The Neutron Beam Expansion Program at the Bragg Institute

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Abstract. The Bragg Institute is operating the neutron scattering science facilities at the Australian research reactor OPAL. The first set of seven neutron scattering instruments was provided as part of the OPAL construction project which was completed in 2007. During the period 2008 - 2013, the instrument suite was significantly expanded by a further seven instruments. In addition to this, major investments were made to establish a world-class infrastructure for supporting these instruments, including new sample environments, ³He polarisers/analysers, additional neutron guides and a Be filter option for chemical spectroscopy.

1. Introduction
Over the past few years, the Bragg Institute went through a large instrumentation expansion phase, doubling the number of instruments from 7 to 14 and adding or upgrading support infrastructure such as neutron guides and sample environments. The funding for the program came from the Australian government through ANSTO internal funding for the TOF inelastic spectrometer PELICAN, the ultra-small-angle neutron scattering instrument KOOKABURRA, the Laue diffractometer JOEY, the Be Filter spectrometer for chemical analysis and ³He Polarisation Project. In addition to this, the Taiwanese government enabled participation of their neutron science community in OPAL by investing at the Bragg Institute and constructing the cold triple-axis spectrometer SIKA.

The most significant portion of the funding for the new instruments, however, was secured during the time of the global financial crisis when Canberra asked ANSTO to propose possible infrastructure areas where additional funding might be productively allocated. The Bragg Institute proposed a significant Expansion Plan for Neutron Science in Australia. The proposal was successful and funding was publicly announced on 12 May 2009 as part of the Super Science – Future Industries initiative. This enabled the construction of the TOF-based small-angle neutron scattering instrument BILBY, the backscattering spectrometer EMU, the radiography/tomography instrument DINGO, two new cold neutron guides CG2A and CG2B as well as new sample environment equipment, including a 12 Tesla split-coil high-field magnet. The description of the $37 million NBI2 project reads as follows: “This project will significantly enhance the research capabilities of the Australian neutron science facilities at ANSTO. It will provide university, government and industry based users of the new ANSTO research reactor OPAL with new world-class facilities for investigating the structure and dynamics of condensed matter with particular emphasis on the areas nanoscience, soft matter

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Figure 1. New instruments and projects constructed during the Neutron Beam Expansion Project (2008 - 2013).

Table 1. List of new instruments and projects constructed during the Neutron Beam Expansion Project (2008 - 2013)
dynamics and biology which are key areas for future technology and industrial developments in Australia”. The total investment for the Neutron Beam Expansion Program at the Bragg Institute exceeds AUD 65M (see Figure 1 and Table 1 for a listing of all new instruments and neutron infrastructure projects).

The choice of the new instruments was based on earlier requests by the scientific users of the Bragg Institute (e.g. the Blue Mountains Workshop in 2005) and initial specifications were developed at the NBI2 Scoping Workshop in 2009. More detailed scientific specifications, schedules and costings were developed during the NBI2 Conceptual Design Workshop which was generously hosted by the Center for Neutron Research of the National Institute of Standards and Technology, USA.

During the peak period from 2011 to 2013, well over 40 staff worked on the Neutron Beam Expansion Program. Our Beam Instruments Advisory Group (BIAG) reviewed the progress of the instrumentation projects on a bi-yearly basis. Major installations of the new instruments started in 2008 and major changes to the OPAL reactor (i.e. the insertion of the new cold guides) were completed in December 2012. In December 2013, PELICAN, SIKA JOEY, DINGO and KOOKABURRA are in the hot-commissioning stage. Early in 2014, these instruments will obtain their operational licenses and will later commence the regular user operation mode. Almost all major components of BILBY and EMU have now been installed and these two instruments are scheduled to commence their hot-commissioning phases in Feb 2014 and June 2014, respectively.

