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Nested partnerships and interdisciplinary science: from the National Medical Cyclotron to the research cyclotron of the National Imaging Facility

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Abstract

In Australia, the routine use of medical isotopes produced by a prototype cyclotron for diagnostic imaging commenced in the early 1990s. Since then, the mainly clinically focused imaging in nuclear medicine has become a broader and more interdisciplinary endeavour. As 'molecular imaging', it has become a field that supports a wide range of basic, translational and clinical research and draws in skills from many areas, including physics, chemistry, engineering, biology and medicine. Such growth has been accompanied by the emergence of scientific collaborations well beyond individual institutions.

This paper provides the historical context to the former National Medical Cyclotron (NMC) facility (1992-2009) at Camperdown, Sydney and the subsequent partnerships that led to its refurbishment as the new site of the National Imaging Facility (NIF) Cyclotron, a flagship research facility enabled by the National Collaborative Research Infrastructure Strategy (NCRIS). It is now the centrepiece of a physical research infrastructure as well as a growing network of collaborations that open up access to medical isotopes for research and clinical applications across Australia to new users and applications. It is also a contemporary example of how science has moved from individual scholarly endeavour to highly networked activity.

The funding model initiated through NCRIS included shared funding, funding leveraging and in-kind contributions primarily for the establishment of the large instrument and laboratory infrastructure rather than their operational costs. Here, we illustrate how partnership arrangements emerged at institutional, state and national level and how they address the task of providing open access to, and sustainable operation of, a major piece of research infrastructure that spans multiple institutions.

Introduction

Molecular imaging is the visualisation, characterisation and measurement of biological processes in humans and other living systems at the molecular and cellular levels. Molecular imaging typically consists of 2- or 3-dimensional imaging as well as quantification over time. The techniques used include radiotracer imaging/nuclear medicine, magnetic resonance (MR) imaging, MR spectroscopy, optical imaging, ultrasound and others (Mankoff 2007).

Molecular imaging using medical isotopes for clinical diagnostics and research into cancer, cardiovascular, immunological, as well as nervous systems diseases is one of the most important applications of the radiotracer principle first utilised by George Charles de Hevesy in 1911 (Hevesy 1923, Myers 1979). There is a broad range of isotopes, the reactor-produced Tc-99m being the predominant isotope for routine clinical applications, while the cyclotron-produced isotopes, such as I-124, I-125, I-131, C-11, F-18 and others have clinical as well as research uses. Notably, C-11 is the isotope of choice for research since it allows the labelling of organic molecules with relative ease without introducing into the molecule atoms other than carbon that might alter its functional properties. However, since C-11 has a short half-life of only 20.38 min, such work can only be carried out if the source, i.e. the cyclotron, and the radiochemistry and imaging laboratories are in close proximity.

Technically and operationally challenging and dependent on highly skilled staff, non-invasive, radiotracer-based molecular imaging requires substantial up-front and ongoing operational investments. Recent reviews initiated by federal and state departments (McKeon review (Ministry of Health 2013) and the Wills review (NSW Ministry of Health 2012)) of the existing practices in biomedical research have, therefore, emphasised the importance of partnerships across often competing institutions and the formation of research hubs that promise better use of resources and sharing of knowledge.

> *"The challenge for the 21st century is to understand how the casts of molecular characters work together to make living cells and organisms, and how such understanding can be harnessed to improve health and well-being… this quest will depend heavily on molecular imaging, which shows when and where genetically or biochemically defined molecules, signals or processes appear, interact and disappear, in time and space."* (Tsien 2003).

Such a research hub has been created at Camperdown, Sydney, a research precinct that amongst others is home to the collaboration between the University of Sydney's Brain and Mind Research Institute (BMRI) and the Australian Nuclear Science and Technology Organisation (ANSTO), both with strong research interests in the development and use of medical isotopes and molecular imaging.

ANSTO currently operates at a number of sites: Lucas Heights, which is 40 km south of Sydney and the site of Australia's only research reactor as well as a number of large accelerators; the ANSTO-Camperdown site, formerly the National Medical Cyclotron (NMC), which is adjacent to the University of Sydney; and the Australian Synchrotron, which is located in a growing research precinct in Clayton, Melbourne.

Three initially independent, partly visionary, partly pragmatic developments came together to form a partnership that is now the

University of Sydney node of the National Imaging Facility in the Camperdown precinct:

- an initiative of the University of Sydney under the then Vice-Chancellor Gavin Brown to reinvigorate some of its basic neuroscience research, join it with clinical research and place it under one roof at the Brain and Mind Research Institute (BMRI), while making better use of partly vacant, formerly industrial spaces that the University owns at its Camperdown site;
- the participation of the BMRI in a federal research infrastructure development initiative, after having received substantial Commonwealth, State and philanthropic funding to undertake interdisciplinary basic and clinical research into mental health. Notably, philanthropic seed funding was received from the Clive and Vera Ramaciotti Foundation for an experimental positron emission tomography (PET) scanner to establish a Brain Imaging Laboratory, which established the need for radioisotopes and radioligands for research that could not be provided with sufficient priority through the clinical cyclotron at the nearby Royal Prince Alfred Hospital;
- and the formation of a more research-intensive ANSTO Radiopharmaceutical Research Institute (RRI), later to become the broadly mandated ANSTO LifeSciences, which needed medical isotopes for research that ANSTO's own ageing National Medical Cyclotron (NMC) at Camperdown could not easily supply. Details on the NMC's development and its demise are addressed in a separate section.

Below, we provide part historical narrative, part description of how the National Collaborative Research Infrastructure Strategy (NCRIS) and the Science Leverage Funding mechanism of the New South Wales Government lead to the formation of the National Imaging Facility (NIF) at Camperdown and discuss some of the broader aspects of interdisciplinary and networked science.

