Australia's Major National Research Facilities: A submission to the National Collaborative Research Infrastructure Strategy Advisory Committee (NCRIS)

Australian Academy of Science

February 2005

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The NCRIS Draft Implementation Framework represents a landmark in the provision of national research infrastructure facilities in that funding under the program is assured until 2010/11. The Australian Academy of Science has long argued that the ad hoc nature of earlier competitive rounds for Major National Research Facilities (MNRFs) did not serve the nation well as it lacked a strategic component and mitigated against long-term strategic planning and against the building up of long-term collaborative partnerships.

As the Academy pointed out in 2003 in its submission to the National Research Infrastructure Taskforce (NRIT), the states and territories, together with overseas agencies and international organizations, are in a position to make substantial contributions to MNRF and larger-scale research facility funding. It is therefore in the national interest that there be no administrative impediments to this potentially important avenue for leveraging federal funding.

A carefully crafted implementation framework will remove the uncertainty generated by the ad hoc nature of the former MNRF program, the tight time frames for bidding, the lack of sychronisation between the federal and state/territory bidding processes and the limited potential to attract overseas funding in the MNRF bidding process. The federal government, in its commitment to NCRIS, has provided the opportunity for states and territories to improve their capacity and scope for leverage on this resource. States and territories that have yet to do so can help to improve the scope for leverage by creating programs designed to fund research infrastructure, and in so doing significantly improve the capabilities in the Australian science and innovation system.

The NCRIS consultation paper seeks comment on a number of implementation issues. The Academy provides comment on three of these issues.

Section 6: Stakeholders are invited to provide their initial responses to the Strategic Roadmap, including conceptual and structural issues, and suggestions for developing and improving.

It is a sensible strategy to align the research infrastructure with national research priorities and priority goals, especially as it is intended that the future Research Infrastructure Advisory Committee (RIAC) will liaise closely with the National Research Priorities Standing Committee. However, the Standing Committee is charged with overseeing the implementation of the national research priorities, not with revising them. It seems unlikely that the research priorities that were appropriate for the nation in 2003 will remain apposite in 2010/2011. How will the Strategic Roadmap remain vibrant and relevant over time?

The NCRIS Strategic Roadmap includes a number of specific suggestions for facilities. These suggestions were drawn from submissions made to the Taskforce and 'other sources available to the Department'. It is really quite unhelpful to be putting forward these suggestions at this early stage of the consultation process and it is unhelpful to include in the Strategic Roadmap items such as the Square Kilometer Array telescope that are beyond the scope of NCRIS.

The Academy, in its submission to the Taskforce, analysed areas of particular need that remain in Australia's research infrastructure - as indicated by unmet funding requests to the earlier competitive MNRF program. One approach to identifying areas of particular need is to identify the sub-set of bids that have managed to secure some subsequent funding, including funding from internal resources of the partners. This is an indication of the merit of the proposal and of the commitment of the partnership to developing the project.

MNRF bids (unsuccessful in 2001) that have demonstrated continued need by securing low levels of subsequent funding

The 13 bids that fall into this category are in the following research areas:

- the preservation of material and data on Australia's natural genetic endowment in plants, animals and fish onshore and offshore (3 bids);
- support for experimental activity on the exploitation of biomass resources (1 bid);
- monitoring and prediction of ocean behaviour (1 bid).
- integrated support for clinical trials (2 bids)[14];
- state-of-the-art electron beam instruments (1 bid);
- ion beam experiments (1 bid);
- dedicated supercomputers for use in fluid dynamics and lattice gauge theory (1 bid);
- experimental production of silicon-based microelectronic devices (1 bid);
- bulk solids handling technology (1 bid);
- large-scale experimental fire test facility (1 bid)

MNRF bids (unsuccessful in 2001) that have not secured subsequent funding

There are 23 bids that are still actively seeking funding but which, as far as we are aware, have yet to secure subsequent funding. Of these:

- five relate to the commercialisation of research in agriculture and aquaculture and to safeguarding stocks of plants, animals and fish;
- two to generic bio-informatic data-sets and their exploitation;
- two relate to oceanography;
- four relate to R&D, design and development in the ICT, energy, industrial and construction sectors;
- four relate to monitoring and modelling the processes involved in environmental degradation;
- two relate to the earth sciences (upgrading existing seismic imaging capabilities and improvements to analysing isotopes in minerals);
- one to astronomy;
- one to provide upgraded facilities for nuclear magnetic resonance (NMR) for use in medical research;
- one to drug and therapy development; and
- one on plasma containment as part of fusion research.

Section 8.1: National process for identifying research infrastructure investments. Views are sought on the proposals for a national process.

The Academy agrees that advice should be sought from organisations representing wide research community views. This seems a logical strategy that provides transparency, independence and rigour. The Academy supports 21 National Committees of Science, each with a membership of eight persons, and in addition to professional societies, these committees provide an important resource and network for providing investment advice. The Academy's submission includes input from several of our major National Committees, see Attachment A. These are structured by a series of questions put to the Committees by the Academy. It was not possible to obtain feedback from all of the 21 National Committees in the time-frame available and several of the major disciplines are not represented. However, the summary information provides useful information, statistics and priorities for several of the major areas of scientific research. We have included some information about personnel, as the research infrastructure Roadmap must be cognisant of the potential number of facility users. Consideration of numbers of potential users would certainly accord beam-lines for the Australian Synchrotron Facility a higher priority than some other suggestions included in the Strategic Roadmap, such as a new gasification R&D facility (surely the responsibility of the private sector) or the Australian International Gravitational Wave Observatory.

Section 8.5: Stakeholders are invited to comment on the proposals regarding costs covered by NCRIS grants.

The Academy has held workshops with the Directors of the MNRFs that received funding in 1995 and 2001 competitive rounds. These meetings highlighted the lack of targeted funding for researchers to use Australia's MNRFs. If ARC and NHMRC research grants do not provide adequate project funding for using an MNRF, backed up by specialist technical expertise, then the overall contribution of the MNRFs to the efficiency and effectiveness with which Australian research is conducted is reduced. It makes little sense to invest in creating or improving these major research assets unless we also provide adequate funding for the research community to use them. It has been suggested that an MNRF-use line-item in ARC and NHMRC research grants is one means of ensuring that adequate funding is available for researchers to maximise use of Australia's research facilities.

In the Academy's view there is a role for two types of funding arrangement for major research facilities. In situations where it is feasible to attract international funding partners then a facility should be fully funded by these partners with access granted free of charge to users based upon scientific merit. A standard protocol could be drawn up to cover these international partnership-funding arrangements. This protocol should be based upon a contractual relationship between the percentage of full costs contributed by a donor and the percentage of facility capacity used by that donor. There are existing international models for this type of protocol, such as that used by the European Synchrotron Radiation Facility, the Brazilian Synchrotron and the Anglo-Australia Telescope. Relevant state and territory governments and the federal government might unite to provide the Australian funding contribution within such a Protocol.

The model of fully-funded major facilities based upon international partnerships is not appropriate to all types of major research facility. In many cases, the current MNRF funding model is both attractive and feasible provided that MNRF use is funded adequately via a line item in ARC and NHMRC research grants.

Consequently, the most robust method of funding major research facilities in Australia under the NCRIS Program is to adopt a dual approach. This provides the option to develop fully-funded facilities in which the public sector user does not pay, based upon international consortia. The dual approach also provides the option to continue to develop smaller scale facilities in which public sector users do pay. A line item in research grants for access to centralised research infrastructure will guarantee that facility users have the means to contribute adequate funds to operate these national research assets. In turn, these funds should support dedicated technical support for the facilities, for the facilities to keep abreast, and indeed contribute to, cutting edge technologies. Competent technical support is essential for efficient and effective use of the facilities and this in turn will be an inducement to researchers to collaborate with the centralised facilities and will help avoid fragmented national research infrastructure.

Australian Academy of Science

NATIONAL COMMITTEES FOR SCIENCE - SCOPING STUDIES 2004

RESEARCH INFRASTRUCTURE AND PERSONNEL

General

The Australian Academy of Science's National Committees for Science were asked to focus on issues relating to the personnel and infrastructure needs of each discipline. The Committees considered:

- Whether a statement of the major facilities and personnel in Australia is available. If not, how can it be efficiently constructed?
- Whether the Committee could determine the likely infrastructure requirements of the discipline over the proposed strategic planning timeframe.
- Whether the Committee could determine the likely personnel requirements of the discipline over that same timeframe.
- How appropriate is would be to validate the plan with the scientific community of the discipline, and with others with key interests?
- The other disciplines on which the plan will impact, and how should the interaction with those disciplines be managed?
- How much of the work can be done with existing resources, and what additional resources are required to complete the task?

Responses of particular relevance to the National Collaborative Research Infrastructure Strategy appear in this summary document. Responses were received from the National Committees for:

- Astronomy
- Biomedical Sciences
- Chemistry
- Crystallography
- Earth Sciences
- Geography
- Medicine
- Nutrition
- Physics
- Psychology
- Radio Science
- Space Science

A statement of the major facilities and personnel in Australia - is this available and, if not, how can it be efficiently constructed?

Astronomy	The last detailed statement of facilities and personnel is available from *Australian Astronomy: Beyond 2000*. This statement will be updated as part of the current Decadal Planning process.
Biomedical Sciences	We are unaware of this having been done. For example, for such an appraisal of cancer research in NSW, consultants were commissioned to carry out a survey of everyone who purportedly did cancer research. The survey took the form of a relatively (poorly designed) questionnaire but it was most revealing; whether it forms the basis for further channelling of resources is moot. For the Universities this would be a relatively simple matter of checking inventories and polling the various schools and departments. However, it would take considerable human resources.
Chemistry	No, although there is a statement *Mapping Australian Science and Innovation* prepared by the Science and Innovation Taskforce in the Department of Education, Science and training, the Department of Industry, Tourism and Resources, and the Department of Communications, Information Technology and the Arts.
Crystallography	The major facilities (synchrotron and reactor) are readily identifiable, as are the major aggregations of scientists. Constructing a list of all personnel and equipment would require significant input from SCANZ and probably also Universities. The National Committee for Crystallography (NCC) represents two professional societies. *The Society of Crystallographers in Australia and New Zealand (SCANZ)* has 170 professional members (approximately 30 non-Australian citizens) and 50 student members. *The Australian Microscopy and Microanalysis Society (AMMS)* has 370 members. Access to major science facilities, both overseas and at home, for this community has been an agenda item for the NCC for the past decade or so. Partly as a result of activities related to this concern, three important items of infrastructure are presently being established. *The Replacement Research Reactor* (RRR) at Lucas Heights is under construction and will be fully operational in the second half of 2006. Capital cost is approximately $360M, including the beamline hall with (initially) seven instruments. The new facility will directly employ 60 staff. The RRR will be operated by ANSTO and operating costs will be provided through the ANSTO budget. *The Australian Synchrotron* in Melbourne is under construction and will be commissioned in 2007. The Victorian Government is underwriting the capital cost, approximately $157M excluding beamline construction. Two major funding issues remain. The first is raising the necessary *circa* $50M to construct the initial suite of nine beamlines. The National Scientific Advisory Committee is actively recruiting ‘membership’ to cover this investment. The second is to source the recurring operating budget, $15M-$20M per annum, and to appoint an Operator. The Australian Synchrotron will directly employ some 80 staff and will cater for approximately 150 visitors at any point in time. *The Nanostructural Analysis Network Organisation* (NANO) is a Major National Research Facility, established in mid 2002. It is a networked organization with nodes across the country. Approximately 100 staff at the various nodes are associated with its research. A Travel and Access Program provides support for visiting scientists. The capital investment in NANO from MNRF was $11.5M. In all cases, these new Australian facilities will greatly diminish, rather than completely abolish, the need for access to specialised

international laboratories. The Australian Synchrotron Research Program received a grant of $14.8M under the current MNRF program and it provides such access to synchrotron users. Some level of continued support will be required beyond 2007. ANSTO administers the ‘Access to Major Research Facilities Program’ that supports Australian access to international neutron sources, including ISIS at the Rutherford Appleton Laboratory (UK) and Institute Laue Langevin (France). Demand for use of these facilities will survive the commissioning of the RRR.

Earth Sciences

Most of the information about major facilities is available in the National Strategic Plan for the Geosciences, published in October 2003. More work would need to be done to have a full accounting of personnel available in Australia, although this could be done relatively easily from the base of information that now exists.

Major Geoscience Facilities and Personnel

Major National Research Facilities
There are two MNRFs of particular relevance to the geosciences.

Australian National Seismic Imaging Resource (ANSIR). ANSIR is an MNRF for seismically imaging the interior of the Earth for use by the resource industries, for environmental and groundwater research, for the mitigation of natural hazards, and for understanding of global geological processes. The facility facilitates access to a vibroseis reflection system, 28 portable broadband seismometers, 85 short-period recorders and associated equipment.

Australian Computational Earth Systems Simulator (ACcESS). ACcESS aims to provide a computational virtual earth facility serving Australia’s national needs; empower the Australian earth science and industrial communities with a computational virtual laboratory facility with a never-before seen capacity that will fuel earth systems science and technology innovations, economic development, hazard management and environmental management through the 21st century; provide a national focal point for scientific and industrial earth systems simulations to form, together with climatic and oceanic research, a holistic earth simulation capability, and act as an international focal point within Australia in earth systems simulations, linking Australia with major overseas research programs and generating momentum in this emergent field within Australia.

