Neutron Beam Facilities at the Replacement Research Reactor, ANSTO

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ABSTRACT

The exciting development for Australia is the construction of a modern state-of-the-art 20-MW Replacement Research Reactor which is currently under construction to replace the aging reactor (HIFAR) at ANSTO in 2006. To cater for advanced scientific applications, the replacement reactor will provide not only thermal neutron beams but also a modern cold-neutron source moderated by liquid deuterium at approximately –250^{o}C, complete with provision for installation of a hot-neutron source at a later stage. The latest 'supermirror' guides will be used to transport the neutrons to the Reactor Hall and its adjoining Neutron Guide Hall where a suite of neutron beam instruments will be installed. These new facilities will expand and enhance ANSTO's capabilities and performance in neutron beam science compared with what is possible with the existing HIFAR facilities, and will make ANSTO/Australia competitive with the best neutron facilities in the world.

Eight 'leading-edge' neutron beam instruments are planned for the Replacement Research Reactor when it goes critical in 2006, followed by more instruments by 2010 and beyond. Up to 18 neutron beam instruments can be accommodated at the Replacement Research Reactor, however, it has the capacity for further expansion, including potential for a second Neutron Guide Hall. The first batch of eight instruments has been carefully selected in conjunction with a user group representing various scientific interests in Australia. A team of scientists, engineers, drafting officers and technicians has been assembled to carry out the Neutron Beam Instrument Project to successful completion. Today, most of the planned instruments have conceptual designs and are now being engineered in detail prior to construction and procurement. A suite of ancillary equipment will also be provided to enable scientific experiments at different temperatures, pressures and magnetic fields.

This paper describes the Neutron Beam Instrument Project and gives an update on the current status and applications of the neutron beam instruments.

1. INTRODUCTION

ANSTO is in the process of replacing its 1950s-vintage HIFAR research reactor with a state-of-the-art facility by 2006, along with a suite of eight 'leading-edge' instruments to replace old instruments (Figure 1) at HIFAR. Like its predecessor, the replacement reactor will be a multipurpose facility for neutron beam research and radioisotope production. With more than three times the neutron flux of HIFAR, and modern neutron optics, the replacement facilities will rate with the best in the world.

The neutron is an ideal tool for probing solids and liquids. Like electrons and x-rays, neutrons can be used to see atomic structure. Thermal neutrons generated in research reactors are scattered by atoms in the material being probed. The scattering pattern reveals the sample's structure and dynamics. Neutron scattering is contributing to many areas of science, medicine and engineering. Industries use in-situ neutron studies to check and improve welds, and mechanical and thermal properties of components. It also guides the scientists and engineers in designing new materials for the 21st century, such as super-conductors, medical body implants, ceramics, opto-electronic materials, sensors and building materials.

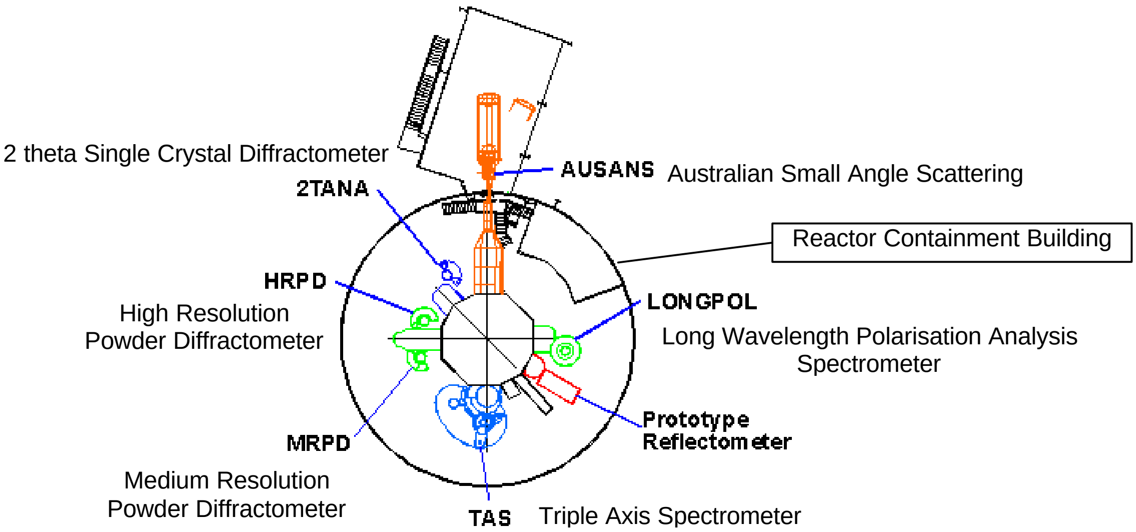


Figure 1. Seven Neutron Beam Instruments at HIFAR

2. NEUTRON BEAM INSTRUMENT PROJECT (NBIP)

This project is run in parallel with the Replacement Research Reactor Project. The Project Coordination Group (PCG) was created in 2000 to plan and set up strategies to run the project, followed by the assembly of the Scientific Team and the Engineering Team. The organisational structure is shown in Appendix A and job-flow diagrams in Appendix B.

The NBIP is run in two stages: Stage 1 (2000 to 2006) to supply a suite of eight instruments described in this paper; and Stage 2 (2006 to 2010) to supply more instruments yet to be determined. Each of the eight instruments is managed as a sub-project and led by a dedicated scientist with support from the Engineering Team. The sub-projects are run in 3 phases:

- Phase 1: Conceptual design where the instrument objectives and specification are set.
- Phase 2: Engineering design to installation
- Phase 3: Commissioning

A standardisation policy is applied to all instrument designs to maximise interchangeability of major components for better utilisation of available resources, and to reduce design and maintenance efforts/costs.

3. DESCRIPTION OF INSTRUMENTS

The current layout of the instruments is shown in Figure 2 and elaborated on in the following sections of this paper. Seven of the eight instruments are located in the Neutron Guide Hall and one at the reactor face. Most of the instruments are currently in the engineering design stage (as of February 2003) and some have progressed into procurement.

(a) Neutron Guide Hall

– Thermal Guide:

- High Resolution Powder Diffractometer, TG1 (downstream)
- High Intensity Powder Diffractometer, TG1 (upstream)
- Quasi-Laue Diffractometer, TG3 (downstream)
- Residual Stress Diffractometer, TG3 (upstream)

– Cold Guide:

- Polarisation Analysis Spectrometer, CG1 (upstream)
- Small Angel Neutron Scattering, CG1 (downstream)
- Reflectometer, CG3

(b) Reactor Face (Thermal):