The Partners

National Imaging Facility (NIF) and the National Collaborative Research Infrastructure Strategy (NCRIS)

In 2005, the federal government of Australia launched an initiative investing $542 million over 2005-2011 in support of infrastructure and networks necessary for world-class research (NCRIS 2005). Twelve priority areas were identified, which resulted in a roadmap with the following funding and capabilities:

- Evolving Biomolecular Platforms and Informatics (includes associate membership of European Molecular Biology Laboratory) ($53 million);
- Integrated Biological Systems ($40 million);
- Characterisation ($47.7 million);
- Fabrication ($41 million);
- Biotechnology Products ($35 million);
- Networked Biosecurity Framework ($25 million);
- Optical and Radio Astronomy ($45 million);
- Integrated Marine Observing System ($55.2 million);
- Structure and Evolution of the Australian Continent ($42.8 million);
- Platforms for Collaboration ($75 million);
- Terrestrial Ecosystems Research Network ($20 million); and
- Population Health and Data Linkage ($20 million).

Five expert working groups were established to review the roadmap, with four of these aligned with the National Research Priorities (Environmentally Sustainable Australia, Promoting and Maintaining Good Health, Frontier Technologies, Safeguarding Australia). In addition to the fifth expert working group covering the Humanities, Arts and the Social Sciences, an ICT Strategy Group identified and synthesised current and future ICT research infrastructure requirements.

The characterisation capability became constituted as the Characterisation Council (DIISR 2008, DIISR 2010) which consists of the National Imaging Facility (NIF), the Australian Microscopy and Microanalysis Research Facility (AMMRF), the National Deuteration Facility (NDF), the Australian Synchrotron and the Australian Synchrotron Research Program.

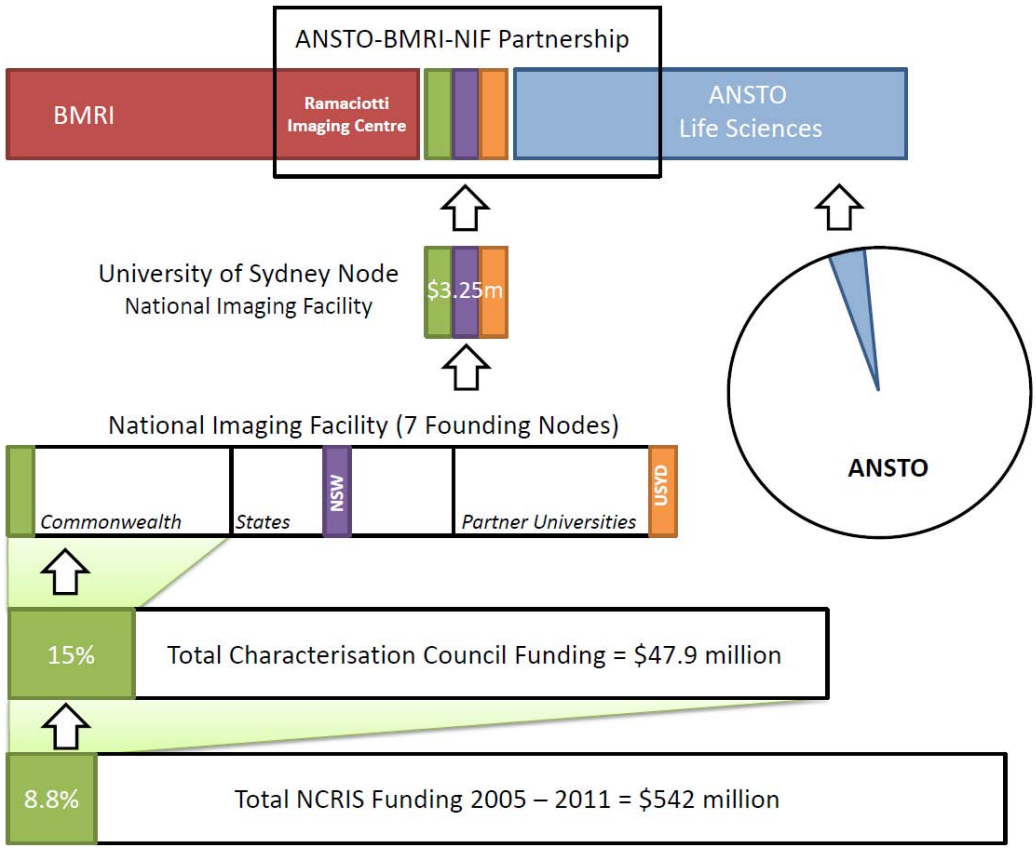

Figure 1: This figure shows how funding and in-kind contributions to new research infrastructure from Commonwealth, State, institutional and philanthropic sources created a nested partnership embedded in a larger network. The main philanthropic contribution towards the molecular imaging infrastructure has been the seed funding from the Clive and Vera Ramaciotti Foundation for a state-of-the-art imaging laboratory, the Ramaciotti Centre for Imaging at the BMRI.

Seven founding members (University of Queensland, University of New South Wales, University of Western Sydney, University of Sydney, Monash University, Florey Institute of Neuroscience and Mental Health, Large Animal Research and Imaging Facility) formed the National Imaging Facility consortium. The funding scheme stipulated that the institutional investment would receive matching contributions from federal (through NCRIS) and state governments.

A subsequent expansion programme included the University of Melbourne, Swinburne University of Technology, the University of Western Australia and ANSTO. Matching contributions were provided by the state governments of New South Wales, Queensland, South Australia and Western Australia. Figure 1 shows the funding contributions from various sources to the new research infrastructure and the creation of partnerships nested in a larger network. The overall evaluation of NCRIS in 2010 (DIISRTE 2013) concluded that the initiative had been successful in engaging the Federal Government, the State and Territory Governments and government agencies in the priority areas without compromising a national approach to funding the intended research infrastructure.

