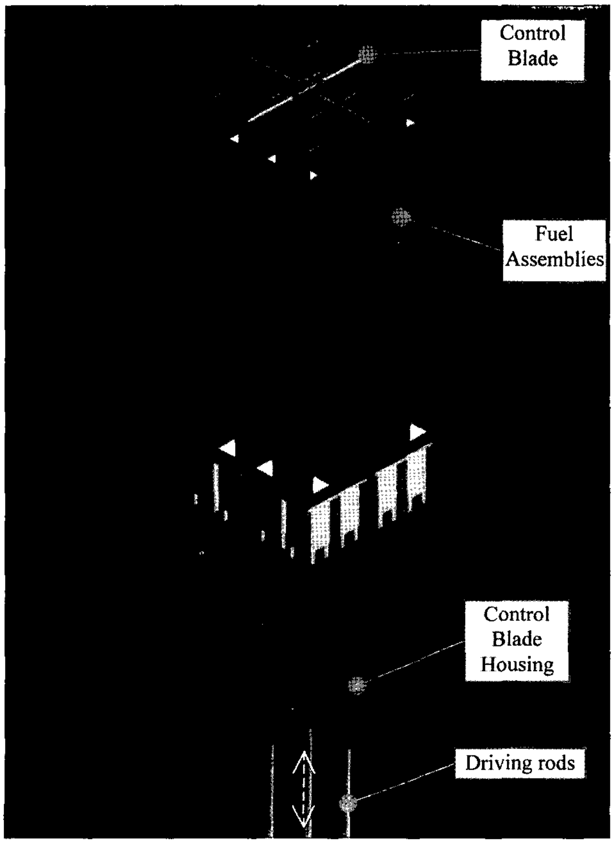

Fig. 6. The Core

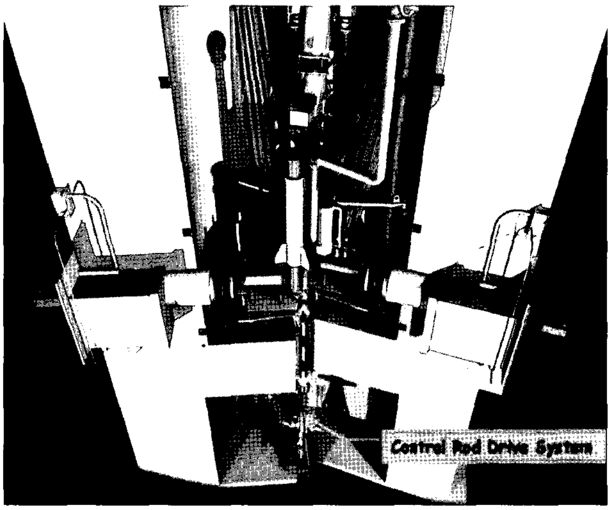

Fig. 7. Control Rod Drive System

2.3 Reactor Pools and Reflector Vessel

The Reactor Pool (Stainless Steel) contains:

- the core;
- the Reflector Vessel (Zircalloy);
- the piping for cooling systems;
- rigs for irradiation facilities; and
- nuclear and non-nuclear instrumentation.

The Service Pool (Figure 8) is connected to the Reactor Pool via a Transfer Canal and provides a working area and storage space for the spent fuel likely to be generated during 10 years of operation.

The Reflector Vessel contains heavy water and provides a home for the irradiation rigs, Cold Neutron Source (CNS), provision for Hot Neutron Source, and neutron beam tube penetrations. (Figure 9) The Core Chimney above the Reflector Vessel contains the core coolant before it enters the pump suction line of the primary system piping, and provides an additional enclosure for water that protects the core in case of a loss of coolant accident.

2.4 Shutdown Systems

Safety variables are monitored by the Reactor Protection Systems, which trigger safety systems automatically when the trip set points are reached, or under operator initiation. At any time, the fission chain can be promptly terminated by either of two independent shutdown systems, including the First and Second Shutdown Systems.

First Shutdown System : When triggered, all five control blades (Figure 6) gravity fall into shutdown position in the core in less than 0.5 seconds. The blades are held in the normal operating position by a fail-safe electro-magnetic coupling system that naturally de-energises on a trip signal or power failure.

Second Shutdown System : This system provides an alternate means of fail-safe reactor shutdown by dumping approximately half of the heavy water in the Reflector Vessel into a storage tank beneath the core on command from the Second Reactor Protection System. It takes less than 30 seconds to complete the process. The heavy water in the Reflector Vessel is released into the storage tank by 6 fail-safe 'Normally-Open' valves installed in parallel for redundancy. On a trip signal or power failure, the valves are de-energised and open naturally to allow the heavy water to flow. (Figure 10).