- Three-Axis Spectrometer, TG4

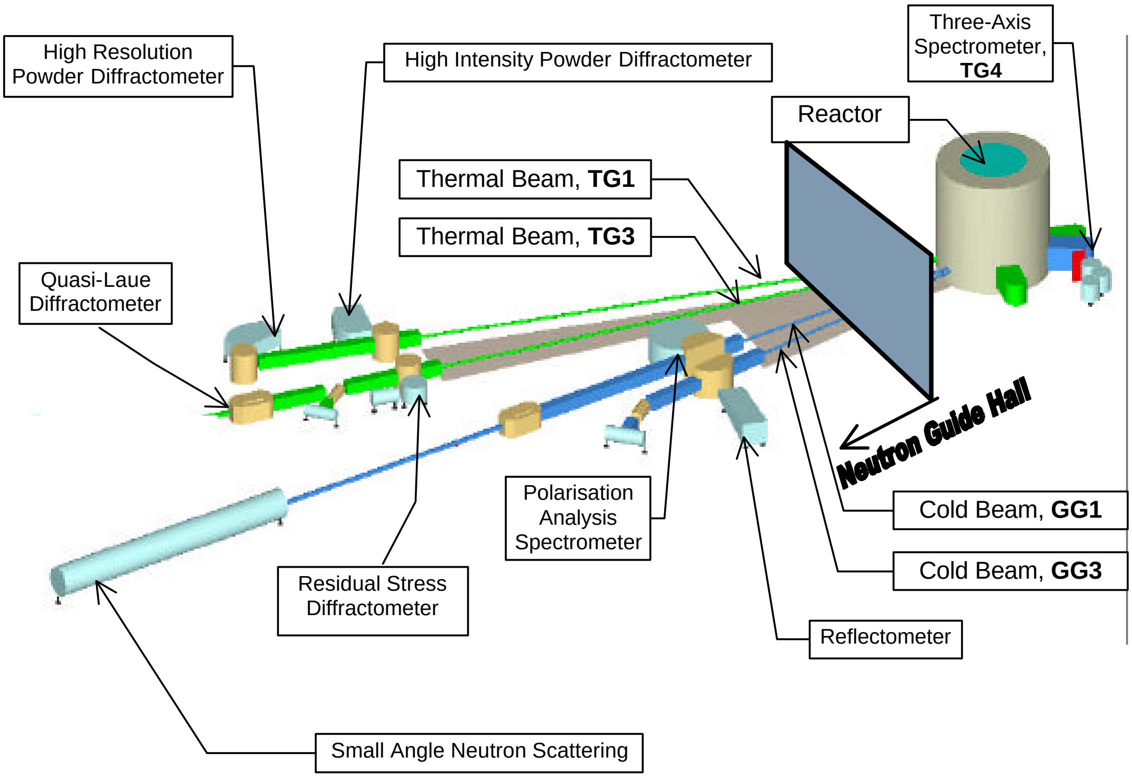


Figure 2. Layout of Neutron Beam Instruments – Stage 1

3.1 High Resolution Powder Diffractometer (HRPD)

Installed on a thermal guide TG1 in the Neutron Guide Hall, this instrument will provide a significant improvement in resolution over the current HIFAR instrument with a reduced average data collection time. The goal is to have a high-resolution powder diffraction capability with d-spacing resolution at least as good as that of the best current reactor instrument of this type in the world, e.g. D2B at the Institut Laue Langevin in Grenoble ($[\Delta\delta/\delta]_{min}$ = 0.0006). It will collect a powder diffraction pattern in 5 hours from a 1 gram sample with complex crystal structure. It would then be equal to the best high-resolution neutron powder diffractometers currently available in the world and used to study structures of complex crystals, e.g. ceramics and minerals.

Equipped with two selectable monochromators and vertically lifted shielding shutters as shown in Figure 3, the incoming neutron beam can be diffracted and re-directed to the sample/target at variable take-off angles of 90^o to 155^o allowing the users to select desired wavelengths for the experiments. The sample stage is supported by a cushion of air and slews around the monochromator with the detector assembly trailing and orbiting around it.

Engineering design is nearing completion. The latest information on this instrument is available at http://home.ansto.gov.au/ansto/bragg/2005/hrpd/instrument_hrpd.html

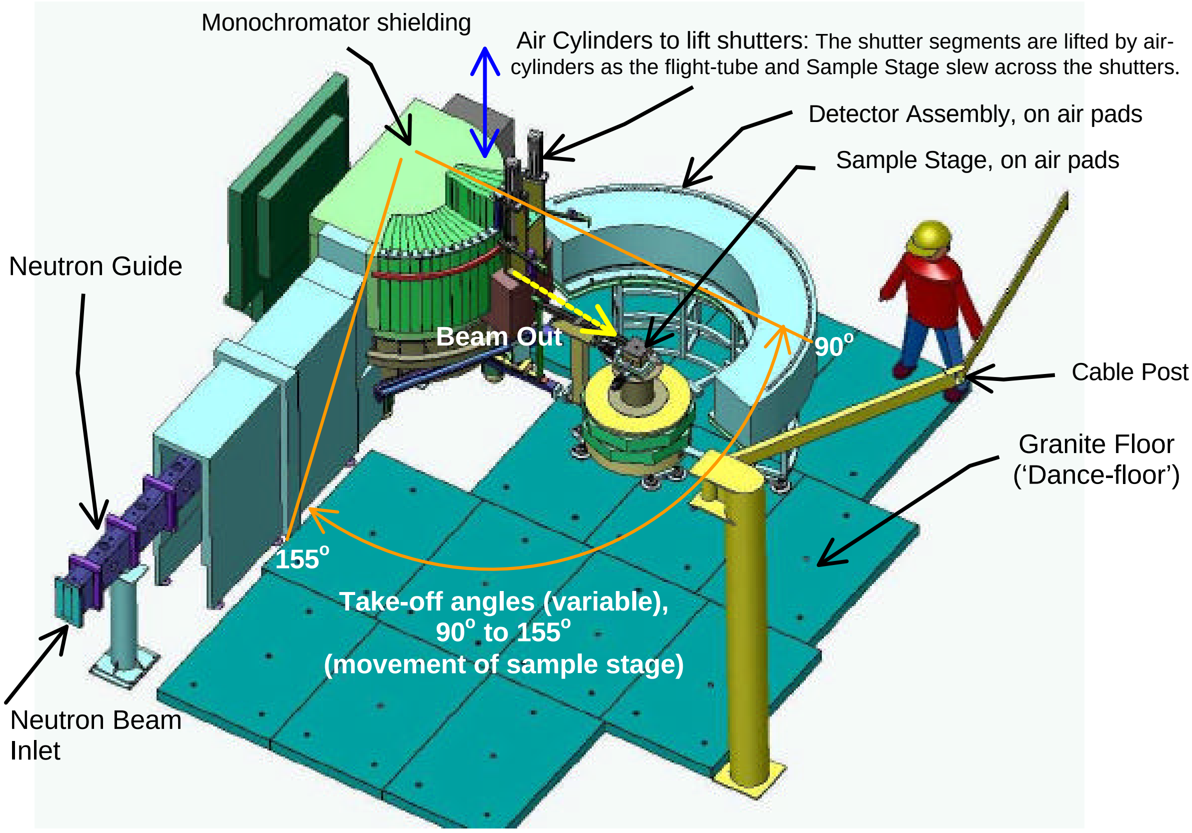


Figure 3. High Resolution Powder Diffractometer
NB, Interlocked Fences are not shown for clarity.

3.2 High Intensity Powder Diffractometer (HIPD)

Installed on a thermal guide TG1 (upstream of HRDP), this instrument shares many standard design features developed for the HRPD, such as monochromator shielding assembly, monochromator mounts and motion control. However, this instrument is optimised for speed with a view to providing kinetics information and diffraction data in a reasonable time scale while delivering data of sufficient quality to allow quantitative analysis of the results. The aim is to determine crystal structures quickly for phase transitions, chemical reactions and kinetic studies. The method for achieving this is to build a flexible modular instrument which can exploit the advantages of (i) focussing neutron optics in the monochromator system over a wide range of incident wavelengths, (ii) a large solid angle detector with position sensitive detection capabilities, (iii) an advanced data acquisition electronics and (iv) a re-configurable collimation system which optimises the background reduction in each experiment.

It will have a detecting power at least 100 times that of the current Medium Resolution Powder Diffractometer at HIFAR, with some improvement in resolution. It will be used to study structural and magnetic phase changes as a function of temperature, pressure, magnetic and electric stimuli and time.