The joint University of Sydney/ANSTO node of NIF is dedicated primarily to tracer-based molecular imaging and radioligand development. As a shared facility, it now provides the research community with open access to cyclotron-based radioisotopes (F-18 and C-11) and radiochemistry/pre-clinical imaging technologies mainly for collaborative, publicly funded research while also allowing for some commercially supported research. The NCRIS-funded flagship instrument, a research-dedicated 18 MeV cyclotron and associated radiochemistry hot cells (Figure 2B), is located in the ANSTO Camperdown facility, close to the BMRI, and is supported by the expertise of ANSTO cyclotron engineers and radiochemists.

At the inception of NCRIS and NIF, ANSTO still operated the NMC (Figure 2A shows hot cells at the NMC), and retained an observing position vis-à-vis the NIF consortium. As ANSTO pondered the options of whether and how it should continue supporting research using cyclotron-produced medical isotopes, whether to decommission its site at Camperdown or to re-engage in research, a new convergent dynamic towards partnerships became apparent. Below follows the history of the National Medical Cyclotron.

A  B 

Figure 2: Hot cells (A) at the NMC were designed to handle comparatively long-lived single gamma-emitting radioisotopes (often requiring external manipulators) and short-lived positron-emitting radioisotopes, whereas the hot cells at the new NIF node (B) handle positron emitters only (C-11, F-18).

The National Medical Cyclotron (NMC)

The history of the NMC illustrates the various modes of government influence in the development of scientific infrastructure. Cyclotron science in Australia goes back to Sir Marcus Oliphant's return from England in 1948, to establish the physics research program within the new Australian National University. However, his planned Australian cyclotron never materialised due to runaway costs and technological complications, subsequently becoming known as "The White Oliphant".

44 years later, spurred by a sense of national need within the medical community, Australia came to operate its first cyclotron, albeit for medical rather than physics research applications. At the Royal Prince Alfred Hospital (RPAH) in Camperdown, the NMC was commissioned on 13 March 1992. It represented nine years of planning and construction, but nearly half a century of ambition.

The proposal

In 1979, the predecessor to ANSTO, the Australian Atomic Energy Commission (AAEC), formed a national cyclotron advisory committee with representatives from all States as well as federal bodies such as the National Health and Medical Research Council and the Australian Radiation Laboratory to advise on the need for a cyclotron for the production of medical isotopes. Although the committee provided support for a national cyclotron, as well as a National Institute of Nuclear and Radiation Medicine, the committee's work resulted only in a series of proposals to government over the next half-decade.

In 1983, an ad-hoc committee, chaired by Professor Tony Basten of the University of Sydney and RPAH, took ownership of the national cyclotron concept. In the context of gaining funding from the 1983 federal budget, the concept was placed before government, through the Minister for Health, as a new policy proposal. The Minister for Health appointed the Medical Cyclotron Committee (MCC) to examine in detail the need for a national cyclotron. For this, the AAEC submitted the original proposal for a dual-purpose cyclotron for commercial production and research, taking the single purpose commercial option off the table. Competing with the AAEC's proposal was one from Austin Hospital in Melbourne, for a single-purpose radioisotope production facility, of lower energy and lower cost. The committee was tasked with producing a recommendation based on cost-benefit analyses of each proposal.

The Australian Medical Cyclotron Workshop (Canberra, 14 December 1984) recommended that the facility should be located within close proximity to nuclear expertise, such as that available at the AAEC; and that it be located within a teaching hospital, such as the RPAH, to ensure both the production and research capabilities could be exploited – a dual-purpose cyclotron, excluding by implication the Austin Hospital proposal. With strong support from both the domestic and international medical communities, the Committee recommended that the federal government support the AAEC proposal for a dual-purpose national cyclotron located at RPAH, but the cost-benefit justification for establishing such a facility, as judged by the MCC, was based primarily on the research applications being made available. However, the MCC recommendations were not a guarantee that the cyclotron would be built, as the Minister