Other Key National Research Facilities

ANSTO facilities. The High Flux Australian Reactor (HIFAR), the Australian National Tandem Research Accelerator (ANTARES), the 3 MV Van de Graaf accelerator, and the Metal Vapour Vacuum Arc Iron Source (MEVVA) are national research facilities that are used for many applications, including the geosciences.

Australian Synchrotron Research Program (ASRP). The Australian Synchrotron Research Program (ASRP) provides Australian researchers, including geoscientists, with access to state-of-the-art synchrotron radiation research capabilities at overseas synchrotron light source facilities. These are the Australian National Beamline Facility (ANBF) at the Photon Factory, Tsukuba Science City, Japan, and the Advanced Photon Source, at the Argonne National Laboratory in Chicago, USA.

CRC Facilities

There are eight CRCs focussing on minerals/energy specific issues and eighteen environment focussed CRCs — each with facilities of relevance to the geosciences. These are:

Minerals & energy focussed CRCs

- AJ Parker CRC for Hydrometallurgy
- CRC for Clean Power from Lignite
- CRC for Coal in Sustainable Development
- CRC for Landscape Environments and Mineral Exploration
- CRC for Predictive Mineral Discovery
- CRC for Sustainable Resource Processing
- CRC for Greenhouse Gas Technologies
- CRC for Mining

Environment focussed CRCs

- CRC for Australian Weed Management
- CRC for Biological Control of Pest Animals
- CRC for Catchment Hydrology
- CRC for Coastal Zone, Estuary and Waterway Management
- CRC for Freshwater Ecology
- CRC for The Great Barrier Reef World Heritage Area
- CRC for Greenhouse Accounting
- CRC for Plant-based Management of Dryland Salinity
- CRC for Sustainable Tourism
- CRC for Tropical Rainforest Ecology and Management
- CRC for Tropical Savannas Management
- Environmental Biotechnology CRC
- CRC for Water Quality and Treatment
- Desert Knowledge CRC
- Bushfire CRC
- CRC for Irrigation Futures
- CRC for The Antarctic Climate & Ecosystems
- CRC for Landscape Environments and Mineral Exploration

Facilities of the CRC for Spatial Information, which commenced in 2003–04, are also of relevance to the geosciences.

SRC Facilities

Although the ARC does not fund new centres under this program, it continues to fund many centres. Special Research Centre (SRC) with facilities of relevance to the geosciences include the:

- Tectonics SRC;
- Centre for Ore Deposit Research (CODES);
- Centre for Research on Ecological Impacts of Coastal Cities;
- Centre for Offshore Foundation Systems; and
- The National Key Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC).

University Facilities

In June 2003, Professor Andrew Gleadow conducted a web-based survey of geoscience staff numbers at Australian universities. His survey results[1] are summarised in **Table 1** (page 38). Of the 28 departments listed, 13 departments are geology-focussed, with the remainder providing a broader geoscience focus.

[1] 2003 RMIT staff numbers were not provided, so a best-estimate approach was adopted in this case only.

Government Agency Facilities
In addition to a plethora of local and state government agencies, and education and vocational training institutions, with facilities of relevance to the geosciences, the following Australian Government agencies also have facilities of relevance to the geosciences.

- Agriculture, Fisheries and Forestry Australia (AFFA)
- Australian Antarctic Division (AAD)
- Australian Nuclear Science and Technology Agency (ANSTO)
- Chief Scientist Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- Defence Science and Technology Organisation (DSTO)
- Environment Australia (EA)
- Geoscience Australia
- National Oceans Office (NOO)
- Native Title Tribunal (NTT)
- Office of Spatial Data Management (OSDM)

Personnel and Other Information
Contacts for the facilities listed above are available via the relevant website.

In the 2001 census, 5067 individuals declared themselves to be geoscientists. While the numbers of people involved in geoscience research and tertiary education were not identified in the census, Department of Education, Science and Training (DEST) figures indicate that 1288 equivalent full time students (EFTSU) commenced higher education geoscience education in 2002. Fewer than 200 are expected to graduate with an honours degree, widely regarded as the basic professional qualification. Over the past 12 years, approximately 20 000 Australians have been educated at first year university level in geoscience, with the total number since 1960 estimated to be approximately 40 000. This equates to about 1 in 500 Australians (or 0.2%) having some tertiary education in geoscience. The supply of high-quality graduates with an appropriate mix of skills (e.g. maths, physics, chemistry, biology) is becoming a major long-term issue for science, engineering and technology disciplines in general and for the geosciences in particular.

Within the geoscience discipline, weaknesses include geophysics, hydrogeology, and palaeontology. Fundamental datasets are also of particular concern.

Geography

Geography is a field-based discipline that spans both the natural and social sciences. The discipline is characterised by a breadth of subject matter in which the traditional division has been between human and physical Geography. In recent years a third category of 'environmental Geography' has sometimes been recognised, encompassing many courses that deal explicitly with human-environment relations and sustainable development. Geographic Information Science (GIS) and remote sensing is another distinct teaching area, occurring almost wholly within higher education but increasingly important in secondary schools. There is an emerging global interest in Geography which other disciplines such as geology, biology, physics and computer science are now starting to exploit through subjects such as environmental earth science, landscape ecology, climatology and meteorology and GIS.

The following information was based on a partial response from heads of academic units of geography, combined with exhaustive searching of university web sites. As such, it is indicative rather than definitive. Currently there are just over 200 full-time, "tenured" academic geographers in Australia, spread between twenty schools or clusters within broader academic units (Table 2, page 39). There are now no single discipline schools of geography in Australia, in contrast to New Zealand. The common partners in the amalgamated schools include environmental science (and studies), earth sciences, planning, surveying, anthropology and archaeology. Over the last decade, many geography departments have lost staff in key areas of the discipline due to financial restrictions and early retirements, and thus their teaching and research profile is truncated. While some degree of research specialization is desirable, in regional universities it is difficult to find supervisors for some areas of the discipline that have strategic significance. For example physical geography, both pure and applied, encompasses geomorphology, biogeography and climatology. In many departments these critical areas have been run down in both staffing and infrastructure. In many departments spatial analysis (GIS, remote sensing, spatial statistics) is taught by a single academic, and opportunities for postgraduate supervision and maintenance of research currency are restricted as a result.

The distribution of geographers amongst the academic grades, E (Professor) to A (Associate Lecturer) suggests that there may be a decline in recruitment of academics at the lowest grade, but that there is good representation at higher levels. This may be due to the recent availability of promotional Chairs in many universities, rather than any expansion in disciplinary specific Chairs. Amongst the individual locations, the larger Schools of Geography are in the well established campuses of Flinders, James Cook, Melbourne, Monash, Sydney, Tasmania and Wollongong universities. The smaller clusters of academic geographers tend to specialize in programs such as development studies, planning or other social sciences. The adequate resourcing of these groups is a key problem for the discipline.

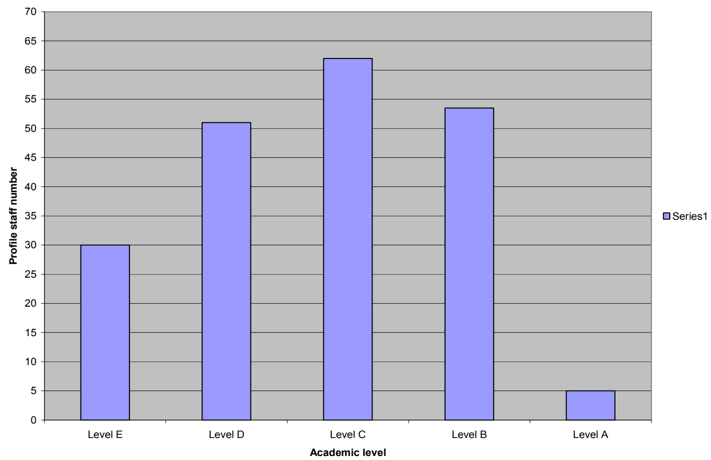

Figure 1: Distribution of profile academic staff in Geography, Australian universities

The equipment needs of the discipline are more difficult to determine. Few School websites provide inventories of equipment, or even the highlights of their holdings. Geographers as field scientists need access to field transport, either 4WD vehicles or boats. In addition, field sampling equipment such as drilling rigs and vibracorers are widely used. Biogeographers using palynology to elicit vegetation histories frequently core lake sediments, peat bogs and related deposits; they use a wide variety of soft sediment corers. Process geomorphologists use a wide variety of surveying and monitoring equipment including differential GPS, EDM survey equipment, S4 Doppler current meters, turbidity and water chemistry probes and dataloggers. In many universities this equipment is now ageing, and there needs to be a strategic program for replacement. In most Schools, any technicians are multi-skilled by necessity and service both teaching and research needs. Many Schools lack a dedicate technician, but rely on postgraduate students paid as casual staff.

Given the importance of spatial analysis to the discipline, attention to the provision of infrastructure in the areas of geographic information science and remote sensing is necessary. This is most commonly through provision of computer laboratories equipped with large screen monitors and specialized GIS and remote sensing software. In addition, many departments have ancillary equipment such as large format colour printers (to A0 size), A3 scanners, digitizing boards, GPS receivers and spectral radiometers. This spans all of the discipline but in several universities infrastructure is either limited or running down due to reduced government funding. This not only includes hardware (high performance computing, GPS) but also software (expensive proprietary programs, digital photogrammetry). An important development area is Web based GIS, independent of platform type and software, but this would need significant resources to be fully implemented across the sector.

It is very likely that major infrastructure development is needed in the area of radiometric dating and stable isotope analysis. This could be developed in cooperation with the NC Quaternary. Existing facilities are limited in capacity and may be outdated. They are also geographically restricted to southern Australia (Sydney, Canberra, Wollongong). It would be advantageous to create a similar facility in northern Australia, taking advantage of substantial research expertise in regional universities. Given the importance of long-term records to understanding the dynamics of Australian environmental change, and the increasing importance of this to natural hazard assessment, such an initiative would advantage several disciplines.

Several universities have consolidated central laboratory facilities which are regularly used by physical geography researchers. Typical analyses carried out for such researchers include nutrient concentrations in water, soil and plant tissues, particle size distributions, XRD and XRF on soils and sediments, and scanning electron microscopy. These facilities are in many institutions critical to the individual scholar's ability to conduct research, and there are widespread issues with their maintenance and upgrading of equipment.

Geographers are actively involved in a large number of Cooperative Research Centres. A partial listing follows; it should be noted that the majority of these are public good CRCs, and the challenge will be to develop links to industry in areas such as planning, environmental management and spatial information science.

- CRC for Australian Weed Management
- CRC for Catchment Hydrology
- CRC for Coastal Zone, Estuary and Waterway Management
- CRC for The Great Barrier Reef World Heritage Area
- CRC for Greenhouse Accounting
- CRC for Sustainable Tourism
- CRC for Tropical Rainforest Ecology and Management

CRC for Tropical Savannas Management
Desert Knowledge CRC
Bushfire CRC
CRC for The Antarctic Climate & Ecosystems
CRC for Landscape Environments and Mineral Exploration
CRC for Spatial Information

In conclusion, academic geography is healthy, has a balanced portfolio of undergraduate and postgraduate students across the country, and is recruiting new staff. Significant issues emerge in the provision of adequate infrastructure for teaching and research. Many schools have ageing field and laboratory equipment and lack central funding of strategic replacement plans. There is not a high disciplinary demand for very large infrastructure items, excepting a radiometric dating facility located outside southern Australia.

Nutrition

I suspect this has been done some time ago but it would not take the committee long to construct such a statement – it could be done during a meeting or via an email using delphi type technique.

Physics

We are not aware of such a statement. This could be constructed by directly contacting the directors of the various facilities. In addition we could directly contact Heads of Departments of physics to determine which national facilities their departments make use of.