As shown in Figures 3, 4 and 5, the HIPD is similar in construction to the HRPD but with different take-off angles (40^o to 120^o) and detectors. A joint design work with the HRPD and the HIPD has incurred major design improvements and standardisation.

Engineering design is nearing completion.

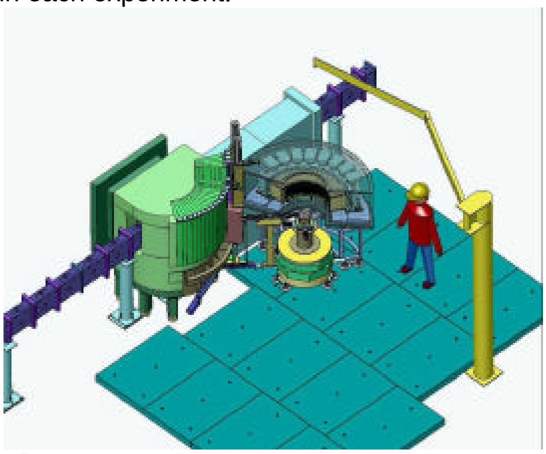


Figure 4. HIPD Layout
NB, Interlocked Fences are not shown for clarity.

The latest information on this instrument is available at http://home.ansto.gov.au/ansto/bragg/2005/hipd/instrument_hipd.html

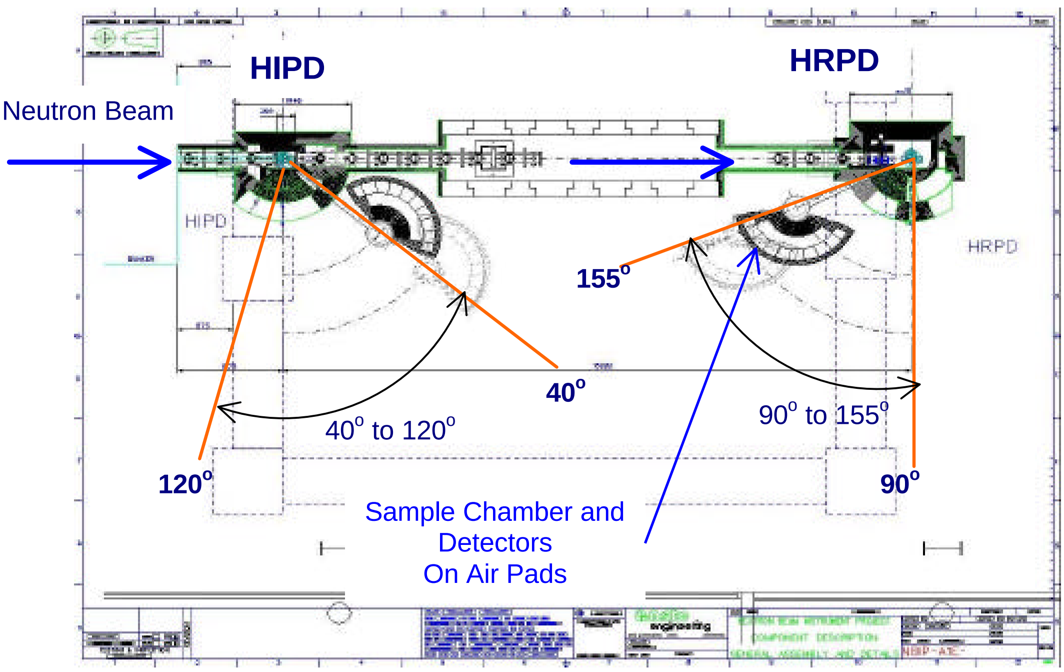


Figure 5. Layout of HIPD and HRPD as installed on TG1 – Plan View
NB, Interlocked Fences are not shown for clarity.

3.3 Small Angle Neutron Scattering (SANS) Instrument

A 40-m SANS instrument will be built on a cold guide CG3 in the Neutron Guide Hall to provide a broad band of cold neutrons, by the combination of neutron source and velocity selector, and a significant increase in the wavelength. The aim is to determine large-scale structures as in macromolecular complexes, porous materials, polymers, nanoparticles, metals, superconductors, magnetic materials and so on. The goal is to have an instrument very similar in the spirit to the 40-metre D22 instrument at Institut Laue Langevin in Grenoble, France and the 30-metre instruments on NG3 and NG7 at the National Institute for Standards and Technology in Gaithersburg in the USA. This instrument is expected to attract a great deal of interest in chemistry, biology and condensed matter physics.

Shown in Figure 6 is a conceptual design of the SANS with neutrons entering from a cold guide, the sample position in the middle and the detector tank at the bottom left. The detector will move on rails within the detector tank. The latest information on this instrument is available at http://home.ansto.gov.au/ansto/bragg/2005/sans/instrument_sans.html