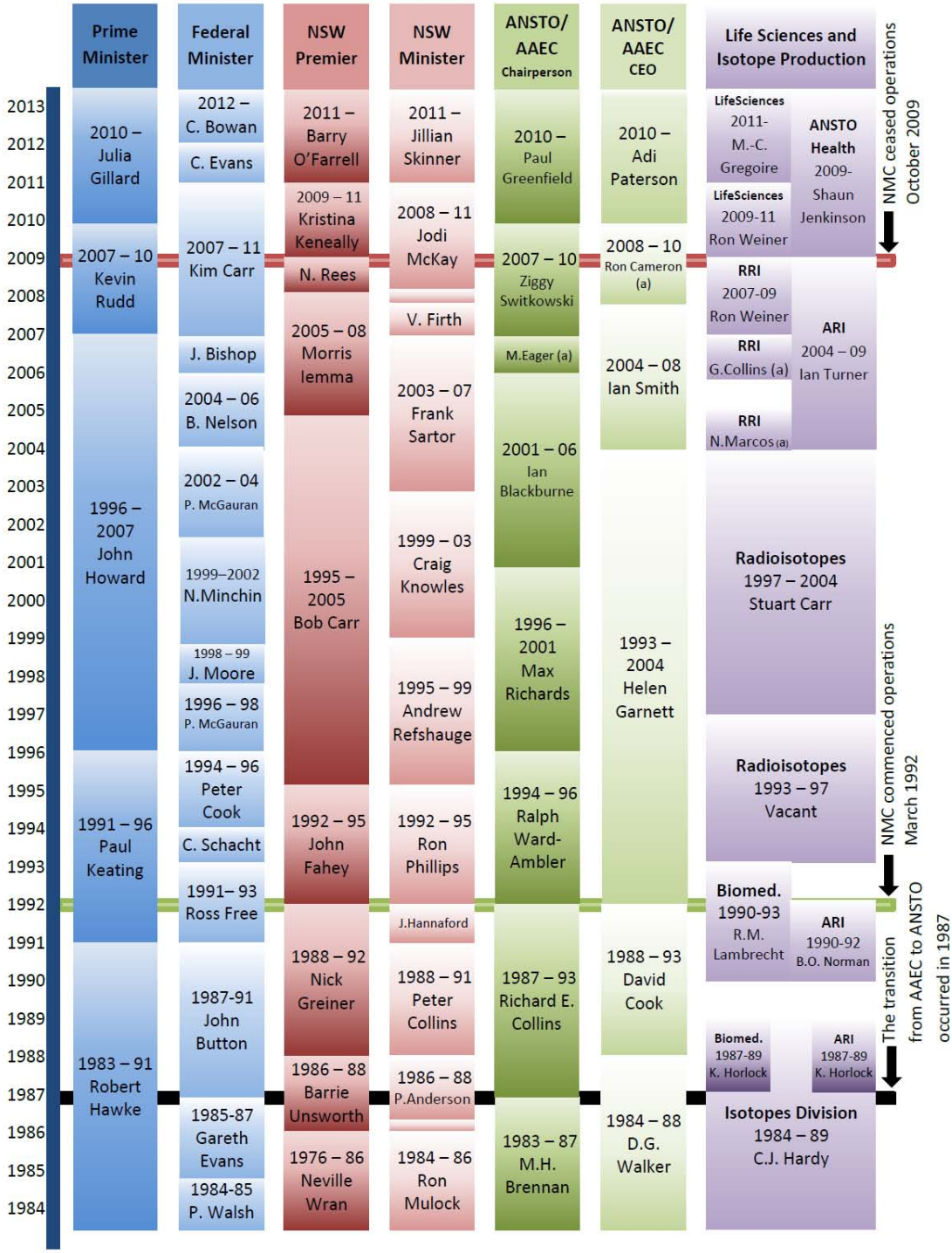

Figure 3: Federal, State and ANSTO leadership from 1984 until present. The development of the NMC and subsequently the national imaging facility cyclotron occurred against a backdrop of significant changes. It illustrates the degree to which the development of a large-scale infrastructure relies on persistent support from successive governments and stability in organisational priorities.

for Health endorsed the recommendations in principle, but was reluctant to release funds from within the Health portfolio. The Minister for Resources and Energy, as the Minister responsible for the AAEC at the time, committed to pursuing the project through the Resources and Energy portfolio, and announced the Cabinet decision to that effect in August 1986. Regardless of Cabinet's decision, the Austin Hospital forged ahead with its cyclotron plans and gaining funding.

The planning

As a dual use facility, the cyclotron's planned objectives were mixed. First, it was to produce radioisotopes on a commercial basis for distribution to nuclear medicine departments in hospitals throughout Australia for use in the clinical diagnosis of a wide variety of health conditions, and thus discontinue expensive imports. Reactor-produced radioisotopes (from the research reactor at AAEC) would complement the cyclotron-based radioisotope production. Second, the plan emphasised the production of very short-lived radioisotopes for use in a national positron emission tomography (PET) diagnostic and research centre associated with the cyclotron. Medical research studies at the PET centre were expected to improve understanding and treatment of many common medical conditions of high social cost, including, for example, industrial/occupational disorders.

Initial plans developed for the NMC, based on the AAEC's 1984 workshop submission, included multiple beam rooms, a radioactive component store, a briefing and conference room, and a display area, around the centrepiece – a 40 MeV cyclotron. However, capital costs had been significantly underestimated, and in February 1987, it was decided to review and amend the project. As a result, there would be only one beam room; production laboratory space was reduced by 30%; the area occupied by the two quality control laboratories was reduced by 35% and 40% respectively; the main store shrank by 20%; the conference room and display area were eliminated; and the number of hot cells for radiopharmaceutical production reduced from ten to five, and for PET from five to three. Most notably, the planned 40 MeV cyclotron was downgraded to 30 MeV, with the selection of a negative ion cyclotron in order to deliver an equivalent production output. Upon completion of the facility, the National Medical Cyclotron represented a $22 million investment in Australian nuclear medicine, double the initial 1985 estimated capital cost of $11.05 million.

Operating the National Medical Cyclotron

On 13 March 1992, the National Medical Cyclotron was opened by the Governor-General Bill Hayden (ANSTO 1992), achieving regulatory approval for the production of specific radioisotopes for medical use in late 1992; the facility produced 130 batches of F-18 and 30 batches of N-30 to the end of the 1992/93 financial year. At the end of the 1993/94 financial year, sales of Th-201 and Ga-67 represented more than one quarter of ANSTO's Australian Radioisotopes' (ARI) total sales. The vast majority of ARI's total demand for these isotopes was provided for by the NMC.

In keeping with its dual-purpose mandate, the NMC made contributions to research. Quantities of I-123 were produced and provided to researchers in Melbourne and Adelaide, and iodine was incorporated into several radiopharmaceuticals for use in clinical trials. However, there was an emerging perception that the facility was being under-utilised, partly as a result of the conflict

between its intended uses. In May 1994, a comprehensive review was undertaken with external consultants from Bain International Inc. and the Battelle Memorial Institute. The Bain & Battelle Review (Bain International 1994) recommended, inter alia, that management of the NMC be transferred to an organisation within the health and medical community, and that mechanisms be sought for spinning off the commercial activities of ARI and the ANSTO Biomedical Health Division as most of the biomedical and radiopharmaceutical activities being undertaken by ANSTO did not seem to fit within its ongoing activity mix. The potential challenges in running a dual-purpose cyclotron became apparent as the NMC at the time was commercially successful but was lacking in research activities, mainly due to the physical and perceived cultural separation of ANSTO from the health and medical community, and the apparently fragmented nature of the nuclear medicine community. During this critical review period, ANSTO's radioisotope leadership position remained vacant, see Figure 3.