Psychology

HODSPA (Heads of Psychology Departments in Australia) can be consulted re this; an email list of all these Heads is available. But we also need to include psychological scientists at the interface of disciplines (e.g., in hospitals, mental health teams, organizations, government departments) as well as psychology departments themselves. Suggestions re appropriate organizations to contact can be solicited from HODSPA

Radio Science

Yes, the NCRS maintains a directory on http://www.ips.gov.au/IPSHosted/NCRS/. The NCRS Directory of Australian Radio Science will provide a range of information about, and of interest to, Australian radio scientists. In the longer term, each of the headings below can become part of the Directory.:

* Research Groups
* Individual Researchers (in alphabetical order)
* Topics of interest
* Upcoming Conferences
* Newsletters, papers, preprints, and journals
* Programs and Utilities
* Organisations
* Other Related Lists
* Commercial Pages

Universities

- University of Adelaide, Atmospheric Physics Group (http://www.physics.adelaide.edu.au/atmospheric/home.html)/

- Robert Vincent
- Iain Reid

- Department of Electrical and Electronic Engineering, University of Adelaide (http://www.eleceng.adelaide.edu.au/)
- Adelaide Electrical Engineering (http://www.eleceng.adelaide.edu.au/RESEARCH/research_main.html)
    - people (http://www.eleceng.adelaide.edu.au/CONTACT/contact_academic.html)
- ANU Atom Manipulation Project (http://wwwrsphysse.anu.edu.au/ampl/research/am/index.html)
- ANU Quantum Optics Group (http://photonics.anu.edu.au/qoptics/)
- ANU Research School of Astronomy and Astrophysics (http://www.mso.anu.edu.au/)
    - Fred Briggs
    - Ken Freeman
    - Carole Jackson
    - Research in astronomy and astrophysics. Astronomical instrumentation and techniques. Astronomy - 21cm hydrogen line - radio galaxies. Radio astrophysics: 1) The phenomena of radio-loud galaxies & quasars, 2) Deep radio observations of key astronomical fields (e.g. Hubble Deep field) and 3) the scientific specifications for new large radio telescopes
- University of Canberra, School of Electronics and Telecommunications Engineering (http://www.dmt.canberra.edu.au/sete/)
    - Paul Edwards (http://www.dmt.canberra.edu.au/sete/site/staff/edwards.htm)
- Griffith U. School of Microelectronic Engineering (http://www.gu.edu.au/school/mee/centres/microfab/)
    - Glenn Wilson
- Griffith U. Laser Atomic Physics Laboratory (http://www.sct.gu.edu.au/research/laserP/)
- Griffith University Radio Science Laboratory (http://www.gu.edu.au/school/mee/centres/radiosci/home.html)
    - David Thiel (http://www.gu.edu.au/school/mee/PPages/David/home.html)
    - electromagnetic geophysics and earth measurements, numerical techniques, antennas (switched parasitic antennas, smart antennas)
- La Trobe University Physics Dept. (http://www.latrobe.edu.au/physics/index.html)
- TIGER radar (http://www.tiger.latrobe.edu.au)
    - Peter Dyson (http://www.latrobe.edu.au/physics/people/dyson_peter.html)
- Macquarie University Electronics Department (http://www.elec.mq.edu.au)
- Quantum Optics and Quantum Informatics http://www.physics.mq.edu.au/quantum
    - Karu Esselle (http://www.elec.mq.edu.au/~esselle)
    - Electromagnetic Engineering, Microwave Engineering, Electromagnetic band, gap structures, Photonic crystals, Antennas for Radio astronomy
- Photonics Research Laboratory, U.Melbourne (http://www.ee.mu.oz.au/research/prl)
- Uni. Melbourne School of Physics Optics Group (http://optics.ph.unimelb.edu.au/atomopt/atomopt.html)
    - Robert Scholten (http://www.ph.unimelb.edu.au/~scholten/)
- Monash University Centre for Telecommunications and Information Technology (http://www.ctie.monash.edu.au/ctie_home.htm)

- John Bennett (http://www.ctie.monash.edu.au/ctie_bennett.htm)
- Le Nguyen Binh (http://www.ctie.monash.edu.au/ctie_binh.htm)

- University of Newcastle Space Plasma Waves Group (http://plasma.newcastle.edu.au/spwg/index.htm)
  - Brian Fraser (http://plasma.newcastle.edu.au/spwg/people/bfraser/bjf.htm)
  - Fred Menk
  - Pavlo (Pasha) Ponomarenko (http://plasma.newcastle.edu.au/spwg/people/PASHA/PASHA.htm)
  - Murray Sciffer (http://maths.newcastle.edu.au/~murray/murray.html)
  - Colin Waters (http://plasma.newcastle.edu.au/spwg/people/colin/clw.htm)
- UNSW School of Physics (http://www.phys.unsw.edu.au/)
  - Robert Clark (http://www.phys.unsw.edu.au/STAFF/ACADEMIC/clark.html)
  - Robert Stening (http://www.phys.unsw.edu.au/STAFF/ACADEMIC/stening.html)
- University of South Australia Institute for Telecommunications Research (http://www.itr.unisa.edu.au/)
- Cooperative Research Centre for Satellite Systems (http://www.itr.unisa.edu.au/crcss/crc_sat_sys.html)
  - Harry E. Green
  - coding and information theory
  - telecommunications networks and services
  - communications signal processing
- The University of Queensland Faculty of Engineering, Physical Sciences and Architecture (EPSA) (http://www.epsa.uq.edu.au)
- Queensland Uni. CRC for Sensor Signal And Information Processing (http://www.cssip.uq.edu.au/)
  - Dennis Longstaff
  - David Noon (http://www.cssip.uq.edu.au/staff/noon/)
  - Radar, Signal processing, Pattern recognition
- U. Queensland BEC and Quantum Optics Group (http://www.physics.uq.edu.au/BEC/)
- U. Queensland Quantum Technology Lab ()
- Queensland Uni. of Technology CRC Satellite Systems Node (http://www.crcss.bee.qut.edu.au/)
  - Rod Walker (http://www.crcss.bee.qut.edu.au/nav.shtml)
  - Navigation, GPS Ionospheric Modelling, GPS Limb Sounding, Electromagnetic Multipath Modelling, Electromagnetic Propagation Modelling
- RMIT University (http://www.rmit.edu.au)
- Swinburne U. Centre for Atom Optics and Ultrafast Spectroscopy (http://www.swin.edu.au/rescentres/soll/caous/)
- Swinburne U. Biomedical Sciences/Engineering (http://www.swin.edu.au/bioscieleceng/biomedical/index.html)
  - possible RF health effects
- University of Sydney Physics Dept. (http://www.physics.usyd.edu.au/)
  - Iver Cairns (http://www.physics.usyd.edu.au/theory/iver_new.html)
  - Don Melrose (http://www.physics.usyd.edu.au/rcfta/melrose.html)
  - Peter Robinson (http://www.physics.usyd.edu.au/theory/peter_new.html)

    - plasma astrophysics, solar physics
- UTS Institute for Information and Communication Technologies (http://ict.uts.edu.au/)
    - Robin Braun (http://www.eng.uts.edu.au/~robinb/index.htm)
- University of Tasmania, Physics Department Radio Astronomy Group Homepage (http://www-ra.phys.utas.edu.au/)
- U. Western Australia Frequency Standards and Metrology Research Group (http://www.fsm.pd.uwa.edu.au)

Cooperative Research Centres - CRCs
- List of CRCs, including former CRCs (http://www.crc.gov.au/centres/centres.htm)
- CRC Satellite Systems (http://www.crcss.csiro.au/)
- CRC for Sensor Signal And Information Processing (http://www.cssip.edu.au/)
- Australian Telecommunications Cooperative Research Centre (http://www.telecommunications.crc.org.au/)
- Australian Centre for Radiofrequency Bioeffects Research (ACRBR)
    - Irena Cosic (RMIT)
    - Michael Abramson (Monash)
    - Rodney Croft (Swinburne)
    - Andrew Wood (Swinburne)
    - John Finnie (IMVS)
    - Ray McKenzie (TRL)
    - the Centre's main research focus is on exploring possible neurological effects from RF exposures. Planned studies cover the broad range of 'proteins to people' and incorporate molecular, in vitro, animal, human, epidemiological and RF dosimetry studies.

Government Organisations
- Antarctic Division Space and Atmospheric Sciences program (http://www.antdiv.gov.au/)
    - Auroral and Space Physics
    - Gary Burns
    - Marc Duldig
    - Ray Morris
- CSIRO Australia Telescope National Facility (http://www.atnf.csiro.au/)
    - Wim.Brouw (http://www.atnf.csiro.au/people/Wim.Brouw/)
    - Aaron Chippendale (http://www.atnf.csiro.au/people/Aaron.Chippendale)
    - Peter Hall (http://www.atnf.csiro.au/people/Peter.Hall/)
    - Mike Kesteven (http://www.atnf.csiro.au/people/mkesteve)
    - Dick Manchester (http://www.atnf.CSIRO.AU/people/Dick.Manchester/)
    - Ray Norris (http://www.atnf.csiro.au/people/Ray.Norris/)
    - Bob Sault (http://www.atnf.csiro.au/people/Robert.Sault/)
    - Bruce Thomas (http://www.atnf.csiro.au/people/bthomas/)
    - Tasso Tzioumis (http://www.atnf.csiro.au/people/Tasso.Tzioumis/)

    - Radio Astronomy; RF systems; Digital signal Processing, Radio astronomy, geodetical measurements using VLBI, Atmospheric and ionospheric influences on the radio wave propagation, Radio Astronomy, Microwave Engineering, MMICs, Synthesis Imaging, Image Reconstruction, RFICs, Square Kilometre Array, space plasma physics, solar radio bursts, radiation mechanisms, wave-particle interactions, space-based radio observations, interplanetary radio emissions, planetary radio emissions, outer heliospheric radio emissions, masers, plasma instabilities, high speed signal processing, low noise receivers, high-bandwidth communications, spectrum management, interference mitigation (EMC)
- SEARFE: Students Exploring Australia's Radio-Frequency Environment (http://www.searfe.atnf.csiro.au)
- CSIRO National Measurement Laboratory (http://www.nml.csiro.au/)
    - Peter Fisk
- CSIRO Telecommunications & Industrial Physics (http://www.tip.csiro.au/)
    - Trevor Bird (http://www.tip.csiro.au/general/KeyPeople/TrevorBird.htm)
    - Carol Wilson (http://www.tip.csiro.au/ICT/Propagation/index.htm)
    - John Bunton
    - Douglas Hayman
    - Geoffrey James
    - Graeme James
    - Information and Communication Technologies: e.g.,Broadband Wireless Systems, Centre for Networking Technologies for the Information Economy (CeNTIE), Mobile Communications, Space & Satellite Communications Systems, Antennas, radio systems, MMIC design, signal processing, indoor and urban area radio
    - Service Industry Technologies: e-Health, Smart Sensing
    - Manufacturing Technologies: Energy & Sustainability, Nano Science & Systems, Optical Sciences & Photonics Technologies, Smart Measurements, Surface Engineering Science
    - National Measurement Laboratory: Australia's primary physical standards body
    - NASA Activities: Canberra Deep Space Communication Complex
- Australian Defence Science and Technology Organisation, DSTO (http://www.dsto.defence.gov.au/)
  A number of DSTO divisions have an interest in Radio Frequency science
    - Electronic Warfare & Radar Division (EWRD)
        - Interests include Devices, Materials, Microtechnology, MEMS, Sources, Microwave Radar, Phased Arrays, Transmitters, Receivers
        - Contacts: Len Sciacca (Chief of EWRD), Andrew Shaw (Research Leader Microwave Radar)
    - Intelligence, Surveillance & Reconnaissance Division (ISRD)
        - Interests include propagation, High Frequency (HF) radar, Synthetic Aperture Radar (SAR), transmitters, receivers, Software Defined Radio
        - Contacts: Bruce Ward (Chief of ISRD), Mr Angus Massie
    - Weapon Systems Division
        - Interests include conformal antennas, plasma antennas, RF systems, high power microwave

        - Contacts: Anthony Szabo (Head of Group in WSD)
    - Information Networks Division (IND)
        - Interests include propagation, satellite communications, spectrum, multi-band antennas
        - Contacts: Mr Peter Kerr (Head Wireless Systems)

    DSTO also maintains a Radio Frequency Hub that has been established to help coordinate RF efforts across DSTO. Current RF Hub Leader is Bevan Bates.
- Geomagnetism Section, Geoscience Australia (http://www.ga.gov.au)
- IPS Radio and Space Services (http://www.ips.gov.au/)
    - David Cole - Director
    - David Neudegg - Section Leader Consultancy and Development
    - John Kennewell - Principal Physicist Learmonth Solar Observatory
    - Garth Patterson - Section Leader Services
    - Phil Wilkinson - Deputy Director
    - Operates a network of vertical incident ionosondes, gromagnetic variometers and solar observatories
    - World Data Centre for Solar Terrestrial Science
    - Australian Space Forecast Centre
    - Interests include: ionospheric parameters, forecasting of radio conditions, space weather, geomagnetic storms, ionopsheric monitoring

Other groups and organisations

- Atmospheric Radar Systems (http://www.atrad.com.au/)
    - David A. Holdsworth (http://www.atrad.com.au/dave)
    - Atmospheric radar, remote sensing, boundary layer, troposphere, stratopshre, mesosphere, ionosphere.
- Bell Labs (http://www.bell-labs.com/)
- Lucent (http://www.lucent.com/)
    - Graeme Woodward
    - 3G mobile telephony, ASIC design for 3G systems, Baseband algorithms for future generation wireless infrastructure, Multi-in/multi-out (MIMO) systems, Equalisation, Turbo coding
- Creativelogistics - -web pending (http://www.creativelogistics.com.au/)
    - Paul March
    - RFID for tracking, identification for livestock, industrial
- GroundProbe (http://www.groundprobe.com/)
    - David Noon
- Ionospheric Systems Research
    - Ken Lynn (kenlynn @ nbcnet.com.au)
- KEL Aerospace (http://www.kel.com.au)
- Motorola - Wireless Comunications and Health (http://www.motorola.com/rfhealth/)
    - Ken Joyner
    - Possible health effects and mobile telephony

- Telstra Research Laboratories: EME Safety Research, Mobile Networks Section (http://http://www.telstra.com.au/ememanagement/emersrch.htm)
    - Robert Mcintosh
    - EM measurement, EM and thermal numerical modelling, EME standards, regulatory and OH&S, RF dosimetry development of EME software tools such as RF field strength prediction, analysis of interference to medical equipment, epidemiology

Societies

- The Academy of Technological Sciences and Engineering (ATSE) (http://www.atse.org.au/)
- The Astronomical Society Of Australia (ASA) (http://www.atnf.csiro.au/asa_www/asa.html)
- The EMC Society of Australia (http://www.emcsa.org.au/index.html)
    - Steven Brine
    - Kevin Goldsmith
    - Franz Schlagenhaufer
- Institution of Engineers, Australia (IE(Aust)) (http://www.ieaust.org.au/)

Space Science

The solar-terrestrial community has a number of existing major infrastructure facilities. The list below is indicative rather than complete.