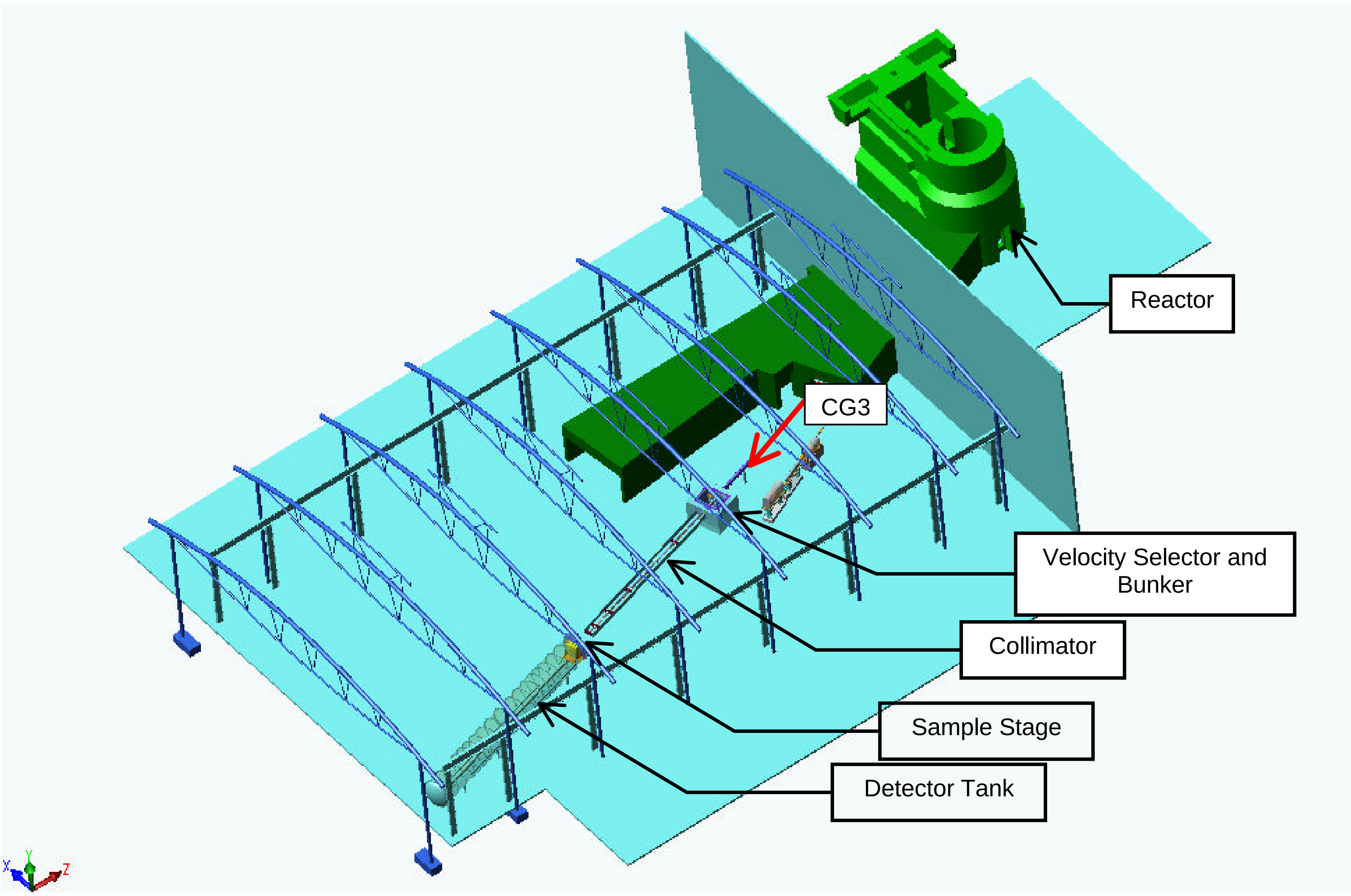


Figure 6. Small Angle Neutron Scattering

3.4 Reflectometer

This instrument will be installed on a cold guide CG1 in the Neutron Guide Hall and permit measurements of neutron optical reflectivity at grazing angles to probe the neutron reflective index of materials, with high resolution perpendicular to the surface, to depth of around 1000Å. This will allow determination of structural profile in liquid and solid interfaces and in organic and inorganic multi-layers. The option of polarising the neutron beam will allow magnetic properties near surfaces and magnetic depth profiles to be studied. Applications in physics, chemistry and materials science are likely to be widespread because Australia has a strong user community in soft matter, polymers and colloids, and there is already clear demand for a neutron reflectometer capable of studying liquid-air interfaces.

Engineering design is in progress. The latest information on this instrument is available at http://home.ansto.gov.au/ansto/bragg/2005/reflectom/instrument_refl.html

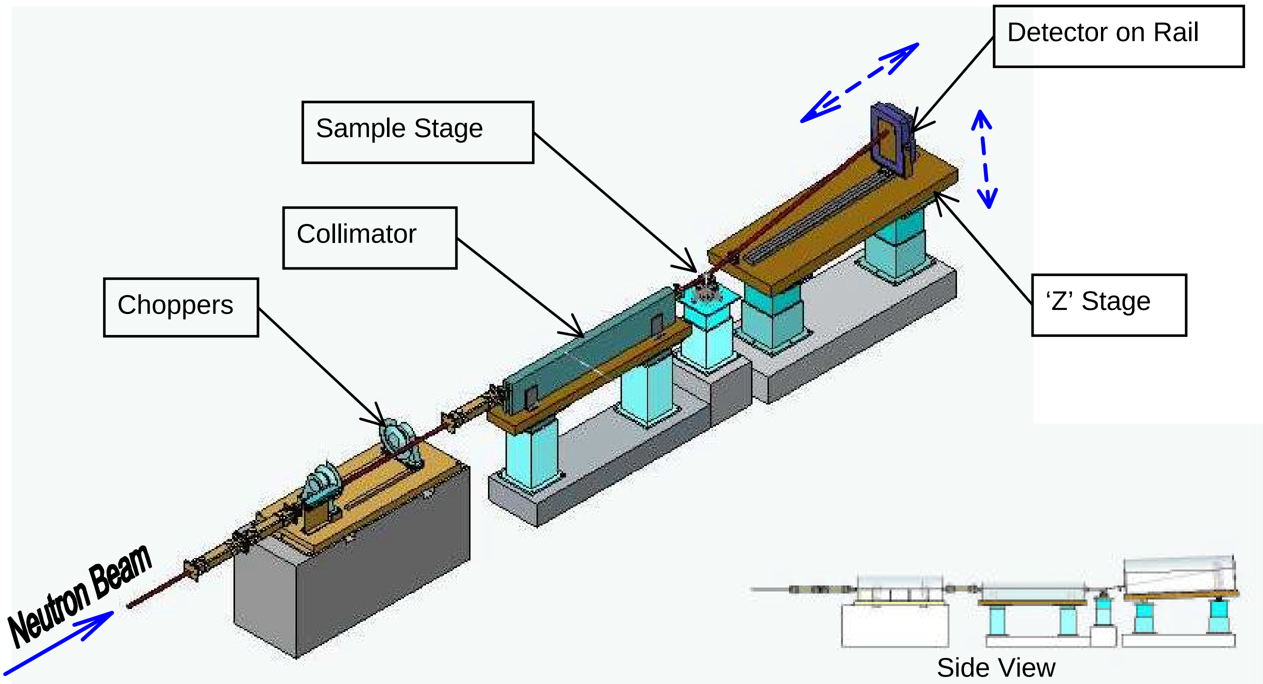


Figure 7. Reflectometer – Time-of-Flight
Note: Vacuum tanks and bunker are not shown for clarity.

3.5 Polarisation Analysis Spectrometer

This instrument will be based on the existing instrument at HIFAR which may be relocated to the Neutron Guide Hall and installed with a new monochromator and housing.

The Polarisation Analysis Spectrometer uses polarised neutrons, a flipping device that can reverse the polarisation direction, and a polarisation sensitive detector system. Analysis of polarisation allows separation of nuclear and magnetic scattering mechanisms and pulsing of the flipper permits energy analysis by the time-of-flight method. Cold neutrons will be of great benefit, permitting use at longer wavelengths and providing increased flux. The Polarisation Analysis Spectrometer is particularly useful for studies of magnetic short-range order and flux pinning mechanisms in HTS crystals. It can also measure magnons, photons, crystal field transitions and diffusion rates.

This sub-project has not yet started due to the late arrival of the Instrument Scientist.

3.6 Quasi-Laue Diffractometer

This instrument will be installed on a thermal guide TG3 and allow the routine use of neutron diffraction to obtain structural information, particularly on the location of hydrogen in biological samples, which cannot be accurately determined using x-ray studies. The instrument will use a broad band of thermal neutrons and a cylindrical image plate detector to record the diffraction peaks. This method of operation, known as Quasi-Laue diffraction, facilitates rapid determination of accurate structures on biological single crystals.

It is planned to procure an instrument similar to VIVALDI (Figure 8) at the Institut Laue Langevin, in Grenoble, France. This is the first of a new generation of very large solid angle, broad-band instruments, using neutron image-plate detectors. The idea is that crystal structures will be determined much more rapidly than is presently possible, and on much smaller crystals. The recent rapid expansion of topical areas of chemistry, such as supramolecular chemistry, crystal engineering and molecular modelling, requires accurate fundamental information concerning weak intermolecular interactions involving hydrogen atoms.