After the 1994 review, the NMC continued to be managed by ANSTO throughout its operational life, under changing government and organisational leadership (Figure 3). Commercial and research radioisotope activities at ANSTO were formally separated in 2004. While commercial production was looked after by ARI, a newly created Radiopharmaceutical Research Institute (RRI) was tasked with developing ANSTO's research using medical isotopes (Figure 3). Notwithstanding this clearer separation of commercial from research activities, the NMC continued to provide mainly commercial radioisotopes and research output or support of research remained minimal.

Replacing the NMC

Ten years later, a major change in the way ANSTO would contribute to research using cyclotron-produced isotopes was signalled as the University of Sydney consolidated many of its clinical and basic neuroscience capabilities in 2004, with the opening of the Brain and Mind Research Institute (BMRI). The institute became home to The Ramaciotti Imaging Centre, a core facility for brain imaging research at the University of Sydney. Brain imaging and molecular imaging using radiotracers is an important tool in understanding the neurochemistry of the living brain. The University of Sydney's participation through the BMRI in the NCRIS was aimed at completing the infrastructure with a research-dedicated radiochemistry facility that would eventually lead to the development of a flagship instrument, the NIF cyclotron. A number of options were entertained, and the University tendered for a cyclotron operator with an operational model that would secure provision of C-11 and F-18 for research purposes. ANSTO submitted a proposal for an extended research partnership. Thus, in 2008, a year after funding from NCRIS had been awarded, an agreement was reached that ANSTO, with its knowledge and expertise of two decades of operating the NMC, would partner with the NIF to operate the new NIF cyclotron as well as undertake joint research with its university partners. With this agreement, an alternative was found to the loss of a unique and strategic inner city presence for ANSTO and the replication of existing infrastructure by the university. The NMC ceased operations in October 2009 (Figure 3). The new NIF cyclotron facility (see new hot cells in Figure 2B) was inaugurated by NSW Governor Professor Marie Bashir on 6 December 2011 (Figure 4), in the presence of the Vice-Chancellor of the University, Dr Michael Spence, and a large

gathering from all parts of the university, ANSTO and federal, state and local government. It thus became, in the words of the Vice-Chancellor at the earlier signing of a Memorandum of Understanding between the partners, one of those 'ritual moments'. It symbolised not only the long partnership of the University with ANSTO, but also a vision for a more integrated approach to science that crosses faculty boundaries and institutions.

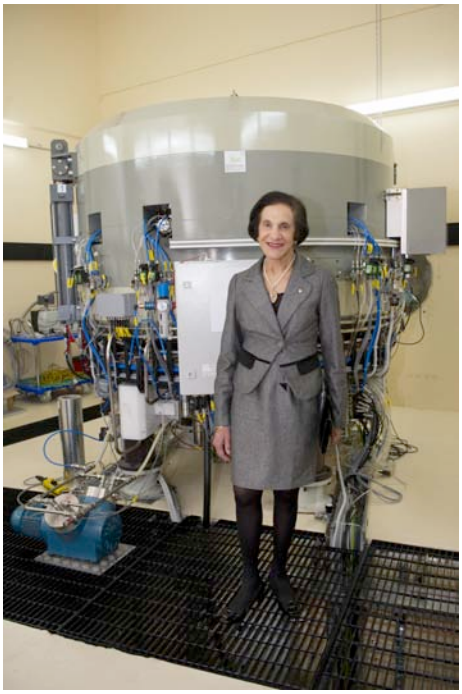

Figure 4: NSW Governor Professor Marie Bashir in front of the new cyclotron during the opening on 6 December 2011.

This outcome has fulfilled some of the predictions of the MCC (ADH 1985) and some of the recommendations of the Bain & Battelle Review (Bain International 1994) in regard to ANSTO's distance from the medical and health community. Counter to the thinking at the time, the field of life sciences today can no longer be seen as an ill fit within a nuclear science and technology organisation which only provided routine medical isotopes for nuclear medicine. The technical advances and conceptual maturation of the life sciences over the last twenty years now give nuclear science and technologies an indispensable role in probing the fundamental structure of living matter, be this by scattering techniques using neutrons or X-rays or by using isotopic techniques for tracing and tracking in complex biological systems from cells to biospheres. With the advent of systems biology and its many applications ranging from food production to nutrition to human health, the life sciences have begun to link more directly with the environmental sciences, for which dating and tracing by isotopic techniques has long been the approach of choice.

Different partners – different cultures

The overarching institutional partners, ANSTO and the University of Sydney, are both substantially publically funded. ANSTO has a defined mandate to maintain, apply and extend knowledge and capabilities in nuclear science and technology, whereas the University is a provider of to varying degrees research-led higher education. ANSTO has been organising itself around core nuclear science and technology capabilities, for which it maintains large research infrastructure. The University aspires to be the home of well-rounded academics striving for research excellence and supporting teaching. Notwithstanding that many differences are only by degree, ANSTO's organisational model gravitates towards teams often structured along technical skills or scientific instruments, while the University model promotes scholarly, usually individual, success. Therein, however, lies a contemporary dilemma. How can individualised activity match challenges that require a collective effort, and how can technical skills-centred capability be recruited

into the creative and innovative process by which those challenges are to be met?

The partnership between the University of Sydney and ANSTO has grown out of the interaction of two recently formed organisational units: the BMRI and ANSTO LifeSciences. While the BMRI is driven by a broader societal demand for knowledge-based improvements in mental health, a task for which it recruits material and intellectual support across faculties and institutions, ANSTO LifeSciences has changed its model from service provision and facility operations to active engagement in partnerships focused on solving specific problems.

Below we present some of the governance approaches and human aspects that have come to the fore in the partnership.

Open access and integration

Partnerships are not only intended to build shared physical infrastructure, but also to create social capital for the individual employee and increase performance of the partnering organisations (Andrews 2010). In science and technology, in particular, most advances now rely on having access to networks of knowledge (Wagner 2008).