(i) Buckland Park Field Station, operated by the University of Adelaide (Contact: Prof Robert Vincent)
(ii) TIGER (Tasman International Geospace Environment Radar), with components at Bruny Island, Tasmania, and now at Invercargill, NZ, operated by La Trobe University on behalf of a consortium of universities, government departments and international partners (Contact Prof Peter Dyson)
(iii) FedSat magnetometer and GPS atmosphere/ionosphere studies, operated by CRC Satellite Systems (Contacts: Profs Andrew Parfitt and Brian Fraser)
(iv) Magnetometer Array, in Antarctica and Australia (Prof Brian Fraser, University of Newcastle)
(v) MF Doppler Radar network providing coverage from the equatorial region to high latitudes (Professor Robert Vincent, University of Adelaide)
(vi) Australian Cosmic Ray Observatory Network. Instruments at Mawson, Antarctica and in Tasmania. (Contact Dr Marc Duldig, Australian Antarctic Division)
(vii) Major Facilities at Davis, Antarctica, making it one of the best equipped station world-wide for studying solar-terrestrial physics and space weather. Some facilities and contacts:
Lidar (Dr Ray Morris, Australian Antarctic Division) Digisonde (Dr Ray Morris, Australian Antarctic Division) VHF and MF Radars (Dr Ray Morris, Australian Antarctic Division and Prof Robert Vincent, University of Adelaide) Fabry-Perot Spectrometer (Prof Peter Dyson, La Trobe University) Magnetometer (Prof Brian Fraser, University of Newcastle) Imaging Riometer (Prof Brian Fraser, University of Newcastle)

The NCSS Community is developing a Space Weather Plan which will cover the type of information sought in more detail. This plan sets an overview and a lot of work is needed to develop initiatives from it. The draft plan was submitted to the AAS earlier this year and it should be consulted. Similarly the 2000-02 Report to the Committee for Space Research

(COSPAR) http://www.science.org.au/natcoms/cospar.pdf also contains relevant information. In particular, Table 1 of that document on pages 10-12 gives a list of instruments at Australian Antarctic stations.

Can the likely infrastructure requirements of the discipline be determined over the timeframe identified for the planning process?

Astronomy

Yes, that is one of the aims of the Decadal Plan.

Biomedical Sciences

Each cognate society is in a strong position to be able to provide input on the strategic developments in biochemistry, biophysics, microbiology, molecular biology, oncology, pharmacology and physiology, and more integrated areas of the biomedical sciences within Australia.

The Australian Society of Microbiology (ASM) provides a good example of how this is currently achieved. This is a large and diverse Society that is currently organized on a scientific basis into four major divisions: (1) Medical and Veterinary Microbiology, (2) Virology, (3) General Applied and Environmental Microbiology, (4) Microbial Genetics, Physiology and Pathogenesis. A National Scientific Advisory Committee (NSAC) with divisional representation chaired by the Vice-President for Scientific Affairs manages the scientific affairs of the society. Within this divisional structure there are 26 Special Interest Groups (SIGs) which cover the major subdisciplines of microbiology such as antimicrobials, mycology, parasitology, public health, food and water microbiology, probiotics and serology to name a few. NSAC would certainly be able to identify the major scientific directions that need to be taken and to determine likely infrastructure and likely personnel requirements for Microbiology. However this would require a consultative process and significant time.

A recent example of the scepticism in the research community about the Government's commitment to funding major items of equipment is afforded by the recent Major National Research Facilities (MNRF) scheme. This scheme appeared to have grown out of a drive towards funding a synchrotron in Australia. It is ironical that in the final analysis the funding for the synchrotron did not come from the MNRF Scheme. The scheme then funded several facilities that are not major national facilities of a kind implied by the initial funding guidelines. Because of the politicization of the funding process several areas of rapid advance internationally have had to develop in an inefficient and piecemeal way. One good example of where this has occurred is in very high field nuclear magnetic resonance (NMR) spectroscopy. Such instruments cost ~$10 M each, and while there are many sites overseas with this equipment, Australia would be 10 years behind the leading edge if funds were made available today. Urgent action is required in this and similar areas if infrastructure support.

The Australian R&D Review, March 2004, describes three reports that have been prepared under the aegis of the government's "Our Universities- Backing Australians Future"; the McGauchie report, the Fell report, and the Sargent report. It seems that many of the issues implied in Question 5 (and, in fact, the other questions of this scoping study) are covered by these reports. It is notable that the AAS is not mentioned in the article in the Australian R&D Review.

Submission from the *National Committee for Biomedical Sciences* (NCBMS) of the Australian Academy of Science (AAS), to the NCRIS enquiry

1. Scope

This document provides general recommendations for where the increased infra-structure-funding for research in Australia might be directed. These recommendations pertain to six areas of research in the Life Sciences because our Committee represents Biophysics, Biochemistry & Molecular Biology, Endocrinology & Oncology, Infectious Diseases, Pharmacology & Toxicology, and Physiology.

The NCBMS performs part of the facilitatory function that the AAS has with respect to participation of Australian scientists in the activities of the respective International Unions.

2. Premises

The most rapidly advancing and most populated areas of Science are those that use the language, techniques, and scientific basis of Molecular Biology.

Molecular Biology is rapidly moving to a phase where the molecular structures of cell-growth factors, hormones, membrane-bound receptors, structural proteins, factors that regulate DNA transcription etc are no longer the end point of scientific enquiries. Rather, areas of study such as Structural Genomics, Bioinformatics, and Systems Biology have led to a much more comprehensive description of the molecular basis of biological systems than the previous less-integrated disciplines.

All these new groupings, and the parent disciplines, now make extensive use of sophisticated equipment often based on massively parallel analytical throughput. The equipment is typically linked to state-of-the-art computers, robotics, and advanced electronics; and in some cases it is the biological research that, significantly, provides impetus for great advances in the 'enabling' Physics and Engineering. Particular, notable examples of these are given below.

3. Caveat

When writing a submission on behalf of such a huge cross-section of Australian scientists, as is embraced by the NCBMS, it is very difficult to give an account that is perceived to be truly balanced. On the other hand the recording of our opinions ensures that our ideas are not lost from the discussions. It is expected that there will be many submissions to the present enquiry and that these will add to and, we hope, complement the present one. Thus at the risk of being accused of being biased, we respond by saying that the comments are from a position of experience in the respective areas. Accordingly, we present the following:

4. Areas of Science using particularly expensive infrastructure

4.1. Metabolomics/Metabonomics

This is an emerging post-genomic tool for understanding nutrition and the metabolic basis of disease and drug action. The post-genomic era has been greatly enhanced by technologies that allow the function of cells and even whole organisms to be explored at the molecular level. This work entails the measurement of global sets of low-molecular-weight metabolites. Profiles of metabolites in body fluids or tissues can be regarded as important indicators of normal or disease states. These profiles provide a comprehensive view of cellular control mechanisms in humans and animals, and raise the possibility of identifying correlative markers of disease.

Metabolomic research uses analytical techniques such as nuclear magnetic resonance (NMR) spectroscopy and mass spectrometry (MS) to measure sets of low-molecular-weight metabolites in biological samples. Advanced statistical and bioinformatics tools are then used to maximize the extraction of information and interpret the large datasets that are produced. It has already been used in studies of toxicological mechanisms and inborn errors of metabolism. It offers a means of investigating the complex relationship between nutrition and metabolism, specific examples include: the metabolism of dietary substrates, drug-induced disturbances of lipid metabolites in diabetes mellitus and the therapeutic effects of vitamin supplementation on chronic metabolic disorders.

Key technologies for metabolomics are MS and NMR spectroscopy; these and propositions for them are described below.

4.2. Ion channel research

4.2.1. General

Ion channel research links electrophysiological measurements with molecular biology to relate the functional properties of the channels with their amino acid composition. It also requires x-ray crystallography and cryo-electron microscopy to precisely relate those functional properties to the molecular structure of the channel proteins. Further information can also be determined by mathematical simulations of ion flow through such channels to better understand the underlying mechanisms at the most fundamental level. In particular, such research promises to determine the basic mechanisms that underlie how channels select between different ions (and water molecules), how they are activated and modulated and how individual amino acid mutations can give rise to channelopathies. It also has great promise for pharmacological interventions in pathological situations. Ion channel research has been expanding exponentially over the last decade or so and has produced at least two Nobel Prizes: Erwin Neher and Bert Sakmann in 1991 for their discoveries concerning the function of single ion channels in cells, which included the development of the patch clamp technique, and Peter Agre and Roderick MacKinnon in 2003 for their work on structure and function of aquaporins and ion channels.

The electrophysiological and pharmacological aspects require individual patch-clamp set-ups, in some cases with fluorescence facilities, for the detailed investigation of channels in single cells. In addition, special large-scale patch-clamp arrays are required for the high throughput scanning of channel modulating agents.

4.2.2. Tools of ion channel research

***Supercomputers**:* Faster and larger supercomputer facilities are required for Brownian Dynamics and especially for Molecular Dynamics simulations of ion permeation through such channels, to more comprehensively cater for the physico-chemical properties of the molecules lining the channels and ion-water interactions, as well as for modelling the molecular structure of the channel proteins. It is likely that the NC for Computing and Information Technology will present a case that includes simulation of biological systems so further arguments for such instruments are not developed here.

Other items of equipment that are needed for cutting edge research into ion channel function are much less expensive and within the scope of current funding schemes. For the record, and not to mount a case in the context of NCRIS except perhaps in an integrated consortium are: Atomic force microscopes that are used for imaging at atomic resolution the surfaces of biological structures such as cell membranes, DNA and single proteins. And, confocal microscopes that are used to building up very clean high (sub-micron) resolution three-dimensional images of biological structures such as muscle fibres and other cells.

4.3. Proteomics

4.3.1. General

Today the genome of many organisms is known, and in the case of some prokaryotic organisms, multiple copies of the genome have been sequenced. While this mountain of genomic data provides an enormous wealth of information about 'the instruction manual' for an organism, it is the proteome which describes what proteins are actually present at a given point in time in a given organism, cell, or tissue. In contrast to the organism's genome, the proteome is extremely dynamic. Thus the level of complexity of a proteome is several orders of magnitude greater than that of the genome. For example the human genome is predicted to contain less than 30,000 genes, yet they result in an estimated half a million proteins, many of which we know little about. The new discipline of proteomics first set out to qualitatively and quantitatively compare proteomes under different conditions to unravel the mechanisms of a wide variety of biological processes. In addition, it addresses the interactions of proteins with each other and with other molecules to give further insight to these processes. Through the development of this knowledge it is anticipated that it will help to unravel biochemical and physiological mechanisms of complex multivariate diseases at the molecular level. The experimental tools used for these studies include some of the most sophisticated ones yet devised, involving multidimensional liquid chromatography, sensitive fluorescent dyes, high-precision robotics and extremely sensitive mass spectrometers.

4.3.2. Tools of proteomics

Sample Fractionation

For a protein to be successfully identified by mass spectrometry it needs to in a relatively pure form. Given that most proteomes contain many thousands of proteins this represents as considerable technical challenge. The traditional separation method is two dimensional gel electrophoresis (2DGE) whereby proteins are distinguished by their isoelectric point (pI), and then by size. On a standard 20-cm square gel it is possible to separate over a 1000 proteins; these appear as discrete 'spots' that can be cut out and identified by MS. By pre-fractionation of the sample before it is run on the gel (for example, only studying proteins located in the nucleolus) and running a series of gels covering a range of narrow pH bands (so looking at proteins of only a small range of pI values in each gel) it is possible to detect a majority of the proteins present in a proteome.

While the equipment for running the gels is commonplace in may proteomics facilities throughout Australia, the recent development of fluorescent protein-dyes (such as Sypro Ruby), difference gel electrophoresis (DIGE, where multiple samples are pre-labelled with different fluorophores and then run on one gel) and multiplexing (whereby one gel can be sequentially stained for membrane proteins, glycoproteins and phosphoproteins) has led to an acute shortage of adequate laser scanners (such as the Typhoon 9410 produced by GE Healthcare) available to researchers. With these methods now essential to most types of proteomics research this type of high quality instrumentation is in heavy demand.