Procurement of the instrument has commenced. The latest information and specification of this instrument is available at http://home.ansto.gov.au/ansto/bragg/2005/sxd/instrument_qld.html

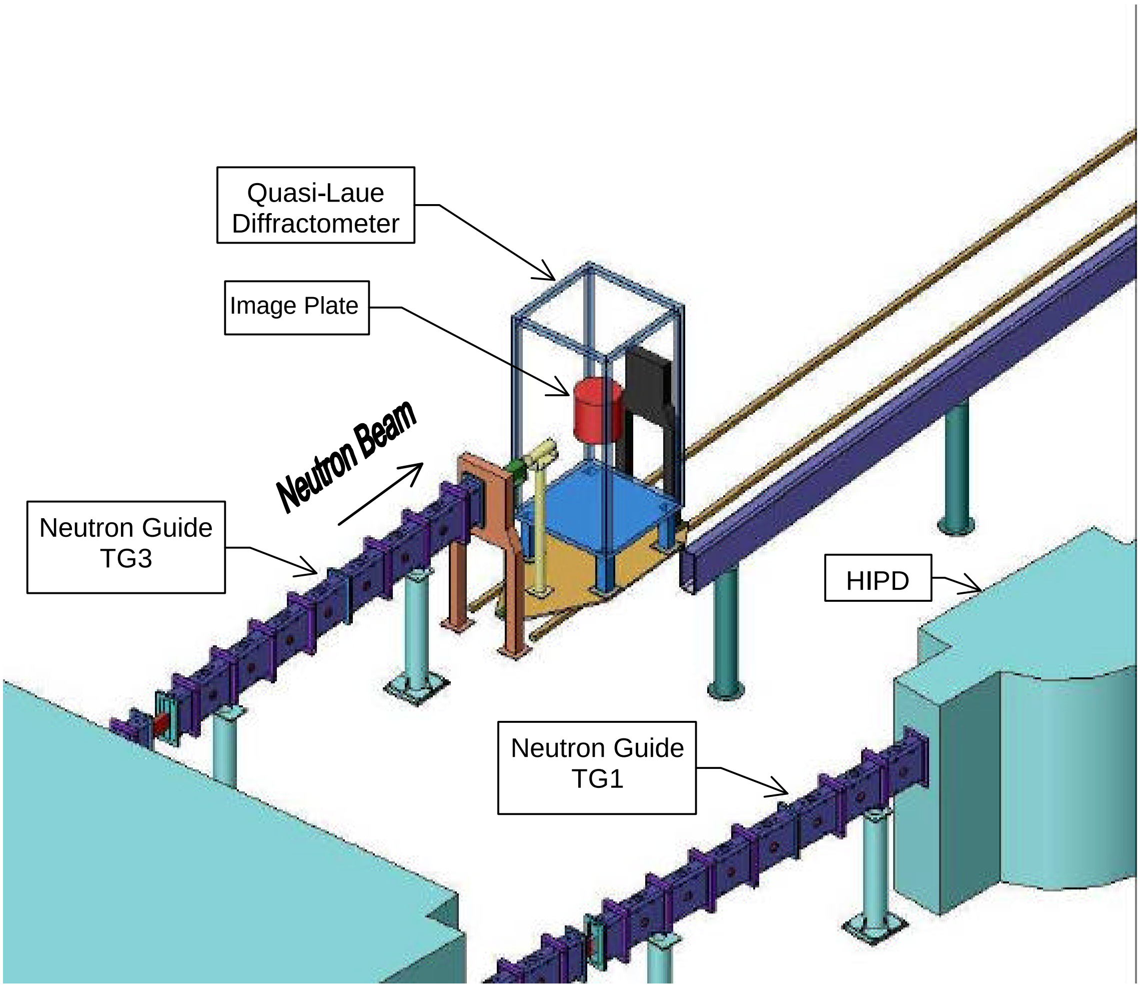


Figure 8. Quasi-Laue Dirrfractometer, TG3
NB, Neutron Guide Shielding and Interlocked Fences are not shown for clarity.

3.7 Three Axis Spectrometer

This instrument, to be installed on a thermal guide TG4 at the Reactor Face, will permit determination of the energy transfer as a function of momentum transfer (scattering angle) and is one of the most versatile of neutron scattering instruments. It enables the measurement of intensity at any scattered wavevector and energy within the instruments range. It is frequently used to study the collective motion of atoms in solids (phonons) and that of their magnetic moments (magnons). Use of polarisation analysis facilitates the separation of nuclear and magnetic scattering.

Engineering design is progressing with special attention being given to the radiological shielding design which is proving to be a major challenge. The aim is to make the shielding as compact as possible to achieve the shortest distance possible between the monochromator (inside the shielding) and the sample (outside the shielding) with a view to maximising the instrument performance. The Sample Table is on air pads and moves around the Monochromator Shielding with the Analyser and Detectors trailing it as shown in Figures 9, 10 and 11. The latest information and technical specifications on this instrument are available at http://home.ansto.gov.au/ansto/bragg/2005/3_axis/instrument_tas.html

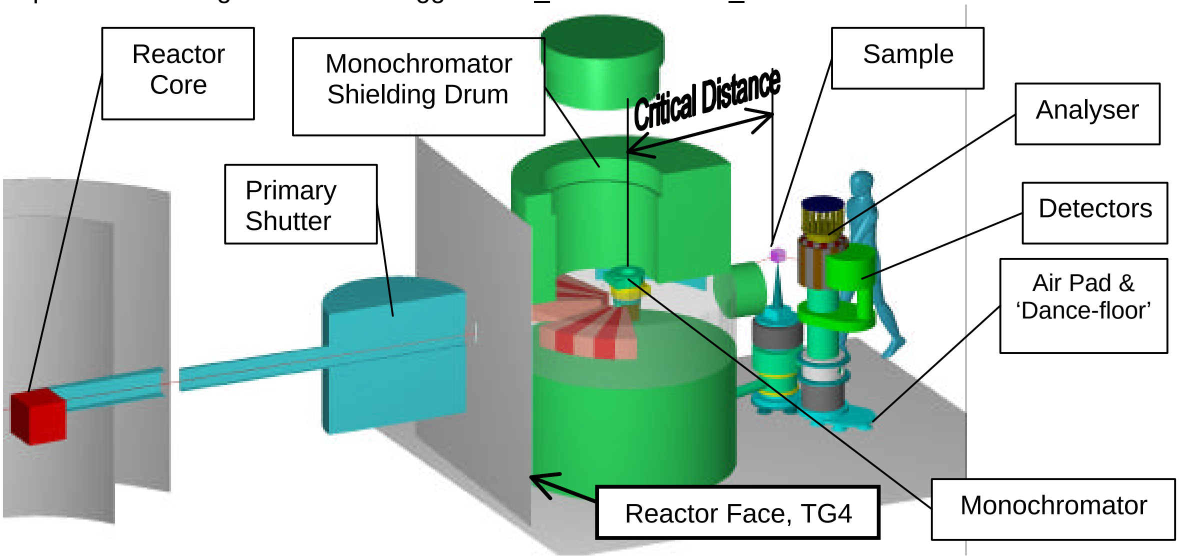
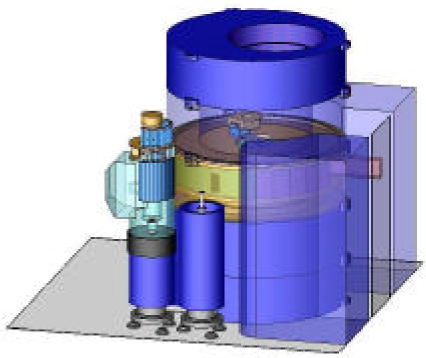


Figure 9. Three Axis Spectrometer – Conceptual Design



The sample chamber and detectors are equipped with air pads for precise and effortless movements.

