OPAL

Australia’s new research reactor: commissioning, operation, opportunities & challenges in engineering, physics & biology
ANSTO Site
Introducing ANSTO

• Centre of Australian nuclear expertise
• Home of Australia’s only nuclear reactors
• Australian government science and technology organisation
• Around 900 employees
• Addressing issues such as health care, environment protection, assistance to industry and regional interactions
Our vision

To be recognised as an international centre of excellence in nuclear science and technology for the benefit of Australia
OPAL Research Reactor and applications

A centre of excellence for the benefit of Australia
Research reactor operation

- HIFAR operating since 1958
- National facilities → Centre of Excellence
  - Neutron beams for science
  - Radio-isotopes for medicine and industry
  - Commercial & research irradiations
Enhanced capabilities at OPAL

- **Neutron Beams**: 2 to 4 orders of magnitude at detectors
- **Radioisotopes**: Up to 10 times higher capacity
- **Silicon production**: Capacity doubled
- **Cold neutron source**: Large liquid deuterium source
- **Passive safety features**: Natural convection cooling
- **Digital control and protection systems**:
- **Pool reactor**: Easier utilisation
- **Working environment**: Many beam users outside containment
- **Spent fuel storage**: 10 year storage in facility
OPAL Reactor

• Multi-purpose facility – neutron beams, radiopharmaceuticals, irradiation of materials
• 20 MW thermal power
• Compact core (~300 kW/L)
• Plate type Low Enriched Uranium fuel
• D₂O reflector
• Upward coolant flow (light water)
• 2 independent & diverse shutdown systems
Design
Reactors Core

- Reactor Core
- Hf Control Rods
- Central Control Rod
- Fuel Assemblies
- Fuel Plates
- Coolant Channels between Fuel Plates
Reflector facilities

- CNS
- Si rigs
- Core
- Pneumatic transfer system tubes
- Bulk irradiation facilities
- PCS suction line
Rigs and cans

- Silicon Ingot
- Bottom Silicon Dummy
- Silicon Ingot
- Silicon Ingot
- Lifting Lug Top Dummy
- Outer Can
- Inner Can
- Targets
- Nozzle
Beams for neutron scattering science
OPAL / Neutron Guide Hall
Reactor face, guide bunker & neutron guides

Thermal neutron guides run ~ 40m in bunker

Mirrotron engineers installing out-of-pile neutron guides

Neutron guide cross-section
Beams vary from 50 - 100 mm wide and from 150 - 300 mm high at exit window
Opal neutron beam instruments & mascots

- Echidna (HRPD)
- Quokka (SANS)
- Platypus (Reflect)
- Wombat (HIPD)
- Taipan (Triple Axis)
- Kowari (Resid. Stress)
- Koala (QLD)
- Sika (Cold-Triple Axis)
- Pelican (TOF-PAS)

Neutron diffraction
Large scale structures
Inelastic neutron scattering

Scheduled for completion in 2009
Acceptance testing – fluxes & spectra

TG1 Au foil measurement
- $\Phi = 1.24 \times 10^{10}$ n/cm$^2$/s (2nd break after RF)
- Estimate $\Phi_{RF} \leq 5.0 \times 10^{10}$ n/cm$^2$/s
- $\Phi = 3.3 \times 10^9$ n/cm$^2$/s (Wombat)
- c.f. predicted value of $2.4 \times 10^9$

TG3 Au foil measurement
- $\Phi = 8.4 \times 10^9$ n/cm$^2$/s (2nd break after RF)
- Estimate $\Phi_{RF} \leq 3.4 \times 10^{10}$ n/cm$^2$/s
- Peak in collimated spectrum is at $\lambda = 1.4$ Å
- Peak in un-collimated spectrum shifted to longer wavelength
- Spectrum is satisfactory
OPAL: thermal neutron distributions

**Wombat**

- \( \Phi = 2.9 \times 10^9 \) n/cm²/s
- \( \Phi_{(10-100 \text{ meV})} = 2.1 \times 10^9 \)

**Kowari**

- \( \Phi_t = 2.5 \times 10^9 \) n/cm²/s
- \( \Phi_{(10-100 \text{ meV})} = 1.8 \times 10^9 \)

**Taipan**

- \( \Phi = 3.7 \times 10^{10} \) n/cm²/s
- \( \Phi_{(10-100 \text{ meV})} = 2.9 \times 10^{10} \)
OPAL: CNS flux distribution
(pinhole measurement)

$\Phi \sim 3.6 \times 10^{10} \text{ n/cm}^2/\text{s}$

$\Phi_{(< 10 \text{ meV})} = ? \times 10^{10}$

10% contours
OPAL CNS: cold neutron spectrum (CG4)

- Peak in cold neutron spectrum at reactor face: $\lambda \sim 3 \text{ Å}$
- with shoulder at: $\lambda \sim 1.1 \text{ Å}$ (rethermalization?)
Early diffraction patterns from Echidna