A second technique which is now becoming almost routine and which would be essential if Australian researchers are to remain internationally competitive in the area, is that of shotgun proteomics (also know as MudPIT) as pioneered by John Yates of the Scripps Institute. Yates demonstrated that it was possible to fragment all the proteins in a proteome prior to running them on a series of nano-liquid chromatography columns to fractionate the mixture of peptides sufficiently to enable the sequencing of each peptide as it is eluted from the final column by electro spray ionisation mass spectrometry (ESI-MS). The process is complementary to a 2DGE based approach, but is still far from routine and requires dedicated nanoLC equipment, high capacity ESI MS and substantial bioinformatics support to analyse the enormous quantity of data generated.

Sample Processing

With the frequent need to identify large numbers of proteins, robotic workstations have often been employed in sample processing, particularly with the excision of protein spots for 2D gels and their subsequent trypsin digestion. While not critical for small proteomics facilities such robots are often relied upon for greater reproducibility, reduced sample contamination and greater throughput in larger centres. However, the robotic workstations can, in some circumstances, also be used in preparing proteins for protein arrays and for setting up crystallisation trays for 'structuromics' projects.

Mass Spectrometry

Mass spectrometry has long been the method of choice for identification of proteins, either by peptide mass fingerprinting (PMF) whereby the presence of a number of peptides of defined mass is sufficiently characteristic to enable identification of the protein, or by selecting individual peptides, further fragmenting them and so determining the amino acid sequence of each peptide (de novo sequencing). While the former has a higher throughput, it is reliant on genomic data being available, whereas the later is independent of genomic data and can also be used to identify modifications to the peptide such as phosphorylation that will be of increasing interest to many researchers. The equipment used to do both methods has developed rapidly in the past decade and there is a constant drive for increasing sensitivity and speed so it is hard for academic institutions to remain competitive, given the high capital expenditure required to upgrade to the next generation of mass spectrometer. For example there are a number of MALDI-TOF/TOF machines such as the Applied Biosystems 4700 which offers state of the art instrumentation for high throughput proteomics available to researchers in Australia, but they are already operating at, or near, full capacity so there is a need to expand throughput in this area.

Globally, the type of mass spectrometer that many proteomics laboratories are aiming towards is that of the 2D ion trap – Fourier transform spectrometer; this is an instrument which redefines performance for metabolic and proteomics analyses and represents a quantum increase in ultra-high sensitivity and high resolution mass spectrometry at fast scan speeds for exceptional mass-coverage. The superior sensitivity and fast scanning produces better peak shape resulting in superior quantification over a wider linear dynamic range; and enhanced MS/MS affords excellent higher order mass spectra that rapidly facilitates both metabolic and proteomic structural elucidation.

Future developments in proteomics instrumentation

An additional area which will continue to develop is that of MS imaging as pioneered by Richard Caprioli of Vanderbilt University, Nashville. It is a process which takes the already successful technique of SELDI, and allows one to characterise individual components of a tissue, down to a spectral resolution of around 50 µm.

While the term proteomics is associated with the high-throughput identification and quantification of multitudes of proteins within a series of samples, a technique which lends itself well to the identification of biomarkers of diseases, and potential vaccine candidates, it only slowly builds up our understanding of the actual function of these proteins. To learn more of the function of the proteins it is useful to understand what other proteins or molecules they interact with and this is another area of proteomics which is developing rapidly.

Protein-protein interactions have traditionally been studied using biochemical and molecular biological methods, often one protein at a time. In 2000 Uetz et al. demonstrated that the yeast two-hybrid system could be adapted for large scale mapping of protein-protein interactions, and then in 2002 Gavin et al. and Hu et al. developed the process further by using bait proteins to pull down interacting partners which were identified by mass spectrometry and were thus able to map an extensive network of protein-protein interactions.

An alternative to these methods, is that of protein arrays. The technique, first demonstrated on a large scale by Michael Snyder at Yale in 2001 and which is currently being commercial developed by Invitrogen, consists of preparing protein arrays consisting of hundred or thousands of known proteins which can then be used as baits to extract unknown binding partners which can then be identified by mass spectrometry.

In summary, proteomics will continue to provide a quick and efficient way to identify potential proteins of interest through an increasingly wide variety of methods ranging from the classical 2DGE to the latest shotgun proteomics methods using state of the art FT-MS. Alongside this there will be a gradual blurring of the distinction between target protein identification and the subsequent characterisation with high throughput techniques being applied to protein-protein and protein-ligand interactions, mutagenesis studies, signalling cascades and ‘structuromics’.

4.4. NMR Spectroscopy and Imaging

4.4.1. Historical Perspective

The phenomenon whereby the atomic nuclei in matter absorb electromagnetic radiation when immersed in a magnetic field (the phenomenon of nuclear magnetic resonance) was discovered in 1945. Viewed initially as equipment that was only of interest to physicists, NMR spectrometers in a comparatively short time, were widely installed in chemistry laboratories to identify and quantify even complex molecules. A slow incremental rise in the power of these instruments, particularly since the 1970s, has provided molecular life-scientists with a potent tool for the determination of the structure of molecules that contain thousand of atoms. The importance of NMR in several scientific fields has been underscored by the award of the Nobel Prize in Physics to the original discoverers (Bloch & Purcell) in 1952, in Chemistry (Ernst, and Wüthrich) in 1991 and 2001, respectively, and in Physiology or Medicine (Lauterbur and Mansfield) in 2002.

The most prominent feature, and the most costly single component, of an NMR spectrometer is its magnet. The highest magnetic field currently commercially available is 21.1 tesla (T) while at least one company (Bruker, Germany) is working on a 23.5 T magnet in which ^{1}H nuclei resonate at 1 gigahertz (GHz). The quest for higher magnetic fields is related to increased sensitivity to detection of the nuclei, an increase in separation between spectral lines (dispersion) and enhancement of special effects (in particular the so called TROSY effect) that provide structural data on relatively immobile molecules such as membrane proteins.

4.4.2. Australia

This nation has a vibrant community of scientists and students (and a society with ~200 members, ANZMAG) whose primary technological focus is NMR spectroscopy. There are two 800 MHz and nine 600 MHz spectrometers at various locations around the country; and around 40 lower field instruments all with modern superconducting magnets.
Australia has no 900 MHz spectrometers in spite of this technology now being ~8 years old. However, such an instrument is likely in the near future at the IMB at the University of Queensland.

4.4.3. Proposition

A 1 GHz facility be planned for the Sydney region. This would be part of a Nationally networked system with the grid containing the two extant 800 MHz spectrometers at the University of Melbourne and the Australian National University, and the likely 900 MHz spectrometer at the University of Queensland. The proposed instrument would be operational in ~5 years. It would place Australia back at the cutting edge of NMR research and its advanced applications.

The scientific argument for such an instrument would be made in a detailed submission akin to that developed for an MNRF bid made 4 years ago.

4.4.4. Other Magnetic Resonance equipment

High Field Whole Body

The whole body MRI/MRS spectrometers with the highest magnetic fields are in the USA and have fields of 8 T. They yield sensitivity and spectral dispersion from humans that are akin to a mid-range laboratory NMR spectrometer. A step up in field is needed before some of the now-routine high-field NMR methods can be applied in human clinical research. A particularly important area for the neurosciences/psychology is functional magnetic resonance imaging, fMRI. It seems reasonable that scientists in these areas in Australia should aspire to gaining access to this equipment.

NMR microscope

This is now a reality. Again, a step up in magnetic fields, magnetic field gradient technology and related hardware is needed to make the technique competitive with some of the remarkable optical methods that are now routine on a modern light microscope. For example the erstwhile difficult setting up of differential interference contrast (DIC) for the time lapse 'filming' of living cells is totally under computer control. On the other hand the NMR micro-imaging experiment is much more difficult to optimize. Australian scientists should aspire to having access to microimaging, including the related flow and rheological analysis, at very high magnetic fields beyond 20 T.

Magic Angle Spinning

At present there is only one report in the literature of the structure of a protein determined from a solid powder of crystallites by NMR spectroscopy. The actual method used, fast-sample-spinning NMR is poised to deliver many more results from previously intractable-to-study samples. Thus Australian scientists should aspire to having access to very high magnetic field, fast-sample-spinning NMR spectrometers beyond 20 T.

5. Conclusions

We have not commented in detail on X-ray crystallography and cryo-electron microscopy as they involve instruments that will be addressed in submissions by others. It should be noted though that the range of experiments and hence the diversity of the information available from such instruments is much more circumscribed than is that from the items we have focussed upon here.

Having a cutting edge 1 GHz NMR spectrometer in Australia would extend by a large margin the already growing activity in the area of structural genomics, but also whole cell function including metabolomics. It would provide a powerful impetus to education and training in the latest fundamental aspects of NMR and this would have flow-on effects into the three other NMR areas noted above, including fMRI.

Having the next generation of mass spectrometers in Australia will be vital to one of the most rapidly advancing approaches to understanding the regulation of cell growth and development, proteomics.

Australian scientists also need access to instruments that are typically in a price range an order of magnitude below that of the above instruments. These include confocal microscopes, and facilities for the large scale preparation of 'engineered' proteins and their purification. These proteins are the subject of structural analysis by NMR spectroscopy and X-ray crystallography. The opportunity should be taken under NCRIS to develop networks of experts and users in all the areas mentioned in this submission including these less costly ones.

Chemistry The second part of a review would do this. At present there has been no discussion about such a review by the RACI. The states have an interest in this issue.

Crystallography Over the past decade, the NCCr has been quite active in promoting the new research reactor and the synchrotron

Earth Sciences The specific infrastructure needed has not been detailed. However, in that the strategic directions have been identified it would now be relatively simple to determine the specific infrastructure requirements.

Geography This would need to be evaluated but some key issues can be identified. Given the importance of spatial analysis to the discipline, attention to the provision of infrastructure in the areas of geographic information science and remote sensing is necessary. This spans all of the discipline but in several universities infrastructure is either limited or running down due to reduced government funding. This not only includes hardware (high performance computing, GPS) but also software (expensive proprietary programs, digital photogrammetry). An important development area is Web based GIS, independent of platform type and software, but this would need resources to be fully implemented across the sector.

It is likely that major infrastructure development is needed in the area of radiometric dating and stable isotope analysis. This could be in cooperation with the NC Quaternary. Existing facilities are limited in capacity and may be outdated. They are also geographically restricted to southern Australia (Sydney, Canberra, Wollongong, Melbourne). Given the importance of long-term records to understanding the dynamics of Australian environmental change, such an initiative would advantage several disciplines.

Medicine The NCRIS has, I believe, addressed issues primarily for the University sector, and for areas of research funded through ARC/DEST. This is sometimes interpreted as excluding major resources for medical research, as medical research is funded primarily through NHMRC/DoH. I can begin to consult "the biomedical research community" through AAMRI, the Institutes, the Universities, ResA and ASMR, but it is only worth doing this if medical research is included in the areas addressed by NCRIS.

If medical research is included, among the obvious needs are some "biomedical stations" for the "Monash" cyclotron (I gather these cost a few million each) and at least two high energy (3t) MRIs each, for human and animal work. One human MRI could be to the Murdoch/University of Melbourne, and one animal MRI to either Monash or Melbourne. I suspect that Sydney and Brisbane also have needs for good research-oriented MRIs. Each MRI costs about $5M.

Nutrition From an analysis of major international directions in nutrition science, the Committee considered the following areas to be of importance:

(a) energy metabolism *in vivo*
(b) foods, homeostasis and disease processes
(c) systems biology and integrative nutrition
(d) nutrition and health economics

(e) non-invasive measurement technology

Key infrastructure requirements for these priorities include:
(i) whole body calorimetry, isotopic labelling and detection techniques, MRI and PET facilities not primarily dedicated to clinical work
(ii) cell & molecular biology and analytical biochemistry (e.g. LC/MS, NMR) facilities, co-located with nutrition professionals
(iii) residential facilities with built-in clinics and controlled catering systems for both intervention and diet-based studies

Physics

Adapting the ARC definition, a major research facility is a world-class instrument, collection of instruments or connected nodes of information and expertise, devoted to research in the physical sciences.

For the purposes of this study a major facility is one with a capital cost of at least $5M. The NC Physics did not consider major facilities in astrophysics/astronomy facilities. There are numerous smaller facilities scattered through laboratories in Departments of Physics throughout Australia that could come close to this lower cut off. We have not included these in our survey.

(I) Over $100 Million

ANSTO - Research Reactors

HIFAR

The High Flux Australian Reactor (HIFAR) is used for research, production of radiopharmaceuticals and industrial radioisotopes, and industrial analysis and services. Among the ways in which ANSTO researchers use HIFAR are:

- Using neutron scattering to learn how new materials can be fabricated, as materials can be studied under conditions of extreme heat, cold or pressure— especially studying the structure of materials that include light elements, ceramics and magnetic elements
- Investigating the impact of processes such as heating, mixing and fermenting on the molecular structure of foods— leading to improved product quality and lifespan
- Development of new radiopharmaceuticals for cancer diagnosis and therapy, as well as other diseases
- Irradiating elements for measuring the movement of sand, sediment, pollution, groundwater and salinity
- Studying molecular mechanisms of basic biological processes
- Probing structures of surfaces, thin-films or buried interfaces as well as processes occurring at surfaces and interfaces, such as absorption, adhesion and interdiffusion
- Pursuing applications of nanotechnology in areas as diverse as pharmaceuticals, environmental research, new materials and traditional industrial problems.