Figure 10. Three-Axis Spectrometer Assembly

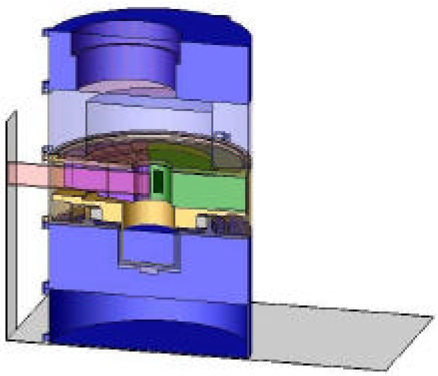


Figure 11. TAS – Sectional View

3.8 Residual Stress Diffractometer

This instrument will be installed on a thermal guide TG3 in the Neutron Guide Hall and used to determine strain distributions in industrial plant components such as turbine blades and in welds. The key feature of the technique lies in the ability to accurately measure strain in small gauge volumes around 1 mm^3 in the specimen. The scattering volume is defined by measuring the diffracted beam only at right angles to the incident beam. The incident beam flux must be as high as possible to enable penetration through large samples. This method maximises flux by using a large fraction of the thermal neutron spectrum via modulation of the white neutron beam.

There are a number of important benefits to Australia in the building of a first-class instrument for materials science and engineering. There are many stress-related problems in a wide variety of fields in Australia, such as the manufacturing industries, mining, oil and gas, rail transport, defence and life extension. Strain scanning provides another tool for solving problems to complement facilities at the major research institutes. It will create a regional pool of experts who may tap into the pool of expertise internationally. The turn-around time for tests for Australian customers will be reduced, not having to go overseas to have the tests performed. From an educational perspective the instrument will build expertise in Australia and will help attracting graduates into engineering.

Shown in Figure 11 is a conceptual design of the instrument. It uses the standardised monochromator shielding developed for the HRPD/HIPD and other standard components.

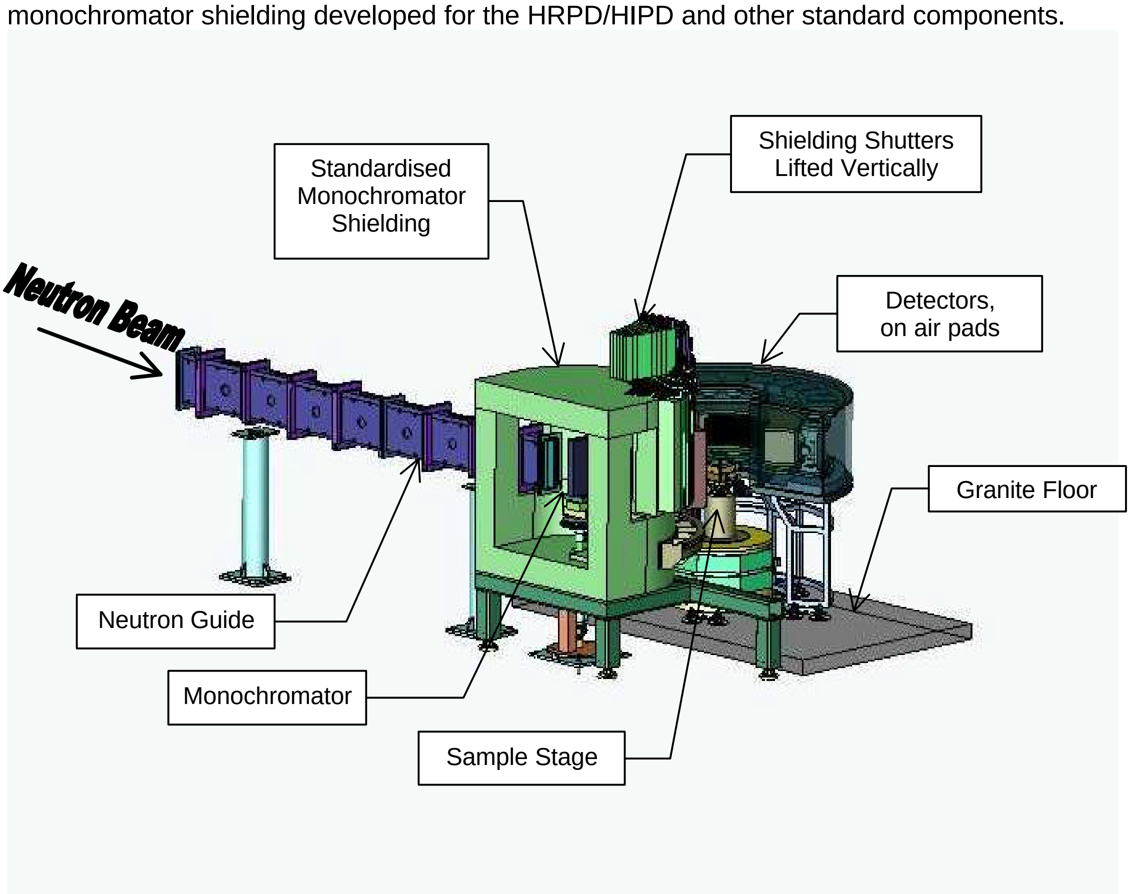


Figure 12. Residual Stress Diffractometer – Conceptual Design
NB, Neutron Guide Shielding and Interlocked Fences are not shown for clarity.

4. SUMMARY

Table 1 below shows the current status of the instrument design and *indicative* time-schedules.

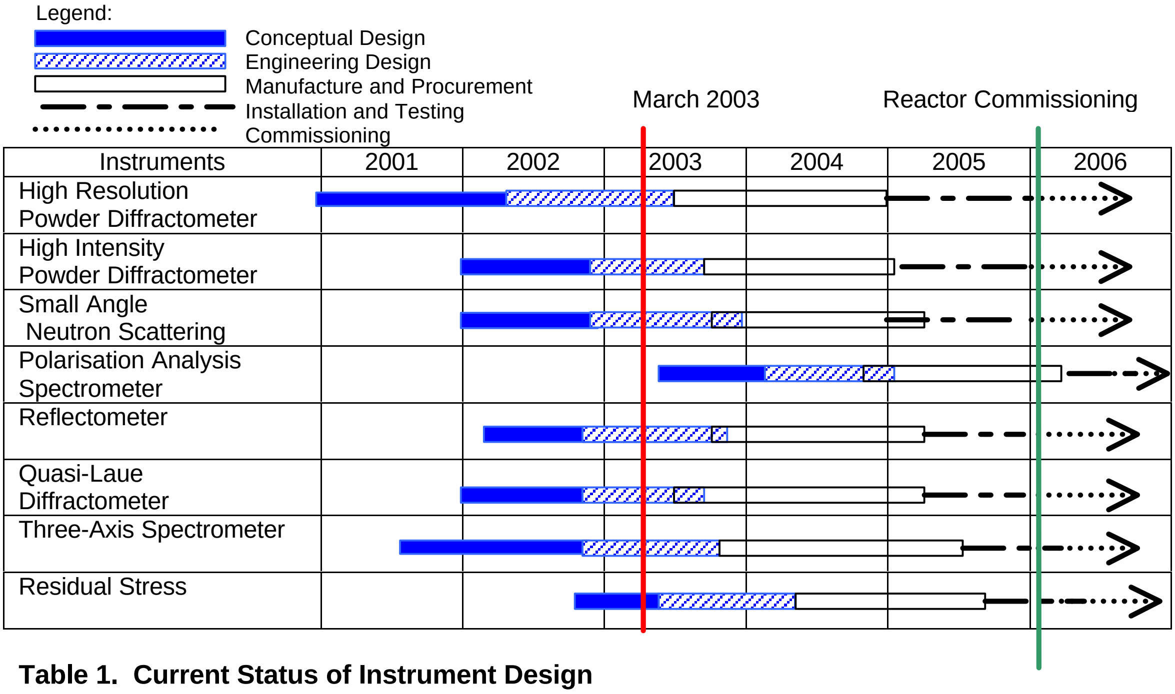


Table 1. Current Status of Instrument Design

5. CONCLUSION

Most of the planned instruments have progressed well according to the master schedule and are being detailed for manufacture. The standardisation policy has continued to be developed and implemented as the project progressed with a view to facilitating design, manufacture, operation and maintenance, thereby saving costs and making major components interchangeable for added flexibility of the instruments.