2. Main characteristics of the new instruments and projects [1]

2.1. PELICAN - TOF inelastic spectrometer

PELICAN is a cold-neutron time-of-flight spectrometer. It is designed for studies of polycrystalline, glassy and liquid samples mainly in chemistry and in studies of soft matter. In order to achieve the required pulsed mono-energetic beam of neutrons onto the sample, a focussing HOPG crystal monochromator and a Fermi chopper are used. Changes in neutron energy induced by interaction with the sample, is detected by time-of-flight measurement between sample and detector (energy resolution: 50 µeV to 1 meV; ~2.5% of Ei). PELICAN will be OPAL’s "first" large time-of-flight spectrometer capable of polarisation analysis (polariser: FeCo/Si supermirrors; analyser: $^3$He cell), and we expect that the instrument will operate in this mode up to 30% of the time.
2.2. **KOOKABURRA - Ultra small-angle scattering**

KOOKABURRA uses the classical Bonse-Hart method for detection of small-angle scattering at very low \( q (q_{\text{min}} = 3 \times 10^{-5} \text{ Å}^{-1}) \), and will be an optimised version of the currently best reactor-based USANS instrument, BT-5 at NIST. The premonochromator consists of a vertically and horizontally focusing PG crystal reflecting at 90°. The instrument has two interchangeable sets of five-bounce channel-cut crystals, Si(111) and Si(311), allowing operation at two distinct wavelengths (\( \lambda = 4.43 \text{ Å} \) and \( \lambda = 2.32 \text{ Å} \), respectively), for optimally accommodating weakly and strongly scattering samples.

2.3. **SIKA - Cold triple axis spectrometer**

SIKA is a cold triple axis spectrometer directly viewing the OPAL cold source. Using the (002) reflection of a doubly focusing HOPG monochromator, the available incident neutron wavelengths range is \( 1.62 \text{ Å} \leq \lambda \leq 5.8 \text{ Å} \), corresponding to an incident energy range of \( 2.43 \text{meV} \leq E_i \leq 31 \text{ meV} \). For neutron detection, both single tube and PSD \(^3\)He counters are available.

2.4. **JOEY - Laue diffractometer**

JOEY is a Laue diffractometer using a CCD camera for neutron detection. This instrument uses the remaining beam transmitted by the instrument KOALA and will be mainly used for pre-orientation of single crystals. The instrument concept is similar to OrientExpress at the Institute Laue - Langevin.

2.5. **DINGO - Radiography/tomography**

The DINGO instrument is located at the reactor beam hall. It uses the direct thermal beamport HB2 of OPAL. DINGO has two experimental configurations, a high-flux mode realised by a 40 mm collimator pinhole (estimated flux at sample: \( 4.75 \times 10^7 \text{ n cm}^{-2} \text{ s}^{-1} \) (for \( L/D = 500 \)) and a high-resolution mode realised by a 10 mm pinhole (estimated flux at sample: \( 1.15 \times 10^7 \text{ n cm}^{-2} \text{ s}^{-1} \) (for \( L/D = 1000 \))). DINGO uses a CCD camera with 200 mm x 200 mm neutron detection area. The maximum image resolution will be about 25 µm.

2.6. **BILBY - TOF small-angle scattering**

BILBY is a 40 m SANS machine, installed side by side with the operating initial SANS instrument QUOKKA. The essential difference between these instruments is that BILBY uses a chopper-based time-of-flight data collection mode (an optional velocity selector operation mode is planned to be added in the coming year). The instrument concept is similar to D33 at the Institute Laue - Langevin. Using TOF, BILBY can cover a very wide \( q \)-range in one single experiment setting (total \( q \)-range with normal pinhole collimation: \( 10^{-3} \text{Å}^{-1} - 1.2 \text{ Å}^{-1} \)). Using a slit collimator, \( q_{\text{min}} \) will be \( 2 \times 10^{-4} \text{Å}^{-1} \). By combining different pairs of choppers (4 choppers are available in total) the wavelength-resolution can
be adjusted over a wide range of 4% - 30%. This allows to trade q-resolution for intensity. BILBY’s
detection system consists of a back detector (area: 64 cm x 64 cm) and four 32 cm x 64 cm front
detector panels, all comprised of 8 mm diameter $^3$He tubes.