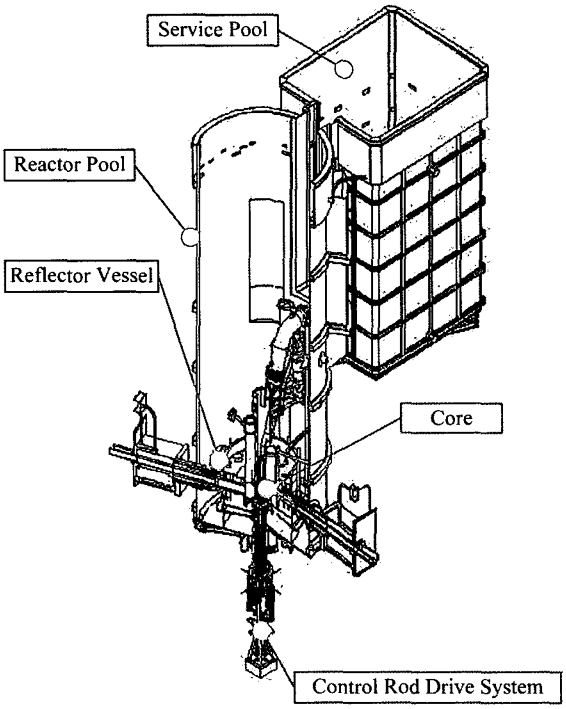

Fig. 8. Reactor and Service Pools

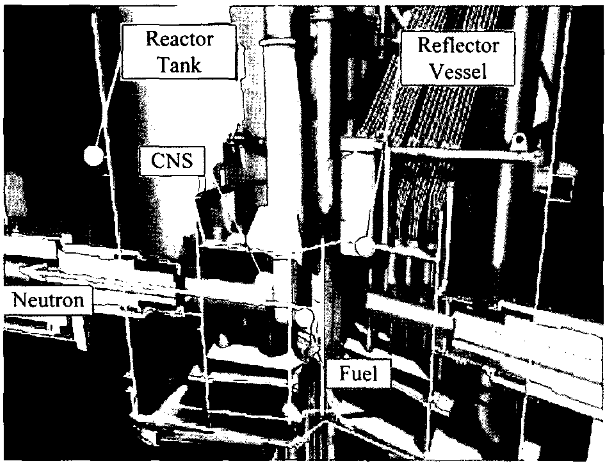

Fig. 9. Reflector Vessel – Sectioned View

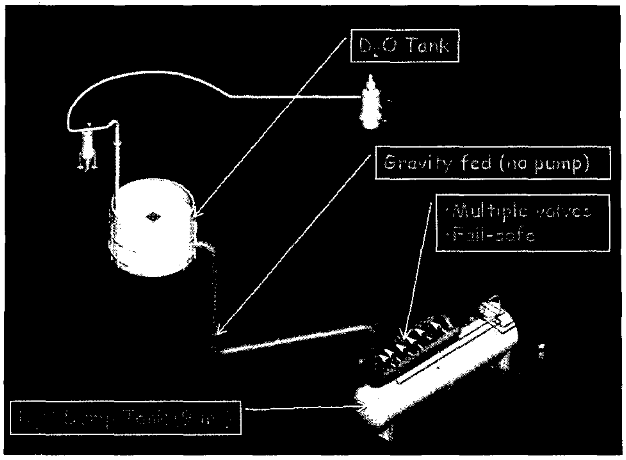

Fig. 10. Second Shutdown System

2.5 Reactor Containment and Protection

The Reactor Containment System is designed to prevent or mitigate the uncontrolled release of radioactive materials to the environment.

The Post Accident Monitoring system monitors the status of the barriers to fission product release and, in the event of an abnormal operating condition, alerts the operators for action.

The Emergency Control Centre Ventilation and Pressurisation System ensures a safe working environment within the emergency control centre in case the Main Control Room requires evacuation.

A Standby Power System ensures that safety systems perform their safety functions in the case of power failure.

2.6 Irradiation Facilities

ANSTO is one of the leading producers of the silicon irradiation or Neutron Transmutation Doping (NTD) in the world, with HIFAR having produced high quality silicon for the computer industry for many years. The OPAL reactor is designed to cater for the growing demand for silicon irradiation and radioisotopes for medical, industrial and environmental applications.

Irradiation services are performed by introducing targets into dedicated irradiation positions in the Reflector Vessel.

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} n cm^{-2} s^{-1}. Target materials are loaded into aluminium or titanium containers, 25mm in diameter and 70mm long, and transferred to the irradiation positions by nitrogen gas which is used both for transport and cooling.

The bulk production irradiation facilities include 17 vertical irradiation tubes, 50mm in diameter and water-cooled, and will be used primarily to irradiate low enriched uranium for the production of Mo99, tellurium dioxide for the production of I131 and iridium metal for the production of Ir192.

The six special rigs will be used for the neutron transmutation doping of single crystal silicon ingots for the electronics industry. A laboratory is provided for the post irradiation scanning cleaning and packaging of the silicon ingots.