All instruments are designed to facilitate in-situ assembly. They will be pre-commissioned before the reactor goes critical. Seven of the eight instruments will be ready for full operations when the reactor is commissioned in early 2006 with the 8th instrument (Polarisation Analysis Spectrometer) to follow soon afterwards.

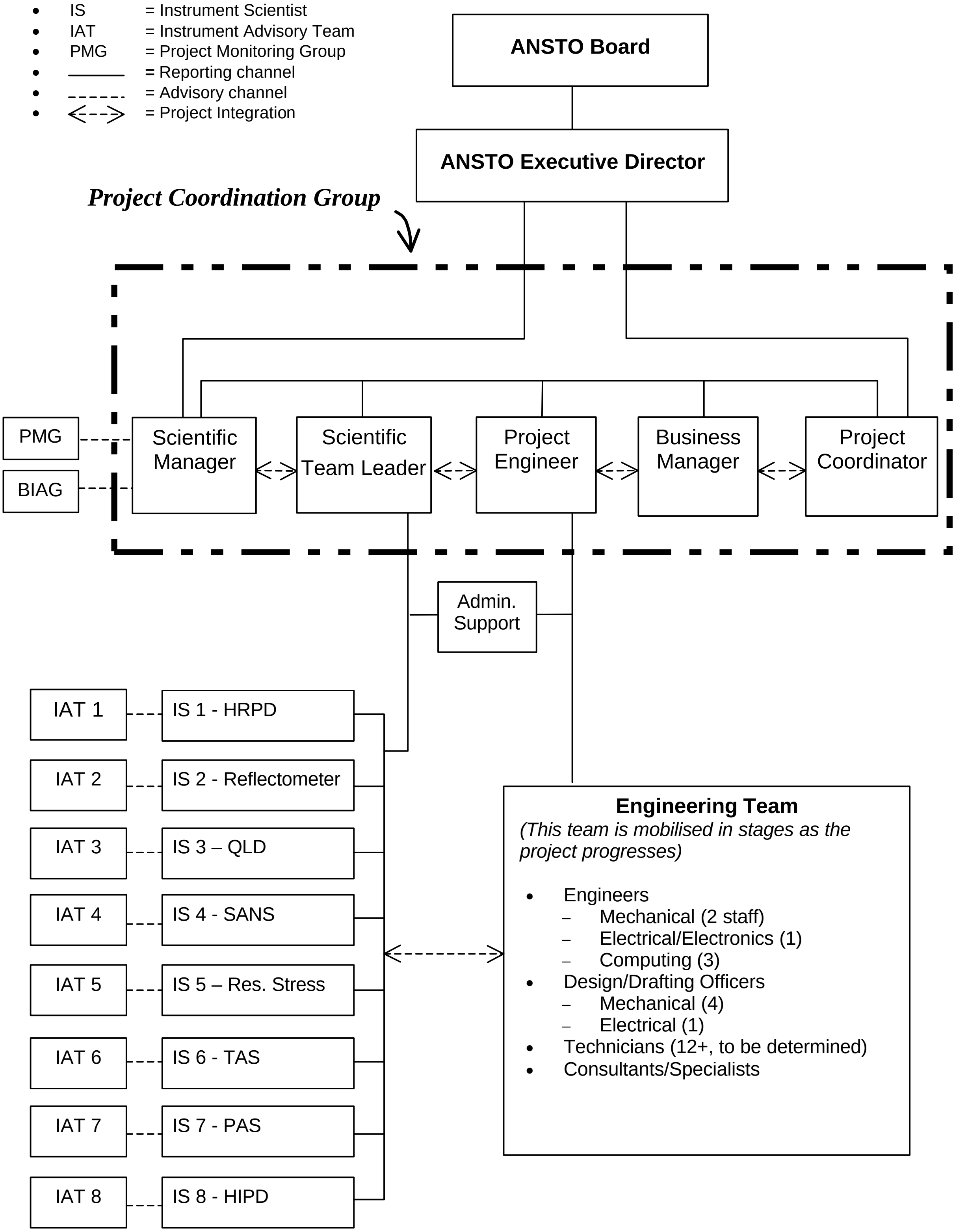
6. REFERENCES

[1] Project Plan for High Resolution Powder Diffractometer, NBIP-SS-401-1004, ANSTO, B. Hunter, September 2002.
[2] A Proposal for A Time-of-Flight Neutron Reflectometry at the Australian Replacement Research Reactor, NBIP-SS-402-1003, ANSTO, M. James & I. Gentle, June 2002
[3] Instrument Acquisition Proposal for a Single-Crystal Neutron Diffractometer, NBIP-SS-403-1006, W. Klooster, November 2002.
[4] Instrument Acquisition Proposal for a Small-Angle Neutron Scattering Instrument (SANSR3) at the Australian Replacement Research Reactor, NBIP-SS-404-1003, ANSTO, Oct. 2002.
[5] Proposal for the Constant-Wavelength Residual Stress Diffractometer "Kowari" for the Australian Replacement Research Reactor, NBIP-SS-405-1002, O. Kirstein, Feb. 2002
[6] Proposal for the Three Axis Spectrometer at the Australian Replacement Research Reactor, NBIP-SS-406-1006, ANSTO, L. Cussen, March 2002
[7] Proposal for the High Intensity Powder Diffractometer at the Australian Replacement Research Reactor, NBIP-SS-408-1002, ANSTO, M. Hagen, November 2002.
[8] Engineering Report, Progress and Current Status, NBIP-ER-400-0026, Jan. 2003.

APPENDIX A: ORGANISATIONAL STRUCTURE

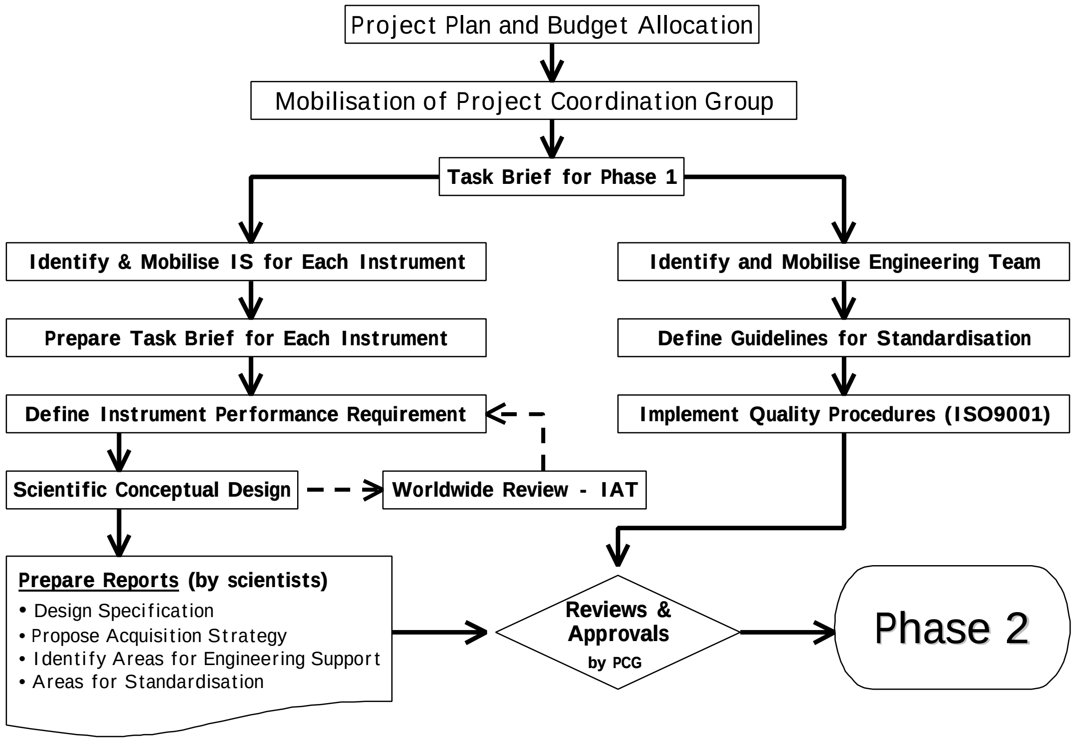
Legend:

- BIAG = Beam Instrument Advisory Group
- IS = Instrument Scientist
- IAT = Instrument Advisory Team
- PMG = Project Monitoring Group
- ——— = Reporting channel
- - - - - - = Advisory channel
- <- - -> = Project Integration

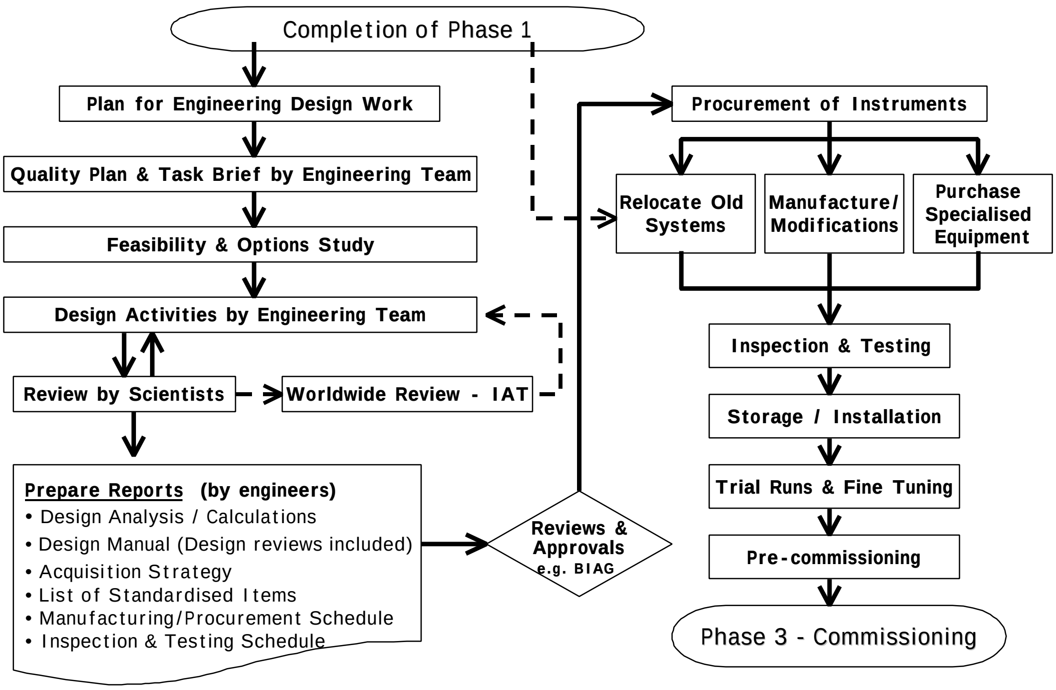


APPENDIX B: JOB FLOW DIAGRAM

Job Flow - Phase 1 (Conceptual Design)



Job Flow - Phase 2 (Eng. Design to Installation)



APPENDIX C: PREVIEW OF SLIDES (Preliminary Only)

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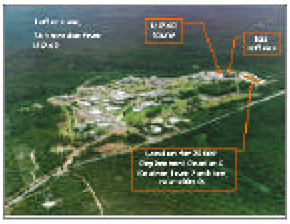

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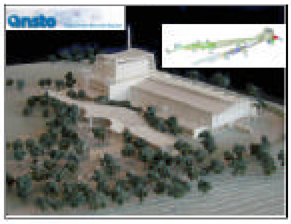

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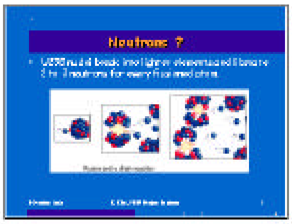

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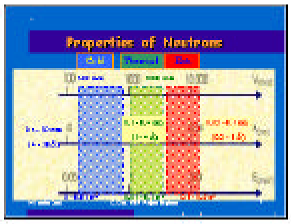

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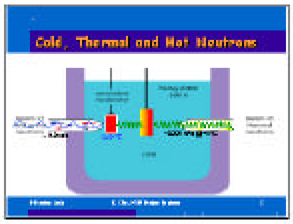

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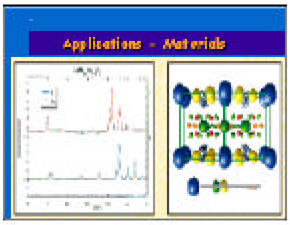

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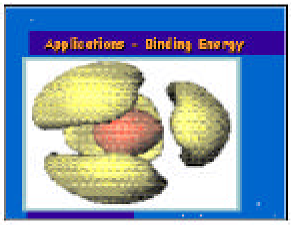

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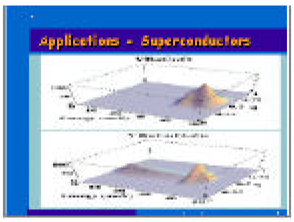

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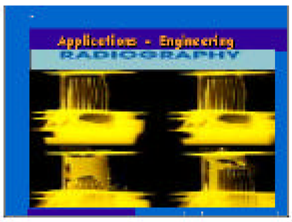

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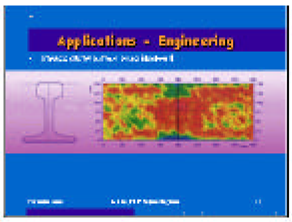

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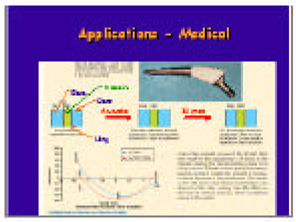

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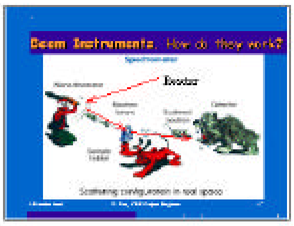

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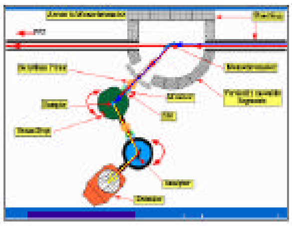

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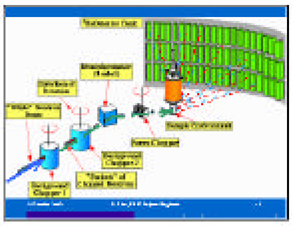

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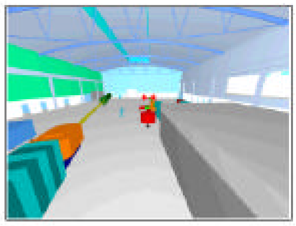

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