The partnership between ANSTO and the BMRI and the wider network of the NIF is an example of a local network nested in a wider national and international network in which the scientific and technological capabilities can no longer be provided by a single institution. This nested structure reflects the funding model under which investments come from various bodies, such as the Ramaciotti Foundation, University of Sydney, ANSTO and Federal and State government departments, see also Figure 1. Government can either directly fund new initiatives, or participate in a leveraged co-funding scheme, such as the NSW Science Leverage Funding mechanism. Such multi-stakeholder engagement is particularly common in the life sciences. According to a recent study by the OECD, the interdisciplinary nature of the life sciences and the specific technological, economic and industrial environment of the medical and health sector foster multi-stakeholder engagements that create knowledge networks as a means to identify new markets (OECD 2012).

One of the challenges is to ensure open access to the research infrastructures. Access policies need to enable high quality research and good use of the facilities, as well as a diverse range of projects. The schematic in Figure 5 shows the process by which access can be organised and has been adopted by the ANSTO-BMRI-NIF partnership. An analysis of the publication output under NIF showed that the University of Sydney-ANSTO NIF node doubled its yearly output to more than 50 peer-reviewed papers in 2011, i.e. prior to the new cyclotron becoming operational (NIF 2013). This illustrates the general growth in the interdisciplinary field of molecular imaging. The data on research output since the new cyclotron was commissioned (December 2012) are not yet available.

In multi-stakeholder research facilities, there is a constant need to reconcile the different priority amongst the partners, who may cater to different research communities. At the Camperdown facilities there are a series of different access routes: either via NIF, ANSTO, or the BMRI. The partners have created formal open access portals as a way to 'democratise' access to the research infrastructure, taking account of their different foci.

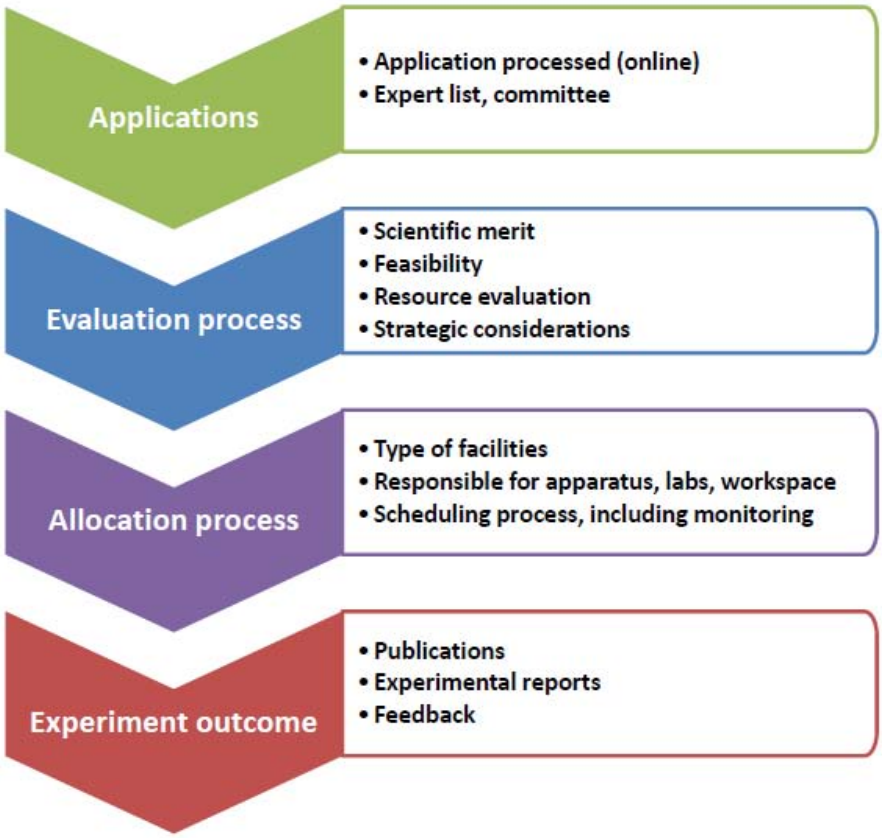

Figure 5: Schematic access scheme for use of the facilities: Applications are reviewed by experts and if successful the experiments are scheduled coordinating the experimental requirements with availability of facilities and people. Experimental outcomes are captured in the academic literature or in annual reports.

Although there are different access routes, all partners have incorporated a review procedure by experts who evaluate the proposals on scientific merit and feasibility, resource availability as well as strategic considerations. The allocation process includes monitoring throughout the project.

The ANSTO-BMRI-NIF platform provides access to a dedicated research cyclotron and radiochemistry capability that includes the development of either already validated or new radiopharmaceuticals at the ANSTO Camperdown facility that, in the case of short-lived radioisotopes, are deployed to the nearby imaging laboratories at the BMRI. These laboratories are equipped with multi-modality preclinical and clinical scanners that use the molecular probes to measure specific biological functions related to disease. In addition, a high performance computing platform provides advanced imaging analysis and modelling.

While ANSTO LifeSciences, BMRI and the NIF have expertise in the areas described, the important added value from this partnership, such as the transfer of knowledge in radiochemistry, imaging data acquisition, data analysis, radiolabelling, and animal models of disease, comes through collaborations with domestic and international scientists, i.e. the respective peer networks of each partner. What in fact emerges is a collective system of knowledge creation, transfer and application.

Varied research groups with a defined focus, such as the ANSTO-BMRI-NIF collaboration, are vital for innovative approaches in life sciences, as pointed out in the OECD paper on 'knowledge networks and markets in life sciences' (OECD 2012). This has been recognised by recent strategic reviews into health and medical research in Australia, i.e. the McKeon review (Ministry for Health 2013) and the Wills review by the state government of New South Wales (NSW Ministry of Health 2012). Both emphasise that the current publicly funded research effort is in need of a better integration between fundamental health and medical research if improved health outcomes and economic benefits are to be realised. It remains to be seen how these calls will influence the existing institutional structures, notably the faculties and disciplines in the higher education sector, and how their epistemological traditions and business models will develop. In any case, the NSW review echoed the international experience that the two major elements of publicly funded research, namely world-class research infrastructure and translation of research into applications, require systematic incentives to build partnerships, which implies the active removal of intra- and inter-institutional barriers. The reviews also acknowledge that the approach has to be long-term, since research impact can be assessed only after a lengthy period of time; "Studies suggests that it takes an average 17 years for research evidence to reach clinical practice" (Balas 2000).