Above are research applications focusing on ANSTO's own research programs. It does not include external research users, such as those from universities who access ANSTO facilities through the Australian Institute of Nuclear Science and Engineering (AINSE). More information is also available on industrial applications.
HIFAR's seven instruments are listed at www.ansto.gov.au/ansto/bragg/hifar/nshifar.html.

HIFAR first reached criticality in January 1958 and now, 47 years later, it is not possible to set a value on the capital investment in it.

Nor is it appropriate to discuss the level of staffing involved in running it, as staffing will be different on the replacement reactor due to substantially different operation requirements.

The Bragg Institute at ANSTO—which undertakes neutron scattering and instrument development as well as providing services to researchers from other organisations—currently has 24 scientific staff, eight scientific operations staff and six staff in its technical support group. (See www.ansto.gov.au/ansto/bragg/staff/staff.html for a full staff list.) . HIFAR is due to close in 2006.

Replacement Reactor

HIFAR is being replaced by a 20 megawatt pool reactor that uses low enriched uranium fuel and is cooled by water. It will be a multipurpose facility for radioisotope production, irradiation services and neutron beam research. Its compact core is designed to achieve high performance in the production of neutrons. It is due to be fully operational in 2006.

Its neutron beams will be many times more effective than HIFAR's as they will be more intense and substantially free of gamma radiation. Unlike HIFAR, the replacement reactor will also produce cold neutron beams which will allow scientists to conduct research into the structure of biological matter, which was not previously possible. This opens up more scientific research avenues.

Eight neutron beam instruments are planned for the reactor when it goes critical. Seven of the eight will be among the top such instruments in the world. ANSTO expects to add more instruments within five years. The facility has the capacity for further expansion, including potential for a second neutron guide hall. A suite of ancillary equipment will enable studies at different temperatures, pressures and magnetic field. (For more information see www.ansto.gov.au/ansto/bragg/2005/nsrrr.html.)

The replacement reactor will cost $330 million. The Minister for Education, Science and Training, Dr Brendan Nelson, will announce the official name of the replacement reactor on 24 January 2005.

Taking into account the fact there are three shifts a day, the total operating organisation will average around 70 people. This covers the range of applications, not only research. This number does not include Bragg Institute staff (see above) and visiting scientists.

In the 2004-05 budget, the Australian Government allocated funding of $7.4 million over four years to ANSTO for scientific staff to exploit the greatly increased neutron beamline capacity of the replacement reactor. This will enable ANSTO to provide maximum support for research at the reactor.

Relationship to synchrotrons

The production of high intensities of neutrons in research reactors complements the use of synchrotrons that produce very high intensities of electromagnetic radiation (in the form of x-rays, ultraviolet light and infra-red light). Neutron scattering penetrates deeper than x-rays, and can be used, for instance, to look inside a pressure device or deep into a weld, or to map the stresses in a casting. Neutron scattering can reveal processes deep inside thick containers or large objects.

ANSTO - Tandem accelerators

ANTARES

The Australian National Tandem Accelerator for Applied Research (ANTARES) is a 10 million volt FN-type nuclear tandem accelerator purchased from a US university in 1990 and completely refurbished and upgraded at ANSTO.

It provides ultra-sensitive radioisotope and isotopic abundance analyses for tracing and dating in the fields of environmental and earth sciences (e.g. atmospheric research, oceanography, archaeology and heritage, Quaternary science and modern climate change), characterisation of new materials, bio-medicine and nuclear safeguards.

Techniques and methods in ion beam analysis (IBA) and accelerator mass spectrometry (AMS) are performed using three ion-sources and five beamlines, each equipped with specialised nuclear detectors to count single ions (or atoms) in the mass range from carbon to uranium.

STAR

The Small Tandem for Applied Research (STAR) is a 2 million volt tandem accelerator. A modern compact and computerised facility, it has state-of-the-art capability for dual functionality, providing both IBA and high-throughput and high-precision AMS radiocarbon analysis.
These sophisticated instruments significantly improve Australia's nuclear research infrastructure. They enable ultra-sensitive isotopic analyses in diverse natural and man-made materials across a spectrum of applications.
STAR will be officially opened by Dr Nelson on 24 January 2005. It is replacing a 35-year-old Van de Graaff accelerator.

Financial aspects

As ANTARES was bought 15 years ago, it is not possible to precisely value ANSTO's investment in it. However, the commercial replacement cost of an equivalent facility with the capabilities of ANTARES is $10 million. Total costs for STAR were $3.2 million. This included the commercial purchase, and buildings, installation and commissioning costs. The funding was collaborative, with AINSE, ANSTO, the Australian Research Council and individual universities all contributing funds. Operation and maintenance costs for the two accelerators are estimated to be $0.6 million.

A total of 20 persons are directly involved in the full spectrum of scientific and technical development activity of these two tandem accelerators. Approximately half of these provide technical, engineering and other support and half are research scientists, ranging from post-doctorals to principal research scientists.

Resource allocation

ANSTO has a matrixed approach to resource allocation and individuals often perform multiple functions. For example, a scientist might conduct his or her own research as well as provide services to users or develop instruments.

Synchrotron

Following national and international consultation, the design objectives for the Australian Synchrotron are:

- energy of 3 GeV to provide high performance in the x-ray energy range 100 eV to approximately 65 keV
- competitive with other third-generation compact facilities under construction
- Adequate beamlines and experimental stations to satisfy 95% of the research requirements of an expected Australian user community of 1,200 researchers
- internationally competitive performance for essentially all Australian industry requirements.

Beamline activities will include: High-throughput Protein Crystallography, Protein Micro-crystal and Small Molecule X-ray Diffraction, Powder Diffraction, Small and Wide Angle Scattering, X-ray Absorption Spectroscopy, Soft X-ray Spectroscopy, Vacuum Ultraviolet Spectroscopy, Infrared Spectroscopy, Microspectroscopy, Imaging and Medical Therapy, Microdiffraction and Fluorescence Probe, Circular Dichroism, and Lithography.

The initial capital cost, estimated to be approximately $206 Million, is for the synchrotron source and an initial set of 9 beamlines, as detailed in the National Science Case (NSC). The operating costs are estimated to be $15 Million rising to $17 Million, as mentioned on page 45 of the NSC. There are of course additional capital and operating costs associated with additional beamlines, but such expansion has not been accurately costed as yet, and will depend on the future demand for specific beamlines from the national science user base. Comparison of a free electron laser with a 3rd generation synchrotron source is potentially sensitive in the sense that 3rd generation technology is proven and FELs as a 4th generation x-ray source is in the developmental stage.

(II) Over $30 Million

Heavy Ion Accelerator Facility
Operated by the Department of Nuclear Physics, Australian National University The facility is comprised of a 15 Million Volt tandem accelerator coupled to a Superconducting Linear Accelerator. A wide range of energetic heavy-ion beams such as 300 MeV Ni-58, are provided for nuclear structure and nuclear reaction studies and various applications including materials science research, and environmental studies using Accelerator Mass Spectrometry.

Capital Investment: Approximately $50 million

Personnel:
- 7 Tenured Academic Staff
- 5 Postdoctoral/Research Fellow Staff (ANU and ARC Funded)
- 5 Scientific Staff at PhD Level for Facility Operation and Development
- 11 General/Technical Staff
- 6 Visiting Fellows (long-term)
- 8 PhD students currently resident and numerous others affiliated with outside users.

Users: Large cohort of local and National users (University, Government and ARC funded) and International Users including UK Physicists who have access through a formal agreement with the Engineering and Physical Sciences Research Council (U.K.). Over 40 Short-term visitors in 2003 as outside users.

(III) Range $10-30M (including aggregated laboratories)

Materials engineering (ANU)
The Electronic Materials Engineering (EME) Department conducts interdisciplinary research in areas such as condensed matter physics, materials science and device engineering. This includes world-class research in the growth, structure, properties and applications of electronic materials. The diversity of the Department's research is one of its key strengths, underpinning its broad collaborative base and its ability to attract students and researchers from a range of disciplines. The Department’s equipment and infrastructure is valued at more than $20m, and it currently employs 6 recurrently-funded academic staff, 16 externally-funded early-career researchers, and 8 general staff. The Department typically has 15-20 PhD students. The Department’s annual budget is over $3m, with approximately 55% of this coming from competitive granting schemes.

Ion-Beam Modification and Analysis of Materials

Ion-Beam Modification and Analysis of Materials research ranges from fundamental studies of ion-solid interaction processes and the development and application of ion beam analysis techniques, to materials science studies employing ion-irradiation and/or ion-beam analysis. The research is centred around state-of-the-art accelerator facilities, including two ion-implanters (150 kV and 1.7 MV tandem) and a versatile ion-beam analysis machines (a 1.7 MV tandem) together with an impressive array of complementary techniques. Extensive use is also made of the 14MV tandem accelerator operated by the Nuclear Physics Department for high-energy, heavy-ion beam studies.

Metal Organic Chemical Vapour Deposition (MOCVD) Growth and Thin Film Deposition

MOCVD Laboratory hosts two MOCVD reactors, including a state-of-the-art Aixtron AX200/4 (3 x 2 inch, 1x3 inch and 1x 4 inch wafer) MOCVD reactor with gas foil rotation. This allows the growth of a range of III-V compound semiconductor structures based on GaAs, AlGaAs, InGaAs, InP, InGaAsP. This reactor is widely used for the growth of quantum wells, quantum wires, quantum dots, strained layers and devices such as lasers, photodetectors, modulators, VCSELs, SESAMs. The second reactor (modified MR Semiconductor Reactor with Thomas Swan Cell) is used for growth of structures with novel materials such as GaAsN, InGaAsN. A range of thin film deposition facilities such as thermal evaporator, e-beam evaporator, plasma enhanced chemical vapour deposition system are available for depositing a variety of metal and dielectric films.

Device Processing

The Photonic Devices Laboratory consists of a Class 1000 clean room with Class 100 yellow room. This laboratory currently hosts a Karl-Suss sub-micron, holographic mask-aligner for optical lithography, spinner, e-beam evaporator, laser direct system, an Oxford PlasmaLab100 Inductively Couple Plasma (ICP) Etching system, an Oxford PlasmaLab 80 Plasma Enhanced Chemical Vapour Deposition (PECVD) and Reactive Ion Etching (RIE) system. This laboratory is widely used for the fabrication of optoelectronic devices and structures, including heterojunction lasers, VCSELs, waveguides, photodetectors and modulators. A new multi-target sputter deposition system has been ordered and will be installed and commissioned during 2005.

Materials Characterisation

EME also has an extensive array of analytical facilities for the structural, compositional, optical, magnetic and electronic characterisation of materials. Selected examples include:

- tandem ion accelerator for Rutherford backscattering/channelling
- double crystal x-ray diffraction
- scanning and transmission electron microscopy sample preparation
- secondary ion mass spectrometry
- powder x-ray diffraction
- photoluminescence
- deep level transient spectroscopy
- Hall effect apparatus
- capacitance-voltage carrier profiling

Characterisation facilities external to the Department are also utilised routinely. Selected examples on-campus include: scanning and transmission electron microscopes of the Electron Microscopy Unit and the tandem ion accelerator of the Nuclear Physics Department, Research School of Physical Sciences and Engineering. EME personnel use the latter for elastic recoil detection and perturbed angular correlation studies. Synchrotrons and storage rings around the world are also used by EME personnel to determine both the electronic and structural properties of materials.

Semiconductor Nanofabrication Facility (UNSW)
The Semiconductor Nanofabrication Facility (SNF) at UNSW provides an Australian capability for the fabrication of advanced nanoscale semiconductor devices and their integration with microelectronics. SNF is a key facility of the Centre for Quantum Computer Technology, an Australian Research Council Special Research Centre.

Australian International Gravitational Observatory (AIGO)
AIGO has been planned for more than 10 years, and since 1999 has been under active development. It was identified in the Decadal Review of Astronomy in 1995, and will be a significant component of the next decadal review. The project has been led by the Australian Consortium for Gravitational Astronomy, with core universities, UWA, ANU, and UofA. The AIGO research facility has been developed on a specially designated site 80km north of Perth, operated by UWA. Total investment in the facility and associated university facilities exceeds $29M, including major corporate donations towards AIGO's public education centre, the Gravity Discovery Centre. Through the Australian activity, CSIRO Centre for Optical Technology won the contract for major optical fabrication for the US LIGO project.
The original proposal for AIGO was for a $30m project (more than 10 years ago) Today it is perhaps surprising to see that the total investment in AIGO, including the associated Public Outreach approaches this amount. The additional funds required to build the long arm instrument will bring the total project cost to ~$50M, which is not unreasonable compared to LIGO and VIRGO, especially when issues such as low university overheads are taken into account.