![Figure 6. DINGO - Radiography/tomography](image1)

![Figure 7. QUOKKA (grey) and BILBY (red) - SANS](image2)

### 2.7. EMU - Backscattering spectrometer

The EMU back-scattering spectrometer will be OPAL’s fourth spectrometer/instrument that can
measure inelastic scattering, after our TAIPAN and SIKA 3-axis spectrometers and our PELICAN
time-of-flight spectrometer. Its distinctive feature is that it has much tighter energy resolution:
between 1 and 30 micro-eV, as opposed to a minimum of ~50 micro-eV for PELICAN or SIKA. The
instrument itself is a very specialised 3-axis spectrometer, like TAIPAN or SIKA, in which the
incident neutron energy is determined by back-scattering from a single crystal, and the final scattered
energy is determined using a huge spherical array of crystals reflecting and focussing these neutrons
back to sample position, behind which there is an array of detectors.

Typically, the exact same crystal reflection (e.g. Silicon 111) is used for both monochromator
and analyser, and the energy scan is achieved by moving the monochromator backwards and forwards
at high speed. This results in a Doppler shift to the incident neutron energy, sufficient to reach ± 30
micro-eV. EMU it will be similar in design to the IN16 backscattering spectrometer at the Institute
Laue Langevin, the HFBS at NIST or the SPHERES instrument at FRM-II.

### 2.8. CG2 - Neutron guides

The new cold neutron guide CG2 is split into two individual guides CG2A (cross-section: 40 mm
width; 100 mm height) and CG2B (50 mm x 160 mm) right from the entrance close to the cold
moderator. Both are curved supermirror guides (top/bottom: $m = 3.0$ and left/right sides: $m = 2.5/2.0$;
radii: 1500 m (CG2A) and 1300 m (CG2B)). CG2A will supply BILBY with neutrons and CG2B will
provide neutrons to future instruments downstream of the Platypus reflectometer. For accommodating
CG2, major changes were made to the OPAL reactor in-pile structures, namely the replacement of the
cold guide in-pile plug and primary shutter. With 70 staff involved in this project, this was the most
tackling task of the entire Neutron Beam Expansion Program.

### 2.9. New sample environments

The sample environment upgrade project features a 12 T split coil magnet with variable temperature
insert (1.4 K - 350 K) and 15 mK dilution insert. This magnet can be operated in asymmetric field
mode which makes it suitable for operation with polarised neutrons. Other new sample environments
are a vapour and sorption system which will allow material studies in controlled gas atmospheres and
a closed cycle refrigerator cryostat which is compatible with the 15 mK dilution insert.
2.10. $^3$He polarisers/analysers
This project aims to provide polarised Helium-3 based neutron polarisers and polarisation analysers to 6 OPAL instruments to enable full polarisation analysis for magnetism research. The key equipment are the Helium-3 polarising station (contracted from the Institute Laue-Langevin), added equipment on the 6 instruments and the infrastructure to enable the operation of the station and the neutron instruments. Up to December 2012, the station has been partially commissioned at ANSTO and instrument equipment have been incorporated into 4 instruments (TAIPAN, WOMBAT, QUOKKA, PLATYPUS). Neutron tests were successfully carried out on TAIPAN and WOMBAT.

2.11. Be filter option for TAIPAN
The Be Filter provides an alternative measurement mode for using the TAIPAN triple-axis spectrometer which is already in full user operation at the Bragg Institute. The instrument is a high throughput angle-integrating neutron energy filter spectrometer designed specifically to measure vibrational density of states. This additional mode on TAIPAN provides a totally new way for Australian scientists to study atomic and molecular motions. A measurement proceeds by varying the incident neutron energy $E_i$ which is delivered by a HOPG(002) or Cu(200) double-focusing monochromator, and then detecting these energy filtered neutrons scattered from the sample, by an arc of $^3$He detectors placed behind the filter assembly. The energy transfer is given as $\hbar \omega = E_i - E_f$ where $E_f$ is the mean energy of the scattered neutrons. For the beryllium/graphite filter combination used, $E_f$ is ~1.2 meV, and the measured Gaussian-equivalent energy resolution is ~1.1 meV FWHM. The spectrometer is based on the design from NIST (FANS).

3. References
[1] More details can be found here: http://www.ansto.gov.au/ResearchHub/Bragg/Facilities/Instruments/index.htm

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