Although the driving force of a network may often be only a small core group of researchers, the broader networking activity promotes learning through more diverse feedback and a 'collective intelligence' that enables better decision making. In regard to this aspect of social capital, Malone (Malone 2012) identified essentially three factors that determined the success of a 'collectively intelligent' group:

- the average social perceptiveness of the group members. The higher the individual ability of participants to read other people's emotions, the more collectively intelligent the group;
- the evenness of conversational turn taking. Groups where one person dominated the conversation were, on average, less intelligent than groups where the speaking was more evenly distributed among the different group members; and
- a good gender balance, whereby a high percentage of women resulted in a greater social perceptiveness effect.

A glance at the senior management involved in the ANSTO – BMRI partnership shows that at the time of writing two out of five are women, most are scientists (albeit from different fields) and most have lived or come from abroad.

Partnership between ANSTO and BMRI

A formal Research Collaboration Agreement defines the principles of the collaboration of the partnership. The day-to-day activities of the ANSTO – BMRI partnership lay in the

hands of two committees: the Steering Committee and the Operations Committee. Whereas the Steering Committee develops the strategic objectives related to research as well as communications and outreach activities, the Operations Committee assesses and schedules all research projects that require access to the facilities and is also responsible for establishing and implementing policies and procedures for the operation of the facilities, including training, maintenance and similar (BMRI 2013). In addition, each partner has their own formal reviews with external assessment that evaluate the outcome of the collaboration.

A general perspective on the workings of inter-organisational networks has recently been given by Gardet and Modet (Gardet 2011) who undertook case studies of innovation networks and their various mechanism of coordination. Their research showed that the following mechanisms advance projects in innovation networks:

- an equitable division of outcomes when outcomes were agreed 'ex ante' decreases the risk of opportunism and thus equity distribution advances the project;
- trust complements formal mechanism; relying on trust in competences is more beneficial than relying on goodwill;
- guarantees should include not only finances, but also special assets and brand image;
- the use of another network member as an arbitrator can facilitate conflict resolutions.

Although robust coordination mechanisms are vital in setting up networks, it is finally human factors, such as a high level of staff and user satisfaction that makes a partnership function well (Andrews 2010). Choi and Pak (2007) discuss the promoters, barriers and strategies that enhance multi-, inter- and trans-disciplinarity. The processes they identified for creating synergies amongst team members are the 'fourteen Cs of teamwork': Communication, Cooperation, Cohesiveness, Commitment, Collaboration, Confronts problem directly, Coordination of efforts, Conflict management, Consensus decision making, Caring, Consistency, Contribution, as well as Corporate support and Chemistry (personality) (Choi 2007, Wiecha 2004), but they also point out a number of barriers that need to be reduced in order to progress a network. In our experience, it is particularly important to remove barriers due to differences in organisational processes and culture. These include (i) differences in processes, such as budgeting and accounting; (ii) differences in institutional jargon; and (iii) differences in the direct influence that top management may or may not exert on the directions of the partnering groups. Ongoing efforts are necessary to provide (i) continuous opportunities for get-togethers to foster and renew engagement in the collaboration; (ii) regular reviews of the impact of the work undertaken and the measures of impact; as well as (iii) careful measures that ensure fair and continued project ownership in order to maintain the motivation to translate research achievements into shared outcomes.

In summary, networks require continual negotiation of differences in order to advance research. In this context, early career development and mobility is another aspect where networks play an important role. Large networks offer inherently better opportunities for workforce mobility, which is a particularly strong motivator for researchers, who move abroad not only for advancing their career, but also for the exchange of ideas and broadening their knowledge (Baruffaldi 2012). In the final part of our paper, we, therefore, look at some of

the training and educational aspects of the partnership.

Education and training

Education and training, is generally provided in the context of defined disciplines. However, molecular imaging is interdisciplinary. It has been pointed out (Bammer 2013) that in order to strengthen interdisciplinary practice and capacity, a re-think and co-ordinated activity would be required. This would include developing agreed frameworks, compiling and classifying what we already know and turning isolated individuals and groups into co-ordinated networks of peers and potentially new disciplines.

Molecular imaging is strongly interdisciplinary with multiple overlapping engagements, as illustrated in Figure 6. Thus, skill acquisition in molecular imaging is complex and needs to be supported by a range of different educational providers, including vocational and tertiary education institutions as well as professional associations and interest groups.

In molecular imaging, we see thus "a team composed of members of a number of different professions cooperating across