Neutron powder diffraction data for Al$_2$O$_3$ collected for ~5h
HRPD: $2\Theta_m=120^\circ$, $\lambda=1.49\text{Å}$; Echidna: $2\Theta_m=90^\circ$, $\lambda=1.54\text{Å}$
First Diffraction Patterns on WOMBAT
High-Intensity Powder Diffractometer
24 February 2007
First Beam on KOWARI Strain Scanner June 18th
First SANS measurements – Natural Opal & Graphite

4 September 2008 and following days
## Summary of neutron beam performance tests

<table>
<thead>
<tr>
<th>Performance Acceptance Criteria</th>
<th>OPAL measured flux (20 MW equiv) (φ in n/cm²/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal neutron flux at RF for TG4 (E &lt; 100 meV)</td>
<td>4.0 x 10^{10}</td>
</tr>
<tr>
<td>Thermal neutron flux at RF for TG3 (E &lt; 100 meV)</td>
<td>~ 2.3 x 10^{10} [1]</td>
</tr>
<tr>
<td>Thermal neutron flux in NGH for TG3 (E &lt; 100 meV)</td>
<td>2.8 x 10^9</td>
</tr>
<tr>
<td>Cold neutron flux at RF for CG4 (E &lt; 10 meV)</td>
<td>2.5 x 10^{10}</td>
</tr>
<tr>
<td>Cold neutron flux at RF face for CG3 (E &lt; 10 meV)</td>
<td>~ 1.3 x 10^{10} [2]</td>
</tr>
<tr>
<td>Cold neutron flux in NGH for CG3 (E &lt; 10 meV)</td>
<td>6.4 x 10^9</td>
</tr>
</tbody>
</table>

[1] estimated with TG4 spectrum calibration factor
[2] estimated with CG4 spectrum calibration factor
Radioisotopes for Nuclear Medicine/ Industrial Isotopes

• Total of 17 Bulk Irradiation Facilities arranged in three different classes, principally for the production of Molybdenum-99 and Iodine-131

• Total of 55 Long Residence Time Facilities available for the production of a range of isotopes for medical, industrial and research purposes.
Bulk irradiation facilities

- Low Flux Facilities Mo-99
- Medium Flux Facilities I-131
- High Flux Facilities
Results - BIF

Compare calculations and measurements
Manufacture of radiopharmaceuticals
The Production Process

LEU in reactor for irradiation & Mo-99 from fission process

Mo-99 separated

Tc-99m Generator to Customer
LEU Mo99 Production in OPAL

- Al clad UAl dispersion flat plate target
- 19.75% enriched U
- Irradiated at $9 \times 10^{13}$ n/cm$^2$/s for 3-7 days
- Plates dissolved in sodium hydroxide
- Uranium precipitates and captured in filter
- Dry filter cakes stored in non-critical array
- Separation by ion exchange & successive purification steps
- Radioiodines remain in solution
- I-131 recovered for use as a product
- Hydrogen released during dissolution is immediately converted to water via CuO$_2$ wires
Silicon irradiation

- 6 facilities for silicon irradiation at OPAL suitable for 5”, 6” and 8” diameter silicon crystals
- Facilities are located in the reactor D$_2$O reflector vessel exposed to a neutron flux with Cd ratio > 1000 (approx)
- Silicon crystals are irradiated in aluminum cans in rotating rigs and water cooled
- Customer base – Japan & Europe electronics suppliers
- World market share - ~ 10%
# Results – Si NTD

<table>
<thead>
<tr>
<th></th>
<th>Thermal Neutron Flux [n/cm²s]</th>
<th>Thermal to Fast ratio</th>
<th>Uniformity (Wafer analysis)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Requirement</td>
<td>Measured Value</td>
<td>Requirement</td>
</tr>
<tr>
<td>NTD-1</td>
<td>1.0E13 (+/- 20%)</td>
<td>8.32E+12</td>
<td>&gt; 200</td>
</tr>
<tr>
<td>NTD-2</td>
<td>3.2E12 (+/- 20%)</td>
<td>2.69E+12</td>
<td>&gt; 200</td>
</tr>
<tr>
<td>NTD-3</td>
<td>1.9E13 (+/- 30%)</td>
<td>1.44E+13</td>
<td>&gt; 200</td>
</tr>
<tr>
<td>NTD-6</td>
<td>3.5E12 (+/- 20%)</td>
<td>2.91E+12</td>
<td>&gt; 200</td>
</tr>
</tbody>
</table>
Neutron activation - NAA and DNAA
DNAA terminal station

- short residence time
- $6.3 \times 10^{12} \, \text{cm}^{-2} \, \text{s}^{-1}$
DNAA can loading device
NAA terminal station

- short residence time
- $2.7 \times 10^{13} \text{ cm}^{-2} \text{ s}^{-1}$
NAA sample loading
Commissioning Stages

- Pre-Commissioning: systems check
- Stage A – Cold commissioning: integration
- Stage B1 – load fuel & first criticality
- Stage B2 – low power tests
- Stage C – Power ascension and full power tests
- Performance demonstration tests
OPAL opened
20 April 2007

Howard opens Australia’s new nuclear reactor

SYDNEY: Prime Minister John Howard has officially opened Australia’s new $400 million nuclear research reactor in Sydney.