Like all major facilities, AIGO offers the opportunity both to spawn new industries and to support major industrial development. AIGO is a currently a National Facility in all but name. Five universities have been actively participating in research at AIGO. AIGO is not a service provider (such as a synchrotron) and is never likely to be one. Rather, it is an international research project at the frontiers of science and technology. Its research program is strongly linked to the US LIGO project and is supervised by an international advisory committee . For facilities such as AIGO it is not appropriate to consider funding it on a user pays principle. Observatories are long-lived facilities. AIGO is likely to require moderate recurrent funding over a long period of time, and like all observatories is never likely to be commercially viable. The WA Government has announced a Centre of Excellence in Gravitational Astronomy which will provide academic support for AIGO.

The development of AIGO is strongly supported by the international community. AIGO already participates in collaborative research with all the other major international projects. Major components of AIGO have to date been donated or loaned by other projects and similar in kind contributions can be expected for the next stage of development. At this stage it is unlikely that the capital costs for AIGO will be provided by other countries.

Much of the development of AIGO to date was funded through Systemic Infrastructure as the first half of a 5 year collaboration and partnership program with the US LIGO project.

(IV) Range $5-10 Million

Atomic Fabrication Facility (UNSW)
The Atomic Fabrication Facility (AFF) was established in 2001 and contains 5 interlinked laboratories all dedicated to the development of atomic-scale devices in silicon and in particular a scalable quantum computer prototype, using a combination of Scanning Tunnelling Microscopy (STM) and Molecular Beam Epitaxy (MBE).

This new facility has been constructed to house three state of the art scanning tunnelling microscopes: (i) an Omicron Variable Temperature STM, (ii) a customised Omicron STM-SEM/MBE system which combines a high quality 4" SiGe MBE system with a dual STM-SEM (Scanning Electron Microscope) system and (iii) a new Omicron Nanoprobe system for the in-situ electrical measurement of hybrid organic-silicon devices fabricated by STM.

HELIAC Plasma Fusion Reactor -(ANU)
Houses the H-1 heliac, a university based toroidal magnetic confinement device for high temperature plasma studies, operated by the Australian Fusion Research Group. Focus is on fusion as future energy source.

Accelerator Lab (Melbourne)
The School of Physics at The University of Melbourne houses A 5 MV Pelletron accelerator providing MeV ion beams for two nuclear microprobe systems. The Pelletron Accelerator consists of an RF ion source. This source can be used with H, He, 3He, C, N, and O beams. The source can then be used with one of five beamlines: These beam-lines are:

1. "MP1" the original Melbourne nuclear microprobe
2. "Blue line" equipped with large scattering chamber for ion implantation or broad beam RBS/channeling
3. "Development line" for construction of commercial projects
4. "Yellow line" for neutron irradiation
5. "MP2" the second generation nuclear microprobe and the most often used line in the laboratory.

National Magnet Laboratory (UNSW)
The Australian National Magnet Laboratory (NML), established at UNSW in 1991, provides an Australian capability for leading edge condensed matter physics research requiring access to high magnetic fields and low temperatures, including electrical, optical and far-infrared (FIR) studies of low-dimensional semiconductor nanostructures, organic layered structures and conventional and high-Tc superconductors.

NML houses a level of cryomagnetic infrastructure the equivalent of that found at the best equipped condensed matter laboratories around the world. Three dilution refrigerators, one with optical fibre access and all with superconducting magnets offer steady field capabilities in excess of 15T. Two of these three systems offer temperatures below 50mK. There are also cryostats for rapid device characterisation, with and without steady magnetic fields, at temperatures down to 1K. In addition to the aforementioned steady-field systems, NML offers pulsed magnetic fields up to 60T at temperatures down to 70mK for advanced research in correlated electron phenomena.

As well as supporting projects associated with the Centre for Quantum Computer Technology, NML serves a wide community of researchers at UNSW and around Australia.

Centre for Quantum and Atom Optics, (ANU)
The ARC Centre of Excellence for Quantum-Atom Optics (ACQAO) combines pre-eminent Australian theoretical and experimental research groups in quantum and atom optics. Our aim is to create a powerful network to advance the rapidly developing field of Quantum-Atom Optics.

Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS, U. Sydney)
CUDOS is an ARC Centre of Excellence in the School of Physics at the University of Sydney. The vision of CUDOS is to develop the experimental and theoretical expertise to design and build linear and nonlinear all-optical signal processing devices, and to miniaturize these, leading to a "photonic chip" believed to be the building blocks for the next generation of optical systems.

The Ultrafast Photonic Laboratory comprises; an Ultrafast Ti:Sapphire laser system: 80 MHz pulse train, 100 fs pulses, 720-1030 nm wavelength range, a figure of eight mode-locked fibre laser: 5 MHz 1pulse train, 1.5 ps pulses, tunable over 1530-1560 nm. Amplified 100 mW average power: pulse energy 20 nJ, peak power 10kW, and a Pritel Ultrafast Optical Clock: Erbium fibre laser, 10 GHz pulse train, 2-10 ps pulses, 20 mW average power, can be amplified to 300 mW: pulse energy 3pJ, peak power 6W.

In the Optical Grating Laboratory fibre Bragg gratings are written into both conventional and chalcogenide glass fibres/waveguides using novel interferometric side-write technique developed in house. A fully flexible grating writing system allows for complex grating fabrication (apodisation, chirp) using high power UV (244 nm) and green (532 nm) laser sources aligned to the interferometric apparatus.

The Picosecond Laboratory contains a diode-pumped mode-locked, cavity dumped pulsed Nd:YAG laser for investigating nonlinear effects in photonic structures: 1.5 kHz pulse train of 80 ps pulses at 1064 nm with pulse 0.1 mJ energy, peak power 1.25 MW.

The Planar Characterization Laboratory comprises a 25 sq m optical clean room has been recently completed and a state of the art Newport/Luminos precision (4 nm resolution) automated waveguide-coupling facility has been installed.

Fiber Tapering Facility houses the fibre taper rig, a computer controlled machine which heats and stretches optical fibre to produce a fibre taper. The taper profiles are tailored by the appropriate choice of flame brushing profile, elongation and rate of elongation. The taper rig is used to modify the physical properties of both conventional as well as microstructured fibers for the various projects currently underway. These include shifting the fundamental band gap of photonic crystal fibre, micro-pipettes for micro-fluidic experiments, nano-wires for photonic circuits and super-continuum generation. A second taper rig is currently being assembled within the CUDOS clean room to augment the current facility. This rig will be able to produce longer, thinner tapers and as well as chalcogenide glass tapers for non linear experiments.

Diagnosis Facilities include:

- Monochromator: spectrally-resolved measurements in the 1-5 ?m range via a computer controlled grating based scanning spectrometer specially modified for the characterisation of photonic crystals.
- Optical Spectrum Analyzers (OSA) and Swept Wavelength System (SWS) to measure passive optical component

measurement system which we use for measuring reflection and transmission.

- Autocorrelation and Frequency Resolved Optical Grating (FROG) of short pulses
- High speed sampling oscilloscopes and high-speed photodiodes.
- Olympus BX61: powerful 1500X inspection microscope with differential interferometric contrast capability.
- Automated and manual waveguide and specialty fibre alignment fixtures.

Applied Physics and Plasma Facility (U. Sydney)
This group at The University of Sydney School of Physics is working in materials modification for applications in energy conversion, the life sciences and engineering.

Major equipment includes:
Thin film deposition facilities (e beam, sputtering, cathodic arc, two source pulsed cathodic arc, plasma CVD). These facilities with their associated power supplies for pulse biasing have a capital cost of say 2.5 million. The pulsed cathodic arc and plasma CVD are field leading facilities and the remainder are state of the art. They have the largest sputtering chamber in Australia for research purposes.

Analytical facilities including ellipsometry, plasma diagnostics, mass spectrometry, insitu FTIR, UVVIS and IR spectroscopy, optical microscopy with spectrophotometry and profilometry, electronic characterisation. The ellipsometry is world class as it is full VASE and is about to be supplemented by IR VASE, he first in Australia. The insitu IR and spectroscopic microscopy are also state of the art and may be unique in Australia. The capital cost of our analytical facilities is of order 1.5 million.

The group has a collaborating laboratory for our life science work in the Anatomy Department where there are cell growth, protein synthesis facilities and associated equipment with a capital cost of 0.8 million. We also have in house facilities for atomistic modelling including the Sydney node of the CQCT which has computing equipment worth 0.1 million. As a part of our work on solar energy conversion we have test facilities worth 0.2 million.

Staffing: Tenured staff including: 2 level E (one Federation Fellow), 1 level D, 2 level C; Other staff including 19 postdoctoral fellows and 12 PhD students.

Hypersonics Laboratory (UQ)
The objectives of the CENTRE FOR HYPERSONICS are: to provide visible international leadership in the centre's areas of expertise, to maintain a high level of activity in both fundamental and applied research, to provide graduate and undergraduate training opportunities of the highest international standards and to play a pivotal role as collaborators in major international projects.

Facilities include:

T4 shock tunnel is a 45 m long free piston driven facility, capable of simulating flows up to 6 km/s (21000 km/hr). Developed specifically for scramjet testing in 1987, it has proven to be a versatile test bed for a wide range of suborbital aerodynamic projects. It was the large-scale prototype on which several major facilities around the world have been based. It was upgraded with a new driver in 2000 and is the test facility in which the world’s first scramjet producing more thrust than drag was tested.

X-Series Expansion tubes combine the free piston driver technique with the expansion tube concept of cascading shock tunnels to achieve superorbital velocities. The primary purpose of these facilities is to create the high speeds encountered by interplanetary re-entry vehicles during aero braking. This is a field where design uncertainty factors of 450% are encountered, and experimental data is sparse. Flight up to simulated speeds of 14.5 km/s (52000 km/hr) have been achieved. Appropriate mixtures of test gas are used to simulate the atmospheres of various planets and moons. These facilities have also been shown to be useful for scramjet testing at lower speeds, due to their very high total pressure simulation capability.

Drummond shock tunnel is a small shock tunnel with a fixed driver in which initiation of a shot is made by piercing the primary diaphragm. It is presently being used to investigate contoured nozzle design for larger facilities. The test section has good optical access with four 100 mm diameter quartz windows.

The Laser Diagnostics is working on the development and application of advanced measurement techniques to high enthalpy flows, flames and plumes. The aim is to characterise such flows by the use of non-intrusive laser-based methods. Two tunable pulsed dye-laser systems and an intensified camera are available for spectroscopic applications while a pulsed Nd:YAG laser is used for interferometric methods. A number of techniques are being used for flow visualisation and for measurement of conditions such as velocity, density and temperature.

(V) Participation in international projects

European Organisation for Nuclear Research (CERN)
Collaboration is shaped by a Memorandum of Understanding between the Australian Centre for High Energy Physics and CERN, for the ATLAS project. Experiments include the origin of mass, the origin of asymmetry between particles and antiparticles, and the masses of neutrinos.

Japanese National Physics Laboratory (KEK)
Collaboration with KEK is involves similar experimental approaches to that for CERN.

Psychology We believe that this will be possible, in consultation with HODSPA and other bodies.

Radio Science Yes, and that will be covered by the national Radio Science plan to be produced in next 12 months.

Can the likely personnel requirements of the discipline be determined over the timeframe identified for the planning process?

Astronomy Yes, that is one of the aims of the Decadal Plan.

Biomedical Sciences Again this would be a big task and we are not sure where we would start with it. In summary this assessment would not be possible without having a comprehensive knowledge of the funding available in the various sectors comprising the constituency of the NCBS and some input from relevant institutions.

Chemistry Yes, providing it is done in conjunction with other bodies. The anticipated RACI/NCC review during 2004/05 is likely to cover this item.

Crystallography	NCCr will continue to monitor the needs of the discipline and could assess the appropriateness of planned staffing arrangements at both the reactor and the synchrotron over the next year.
Earth Sciences	Yes, this could be done.
Geography	Many geography departments have lost staff in key areas of the discipline due to financial restrictions, and thus their research profile is truncated. While some degree of research specialization is desirable, in regional universities it is difficult to find supervisors for some areas of the discipline that have strategic significance. For example physical geography, both pure and applied, encompasses geomorphology, biogeography and climatology. In many departments these critical areas have been run down in both staffing and infrastructure. In many departments GISc is taught by a single academic, and opportunities for postgraduate supervision and maintenance of research currency are restricted as a result.
Nutrition	Yes, but this will require fairly detailed discussion among committee members.
Physics	Yes.
Psychology	In determining the likely personnel requirements, we could first look back to the 1995 Discipline Review, which contained detailed census material across the profession (e.g., age and level of participants etc). In defining personnel requirements we would place strong emphasis on value of clear, funded career research-only career paths for psychological scientists.
Radio Science	Yes, but that will inevitably have the nature of a wish-list, as the NCRS does not itself control any significant resources.

How appropriate is it to validate the discipline strategic plan with the scientific community of the discipline, and with others with key interests?