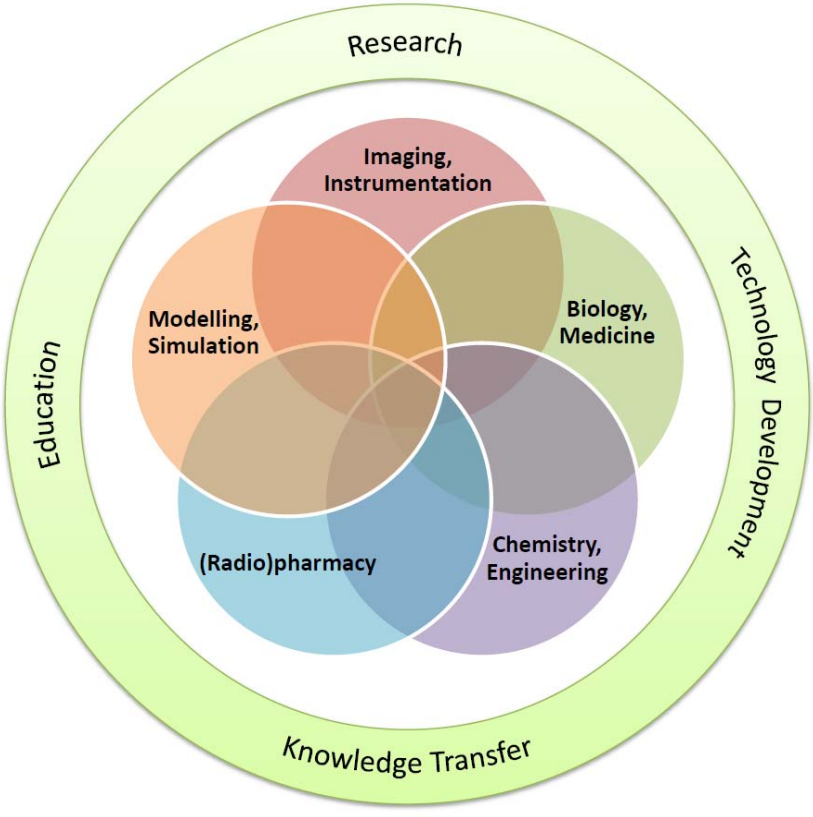

Figure 6: The scheme illustrates the interdisciplinarity in molecular imaging and the broad set of skills that education and training needs to provide (modified from (Grimm 2013) and (BME 2013)).

disciplines to improve patient care through practice or research" (Choi 2006). In the process, discipline boundaries are crossed and developments in one discipline are transformed into the new concepts of another: science has become transdisciplinary. Since the degree to which disciplinary boundaries are crossed or convergence of disciplines is seen as advantageous varies along a continuum, Choi and Pak (Choi 2006) have also proposed the term 'multiple disciplinary'. Indeed, the educational activities in molecular imaging retain elements seen as foundational to a discipline, as well as elements that cross disciplines.

At present, the educational opportunities in molecular imaging include a Master of Molecular Imaging (Master Molecular Imaging 2013) jointly offered by several university partners, as well as vocational training through a professional development program 'Foundations of PET-CT' (Foundations of PET-CT 2013) and a distance-assisted training (DAT 2013) for Nuclear Medicine Professionals (sponsored by the International Atomic Energy Agency – IAEA). The need for collaboration in this area is underlined by the structure of the programmes: the Master's course is a collaboration between three universities – University of Sydney, University of Queensland and University of Singapore; and the vocational training is a combination of distance-learning and hands-on experience, with the practical activities taking place in different locations in Australia. The Master's programme, as well as the professional development training, makes extensive use of on-line modules. Recent studies into the future of learning emphasise that massive open on-line courses, MOOCs, (Austrade 2013) together with the democratisation of knowledge will constitute an important role in the educational sector and is predicted to transform universities of the future (Ernst & Young 2012). While theoretical knowledge can be provided through online technologies, experiential hands-on learning will remain a fundamental part of the educational activities in molecular imaging.

As the boundaries between research fields dwindle, transferable skills become increasingly important for the employability of researchers. A recent OECD study (OECD 2012a) reviews the current landscape for researcher training: "An Australian study identified communication, teamwork, and planning and organisational skills as areas for improvements." However, the OECD study points out that there are many understandings of transferable skills, including enterprise skills and cognitive abilities. The OECD report also notes:

"In 2006, only 26% of doctorate holders in Australia were employed as university and vocational education teachers, and only 28% of recent doctorate holders in 2008 were employed in higher education [Commonwealth of Australia, 2011, p. 22]. The rest had found employment in a wide range of other public and private sectors. United States data show that most PhDs work in service occupations, generally professional, scientific and technical services, or in government [Wendler et al., 2010, p. 19]. The share differs by field; PhD recipients in engineering and physical sciences are much more likely to work outside academia than those in social sciences and humanities."

The special attraction of multidisciplinary settings is that they give exposure to different thinking and working styles, and thus support the development of student and workforce attributes that emphasise the importance of problem solving using a broader range of approaches. To the degree that multi- or

trans-disciplinary work is becoming the norm, foundational skills, such as mathematics, physics and chemistry become rather more than less important. It is in this context that nuclear science and technology, with its far reaching utility across many disciplines, is particularly suited to providing a wide range of transferable skills.

Conclusions

We have described the emergence of an inter-institutional partnership that is nested in a network of relationships reflecting different agendas, infrastructure and funding streams. Though both institutional partners are largely publicly funded, they come from different organisational traditions, one being a higher education institution, the other a publicly funded research agency with a specific science and technology mandate.

The Commonwealth's 2006 National Collaborative Research Infrastructure Strategy (NCRIS) was a multi-level national, state and institutional funding mechanism aimed at creating shared infrastructure and capacity while unlocking existing institutional research infrastructure and encouraging new partnerships. As an infrastructure program, it did not prescribe specific scientific content areas.

The ANSTO-BMRI-NIF partnership played out against the backdrop of organisational renewal in both partner institutions. While the BMRI extended the existing university faculty model towards an integrated, mission-oriented research, teaching and social engagement model (centred on mental health priorities), ANSTO broadened the mandate of its research into medical radioisotope activities by forming ANSTO LifeSciences. The latter opened up its infrastructure and associated specific skills for mission-oriented research and thus went beyond a narrower service and technology provider role.

The described partnership has thus sprung from transformational changes within the partner organisations. Both the university as well as ANSTO remain under constraints imposed through their respective funding and business models. Therefore, future management and policy makers at the level of Commonwealth, State and the institution will need to continue to remove inter-institutional barriers, systematically build trust, retain open access, jointly develop educational and career pathways and new research agendas.

From the perspective of a policy maker, our observations suggest that the benefits of public funding are enhanced if directly tied to incentives for partnerships without being over-prescriptive in regard to operational specifics on the ground.

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