The OPAL reactor at Lucas Heights replaces Australia’s first nuclear research facility, which was shut down in January after 48 years of operation.

Mr Howard toured the new reactor yesterday morning amid tight security, before officially opening the facility before an audience of about 200 scientists, politicians and a delegation from Argentina, the source of the fuel which feeds the reactor. He said the work by scientists at the reactor deserved to be celebrated just as much as the achievements of Australia’s sportsmen and women.

“This facility will relieve human suffering, it will be of direct life-saving benefit to countless thousands of our fellow country men and women,” Mr Howard said.

“It will also be a remarkable demonstration to the world of the expertise and the cutting-edge capacity of the Australian nation.”

The OPAL reactor sits in a 13-metre deep container of water, whereas its predecessor was contained in steel. Its main purpose is to generate neutrons for nine neutron-beam instruments.
Repairs to OPAL reflector vessel

1. Stop the leak of H₂O from reactor pool into reflector vessel (contaminating D₂O)
2. Purify the D₂O (~99.7%)

planned duration of each process is ~ 1 month
Timeline of Events To Date

- Jan 2007: Reduction in D2O purity observed
- Feb 2007: Leak test confirms leaks
- Mar 2007: Pressure Increase #1
- Apr 2007: Pressure Increase #2
- May 2007: Repair options design review
- Sep/Oct 2007: Micro-particle injection
- Feb 2008: HW isotopic purif. design review
- June/July 2008: Reactor S/D Leak tests
- Nov 2008: HW replacement
- Dec 2009: Clamps applied
- 2011: HW isotopic purification system
Research reactor operation

• Reactor Availability & Reliability

- In FY 09/10
- Availability 73% – target was 70%
- To plan 93% – target was 90%
Research reactor operation

• Utilisation
  - Neutron beams – CNS out of service for ~6 months in FY – problems for major customer
  - Irradiations
    - U-plates for Mo99 – regular 2 runs/week → ramping up to 4 runs per week
    - Other radiopharmaceuticals
    - DNAA & NAA irradiations
    - Neutron Doped Silicon – $2M in revenue in 09/10 year
Planning

- ANSTO Strategic & Business Plans
- OPAL Long Term Plan
- Business Plan – integrated into budget process
  - Tiered process
  - Board endorsement
PRINCIPLES

• Multi-purpose
• Safety
• Flexibility
• Sustainability
• International
• Responsive
KEY CRITERIA

• Asset Management
  ➢ Plant maintenance
  ➢ Condition monitoring
  ➢ Spares and logistics
  ➢ Component replacement
  ➢ Obsolescence
  ➢ Plans and IT system linkages
Detector with cables connected

Detector assembly (inside watertight container)

Irradiated detector
Disassembly operation

Disassembled detector showing degraded cables
KEY CRITERIA

• Research Excellence
  ➢ Cold Neutron Source
  ➢ Guide optics
  ➢ Beam instruments
  ➢ User access
  ➢ Other research facilities – NAA, Reactor neutronics and thermal-hydraulics
OPAL / Neutron Guide Hall
KEY CRITERIA

• People
  ➢ Planning
  ➢ Level of redundancy (key staff)
  ➢ Training & re-training
  ➢ Succession Planning
  ➢ Level of knowledge & type of knowledge
KEY CRITERIA

• Regulatory Interface
  ➢ Systems to assure compliance
  ➢ Managing relationships
  ➢ Safety Case up to date
  ➢ Understanding Regulatory Expectations
ACHIEVEMENTS

• Defects being reduced
• Heavy Water Purity stabilising
• Finished Commissioning
• International Recognition
• New Building approved
• Increased Production
• Improved Reliability
• Increased Staff
Science – what are the big opportunities with OPAL?

**Industrial Problems**

- Oil and gas exploration/extraction
- Nuclear: Gen-IV reactors, Fusion materials
- Hydrogen Economy, fuel cells, etc.
- Food
- *In-situ* processes in manufacturing, etc. (e.g. welding, grinding, chemical reactions, extrusion, deformation, …)

**Biology in the post-genomic era**

- Interactions between biomolecules
- Structure & function of membrane proteins
- Bio-devices
Future directions

• **OPAL is a world-class research reactor**
  - Performance in top 5% of more than 250 research reactors world-wide

• **OPAL provides neutrons for:**
  - World class neutron scattering instruments used to study structure of materials for scientific research and industrial applications
  - Production of high quality radiopharmaceuticals for nuclear medicine
  - Irradiation of silicon to produce high quality semiconductors

• **OPAL supports Australia's health, environmental, industrial and national security objectives**
Thank you