Chemistry	Via the RACI.
Crystallography	NCC membership includes strong representation from the elected executive group of SCANZ.
Earth Sciences	This can only be done through the typical and resource intensive process of knocking on all the relevant doors and spending the time to talk with people.
Geography	This is absolutely crucial to the success of the project.
Nutrition	Through consultation with FANO and other learned bodies – we need to ensure that representative from key nutrition bodies are represented on the committee.
Physics	It will be necessary to elicit submissions from the National professional body, the Australian Institute of Physics, from the research community and industrial and community stakeholders.
Psychology	The strategic plan could be validated via APS (Directorate of Science as well as colleges and general membership of that Society e.g., using the Society's annual convention as a forum), via HODSPA, and via various existing scientific organisations associated with subdisciplines of psychology.
Radio Science	The plan will be drafted in sections by key researchers distributed across institutions and disciplines, will be coordinated by the NCRS, and then will be discussed in a series of workshops advertised widely to the radio-science community. The draft will also be circulated for comment to key institutions, companies, and stakeholders, and be made available on the web.

What other disciplines are impacted on by the strategic plan, and how should the interaction with those disciplines be managed?

Astronomy	Other disciplines include mathematics, computing, biology, chemistry and engineering. It is planned to engage the other communities via their national academies once the WG reports are available in March 2005.
Biomedical Sciences	The Disciplines within the Biomedical Sciences train many people, some of whom ultimately work in areas beyond the biomedical sciences [e.g., Agriculture and Fisheries, Environmental Management, Clinical Medicine and Dentistry (including Public Health, Defence, etc.), and the Biotechnology and Biopharmaceutical Industry], and conversely, the Biomedical Institutions employ people trained in other discipline areas [Chemistry, Physics, IT (Bioinformatics)]. Thus the NCBMS has significant overlap in its research interests with the physical sciences/computing sciences and the medicine.
Chemistry	The anticipated RACI/NCC review during 2004/05 is likely to cover this item; and includes biotechnology and nanotechnology.
Crystallography	Chemistry, Biochemistry and Molecular Biology. Because of the importance of structural science in both of these disciplines, some deep cross-talk between them and NCCr would be essential during the planning process. Whether physics should be included in this 'cooperative' is a matter for further consideration.
Earth Sciences	There is a necessary interface with mathematics, physics, chemistry, biology as specific disciplines and there needs to be strong interaction across the interfaces with Climate and Global Change, Environment, Geography, and Earth System Science.
Geography	This activity should be coordinated with the disciplines of environmental science, earth science and ecology, as a minimum set. Because Geography is an integrative discipline that spans the natural and social sciences, the relevant social science disciplines should be involved through the Academy of Social Sciences. It would be best to organize a workshop inclusive of the above and other cognate disciplines (planning, demography, rural sociology, environmental economics, environmental engineering, medical sciences). This workshop could most usefully consider a draft report to be provided to the attendees one month before the meeting.
Nutrition	Medicine, allied health, food science and technology, health promotion, social and behavioural science. NAS could organize suitable liaison activities.
Psychology	Within the Academy's National Committees, the potentially relevant ones are Biomedical Sciences, Medicine, and possibly Sustainability. Liaising with the chairs of those committees will be one way of managing these interactions.
Radio Science	The nature of Radio Science means that this will impact on a number of different disciplines, including (but not limited to) Astronomy, Space Science, Electrical Engineering, Telecommunications, photonics, physics, etc. The interaction with those disciplines will be managed by interacting with their national committees, where they exist, or with other professional organizations.

How much of the strategic planning work can be done with existing resources, and what additional resources are required to complete the task?

Astronomy	The work cannot be done with existing resources. The current project plan for the Decadal planning process identifies an additional $100k in resources over and above the 5-10FTE ($1-2M) 'in kind' resources from the community to be devoted to the decadal planning process over the coming year.
Biomedical Sciences	We have concluded that the NCBMS would not make significant progress with existing resources. This conclusion is based on recent experiences of at least one member of the NCBMS, specifically in the field of cancer in NSW; this is only one (small in many respects, but large in the public mind) field of research in one State and a huge amount of work was done by the committee commissioned to do the planning.
Chemistry	In 1991 the RACI undertook a major Review, *Strategic Review of Chemistry Research in Australia*. The review was commissioned by the ARC, and conducted by comprising Professor Tom Spurling (now a current member of NCC), Professor Frank Larkins (recent former Chair of NCC), Mr Terry Robinson, Professor David Black (a former Chair of the NCC and now a current member of NCC), and Dr Paul Savage. The total cost was of the order of ~$350,000. The combined cost of the two planned reviews is estimated to be ~$500,000 if conducted in 2004+. It is important to note that the current financial climate and business practise would mean that potential major contributors, e.g. CSIRO for the 2001 Review, would be reluctant to contribute "in-kind" support, so that ~$500,000 is "real money". **Other comments:** • In 2004 the NCC will make a submission to EXCOM regarding the development of the synchrotron in Victoria. • NCC members attend the annual Professors and Heads of Chemistry Departments (PHODS) meeting at the end of January each year. The PHODS meeting is organised by the RACI, and the proposal for a Review (see question 3) was floated by the NCC Chair at the 2004 meeting. • The PHODS meeting is always held in Canberra. In future, it is anticipated that the NCC will meet in Canberra on the day preceding the PHODS meeting. The RACI International Committee also meets on this day in Canberra. This arrangement enhances the effectiveness of all three meetings held over these 3-4 days. • There are synergies between national and international activities. The report on international activities indicates this, e.g. the proposed development of a website which will include both national and international aspects.
Crystallography	An executive secretary to drive the planning process would ensure it be done professionally and on-time. Dependent on the responses to this scoping questionnaire from the Chemistry and B&MB national committees, it might be feasible to share one executive secretary for all three Strategic Plans. Some travel support to allow at least two face-to-face meetings of the NCCr over the planning period would also be required.
Earth Sciences	It is unrealistic to think that we can develop quality strategy with existing resources. If we are to develop strategy then it must be done properly: it would be a bad mistake to develop strategy badly. We had a grant of $45,000 to assist. The Academy provided in-kind contribution. Geoscience Australia provided significant in-kind contribution and the members of the committee paid their own (quite significant) costs for all the meetings. They also gave their time for free. Consequently the real cost is quite significant. However, some

of this cost was a consequence of the fact that we were developing the strategic plan in a void. The Academy did not have in place any mechanism for developing such a plan, it was not really possible to build on an extant structure of such planning, and there were no natural mechanisms for interfacing with other disciplines. Also, it was necessary to hire somebody to take on the major task of the first-draft writing. If a central role for the national committees were to become the development of strategy in an on-going process it would then be possible for the Academy to provide much of the infrastructure necessary for this activity at a much lower cost per strategic plan/national committee. Overall it would make the process for development of each strategic plan much more efficient and it would make the plans significantly more effective in that gradually there would become a community (science/university/government) that would be expecting the next strategic plan and that would have the expectation of making use of those plans.

Geography

The membership of the NCG deliberately includes the widest possible range of interests, including geographical education. We see this as crucial to the vitality of the discipline in Australia. We lack representation from geographers employed in government departments (Federal, State and Local) and will attempt to include their interests as well.

Recognising that the appointed members of the NCG and the officers of the member organizations are purely voluntary, it would be helpful if some assistance could be provided for a part-time research officer to compile information and produce drafts of the final document for review by interested parties (including the New Zealand National Committee for Geography). In addition, it would be advantageous for the Academy to allocate funds for the production of the final report as a monograph. This would then update the volume: Heathcote, R.L., ed. (1994) *Building Bridges: Geography in Australia*, Australian Academy of Sciences, Canberra.

Nutrition

Some form of secretariat. Many of the issues can be formed by the committee but support staff are required to ensure that such actions are carried out. The committee membership have (I suspect) little or no spare capacity.

Psychology

We should have enough connections to relevant groups to conduct much of the work with existing resources (and contacts). The need for additional resources may depend on the amount of data needed to address some of these questions appropriately and to consult reasonably and widely within the discipline. The 1996 Discipline was a time-consuming and major undertaking, but yielded a strategic plan which remains relevant almost a decade later. We believe that this will be possible, in consultation with HODSPA and other bodies.

Radio Science

This exercise will require significant resources, which will need to be supplied by key Radio Science institutions. These institutions will, of course, only be willing to commit those resources if the exercise is seen as adding value, with the potential to deliver real returns. However, a few groups, such as astronomy, have already demonstrated the value of such a process, and so, provided we have a credible project to deliver a national plan, we expect to be able to tap in to appropriate resources from those institutions.

Table 1. Earth Sciences - Staffing Numbers - Breakdown by University

	1991	1998				2003			
University	**Teacher**	**Teacher**	**Res**	**Other**	**All Acad**	**Teacher**	**Res**	**Other**	**Department Name**
Adelaide	16	13	11	8	32	10	8	11	School of Earth and Environmental Sciences
ANU	9	7	6	3	16	9	7	23	Geology Department
Ballarat	9	5	1	0	6	4	0	1	Department of Geology
Bendigo	6	3	0	2	5	1	0	2	Department of Physical Sciences and Engineering
Curtin	9	9	3	3	15	11	1	2	Department of Applied Geology
Deakin	0	6	0	0	6	4	0	0	School of Ecology and Environment: Earth Sciences stream
Flinders	7	2	0	0	2	2	0	0	School of Chemistry, Physics and Earth Sciences
James Cook	12	11	6	3	20	13	9	9	School of Earth Sciences
Kalgoorlie	6	5	0	0	5	4	0	1	WA School of Mines
La Trobe	11	7	13	3	23	5	1	2	(Department of Earth Sciences)
Macquarie	20	13	14	2	29	12	19	19	Department of Earth & Planetary Sciences
Melbourne	12	10	4	3	17	10	24	8	School of Earth Sciences
Monash	17	11	7	3	21	12	17	8	School of Geoscience
New England	9	5	1	4	10	4	0	6	Division of Earth Sciences
Newcastle	6	6	1	3	10	7	0	3	School of Environmental and Life Sciences: Geology Discipline
QUT	7	6	0	4	10	3	1	0	School of Natural Resource Sciences: Geoscience
RMIT	7	7	0	0	7	3	0	0	Natural Resources Engineering Discipline
Southern Qld	4	0	0	0	0	0	0	0	Department of Biological and Physical Sciences
Sthrn Cross	4	3	0	2	5	3	0	2	School of Environmental Science and Management
Sydney	13	12	2	2	16	9	8	10	School of Geosciences
Tasmania	12	12	11	7	30	12	15	4	School of Earth Sciences
Queensland	13	14	8	1	23	7	10	4	School of Physical Sciences - Earth Sciences
Canberra	6	4	0	0	4	2	0	1	School of Resource, Environmental and Heritage Sciences
South Aust	6	5	0	0	5	3	0	1	School of Geoscience, Minerals and Civil Engineering
UNSW	17	12	2	6	20	8	0	9	School of Biology, Earth and Environmental Sciences
UTS	9	5	0	4	9	2	0	2	Department of Environmental Sciences
UWA	12	12	17	4	33	10	19	4	School for Earth and Geographical Science
Wollongong	9	7	0	1	8	6	0	7	School of Geosciences
Totals (28)	**268**	**212**	**107**	**68**	**387**	**176**	**139**	**139**	

Table 2. Staffing Profile and Infrastructure of Australian Geography Departments, October 2004

Name	Staffing Level Profile					Major Facilities	Minor Facilities
	E	D	C	B	A	value >$500,000	eg. GIS lab, pollen lab, sedimentology lab.
University of Adelaide. School of Geography and Environmental Studies	3	1	2	1	1		GIS labs
Australian Defence Force Academy. School of Geography and Oceanography	1		3	6	1	Oceanographic field equipment	Water quality lab, GIS labs, boats, 4WD
Australian National University. School of Resources, Environment and Society		3	5				GIS lab
Australian National University. Department of Human Geography	1	2	2				
Curtin University. Geography Program. School of Social Sciences	1	1	1	1			
Flinders University. School of Geography, Population and Environmental Management	2	4	2	5	2		GIS labs
James Cook University. Department of Tropical Environment Studies and Geography	2	6	4	6			GIS labs (3), physical geography labs, molecular biology lab, boats, 4WD
Macquarie University. Dept. of Physical Geography	1	3	6	2			
Macquarie University. Dept. of Human Geography	2	3	4	2			
Monash University. School of Geography and Environmental Science	3	4	7	4			Palynology lab, GIS lab
Queensland University of Technology. School of Humanities and Human Services				2.5			GIS lab
University of Melbourne. School of Anthropology, Geography and Environmental Studies	4	2	5	6			Palynology lab, GIS lab
University of Newcastle. School of Environmental and Life Sciences	1	3	5				
University of New England. School of Human and Environmental Studies	1	1	6	2			Computer laboratories, 4WD vehicles
University of New South Wales. Faculty of the Built Environment		6					Computer laboratory
University of Queensland. School of Geography, Planning and Architecture	1	2	4	4			2 GIS labs physical geography lab
University of Sydney. School of Geosciences	2	3	5	2			GIS lab
University of Tasmania. School of Geography and Environmental Studies	2	2	3	13	1	UV radiation monitoring facility	Boats, 4WD; pollen lab
University of Western Australia. School of Earth and Geographical Sciences	1	2	4	1			Palynology lab, GIS lab
University of Wollongong. School of Earth and Environmental Sciences	3	5	1	2		Drilling rig Pollen lab	GIS labs, boats, 4WDs
TOTAL GEOGRAPHY STAFF	**30**	**51**	**62**	**53.5**	**5**		