The Neutron Activation Laboratory is provided in the reactor building for the analysis of samples that are irradiated in large pneumatic conveyor irradiation tubes for only a few minutes. They travel from the reactor to the laboratory in 3 seconds for immediate analysis of the very short activation products.

Two hot cells are provided for the transfer of targets between the reactor and the radioisotope production buildings, which are located approximately 100m from the reactor. This is achieved either via the remote controlled pneumatic conveyor systems connecting the buildings or via manual handling using transport containers for those exceeding safe radiation limits for pneumatic transfer. An additional isotope transfer hot cell is provided for the unloading of the bulk irradiation rigs and for the transfer of the targets to the loading hot cell.

2.7 Neutron Beam Facilities

The neutron beam facilities at OPAL include:

- Cold and Thermal Neutron Source systems;
- Provision for Hot Neutron Source;
- Neutron guides (M=3 Super-mirror); and
- A suite of beam instruments.

The buildings that support these facilities are:

- The 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.
- The Neutron Guide Hall (NGH) – An area adjoining the reactor building that accommodates the majority of the neutron beam instruments, workshops, laboratories, offices and a viewing gallery.

The Cold Neutron Source (CNS) uses liquid Deuterium at 24K as a moderator and is located close to the peak thermal flux in the Reflector Vessel. The neutron flux will be greater than 1.4×10^{10} n cm^{-2} s^{-1} at the reactor face locations and 2.7×10^{9} n cm^{-2} s^{-1} in the NGH.

The Thermal Neutron Source comprises a heavy water zone located close to the region of peak thermal flux in the Reflector Vessel. The nominal thermal neutron flux at the performance measurement locations at the reactor face will be higher than 1.6×10^{10} n cm^{-2} s^{-1} and higher than 1.6×10^{9} n cm^{-2} s^{-1} in the NGH. The neutron spectrum has a temperature in the range of 40°C to 60°C. Two neutron beams originate at the thermal neutron source.

The Neutron Beam Instruments include a suite of eight world-class instruments that will enable studies at different temperatures, pressures and magnetic fields. These include: (Figure 11)

1. High Resolution Powder Diffractometer
2. High Intensity Powder Diffractometer
3. Reflectometer
4. Quasi-Laue Diffractometer
5. Small Angle Neutron Scattering
6. Residual Stress
7. Polarisation Axis Spectrometer
8. Three Axis Spectrometer

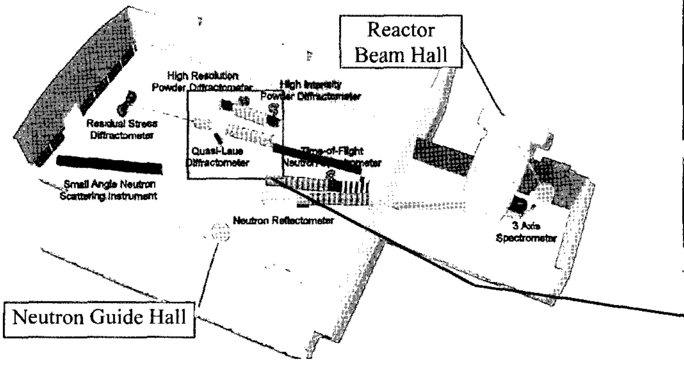

Fig. 11. Neutron Beam Facilities

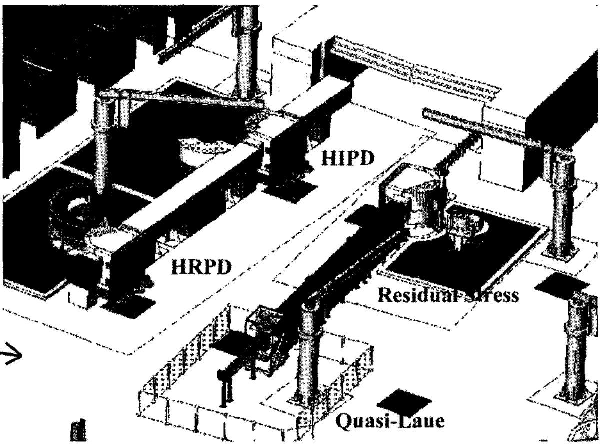

Fig. 12. A Selection of Beam Instruments

3. CONCLUSIONS

The construction and installation of the OPAL reactor facilities are progressing well and scheduled to be practically completed in late 2005, followed by pre-commissioning, final commissioning and routine operation in mid-2006. The OPAL reactor has a design life of 40 years and has been designed to facilitate decommissioning.

ACKNOWLEDGMENT

The writer wishes to thank the engineers and drafting officers of ANSTO and INVAP for producing the computer generated 3-D models and images used in this paper.

REFERENCES

[1] ANSTO web: www.ansto.gov.au