2016 National Research Infrastructure Roadmap
Capability Issues Paper

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The Australian Nuclear Science and Technology Organisation (ANSTO) is one of Australia's largest public research organisations and operator of Australia's only nuclear based businesses that support a range of industry sectors. ANSTO's core mission is to conduct research and development in relation to nuclear science and technology for the benefit of Australia.

A feature that distinguishes ANSTO from other research organisations is the scale of key Australian landmark and national research infrastructure ('NRI'). ANSTO owns and operates a range of globally competitive research infrastructure platforms that are used by more than 5,000 Australian and international researchers annually.

These platforms include the Australian Synchrotron, the Australian Centre for Neutron Scattering, the OPAL Research Reactor, and the Centre for Accelerator Science and the National Deuteration Facility. ANSTO's nuclear science and technology capabilities provide users with to access to enable materials development, synthesis and characterisation, isotope tracing in natural systems, radiotracer and radiochemistry development, radiobiology and bioimaging, environmental impact, standards and metrology.

ANSTO's NRI supports Australian industry through collaborations and proprietary arrangements. Access to instrumentation and expertise provides industry with powerful insights, inventions, improvements and innovations that, in turn, stimulate the Australian economy.

Maximising utilisation, continuous improvement and predictable operation of infrastructure, together with developing highly expert staff who are focused on research support, is of crucial importance to enable research infrastructure to strengthen the science and technology standing of the nation. With a long and successful track record of enabling science and technology through the operation of landmark and national research infrastructure in Australia, ANSTO has a strong capacity to inform and support long-range planning for future landmark and national capabilities. This frames this submission to the 2016 National Research Infrastructure Roadmap Capability Issues Paper ('Issues Paper').

Question 1: Are there other capability areas that should be considered?

The capability areas covered in the Issues Paper are broadly aligned with the National Science and Research priorities, some areas of importance have not been clearly differentiated. Planning of NRI capabilities that position Australia as a global leader in science and technology would be enhanced by considering separate and additional capabilities in the areas of:

- Sustaining food and agriculture industries;
- Low carbon energy
- Resources - enhanced exploration and benefits realisation; and
- Climate variability and mitigation of climate change impact.

The science disciplines included in the Issues Paper underpin a range of national science and research priorities. However there is a concern that the current grouping of the capability described as 'Advanced Physics, Chemistry, Mathematics and Materials' may be too broad to adequately inform sufficient planning of future capability. Recognising that science and innovation today is enabled by a multidisciplinary portfolio of capabilities that enable national leadership and international engagement, an alternative categorisation of these capabilities is proposed as follows:

- Fundamental physics, cosmology and space science;
- Advanced manufacturing, materials science and engineering; and
- Sustainability through novel chemistry and synthetic biology.

It is recognised that the Issues paper itself will not be further refined. The intention in making this proposal is that the community develops a longer term and more inclusive description of capability areas that can be used over a number of future roadmaps.

Question 2: Are these governance characteristics appropriate and are there other factors that should be considered for optimal governance for national research infrastructure.

Landmark infrastructure usually operates in publically funded research agencies (PFRAs) or is operated by PFRAs. National scale infrastructure can be found in PFRAs and in universities and collaborating institutional arrangements. The variety of these arrangements could be reviewed and codified into a set of best practice in governance principles in order to achieve optimal governance for NRI.

Key dimensions for an optimal governance model should include responsibility for access policy, strategic planning (including whole-of-life), measures and indicators of performance and user-experience, risk and finance. Additional characteristics to consider include: user satisfaction and feedback; industry engagement and business development; standards accreditation as well as international engagement (including the role of external national or international experts in advisory capacities).

ANSTO proposes a set of guidelines be formulated which would be informed by successful and contemporary governance structures. This would provide existing, as well as emerging and new, NRI actors with a framework to operate effectively for the benefit of user communities and the nation.

- In any governance model, the costs of effective governance, leadership and management of NRI must be considered and funded within the infrastructure funding programs;

- Governance bodies must have the ability to make substantive decisions that have the ability to affect resource allocation and benefits realisation;
- Strategic planning for periods in the range 5-10 years is important, with annual business plans or 24-month rolling forecasts driving actions to achieve overarching objectives and capture or manage shorter term opportunities or unplanned barriers;
- In accordance with established governance principles, the structure providing governance should remain separate to facility operations and management.

At the level of the overall strategy for NRI, it is essential that there is a clear timetable for strategic reviews and future strategy development. It is challenging for individual national facilities to operate in an environment where the predictability of reviews and forward looking strategies is low and where it is not clear what requirements are being set for future resource allocations. It is important therefore that at a minimum, a five-year cycle is considered for strategy reviews, and in general, a decadal forward plan developed and resourced over the same period.

At the level of individual facilities and consortia, reporting and compliance obligations should remain reasonable and in line with annual reporting practice or a 24 month rolling forecast. Mid-term reviews of performance and operations against strategic plans are critical to ensure capabilities are aligned to priorities and best-practice operation is maintained.

Question 3: Should national research infrastructure investment assist with access to international facilities?

ANSTO agrees that NRI funding should assist with access to international facilities, and that there is a strong need for a broad- based program to be re-established, as was the case when the Access to Major Research Facilities program, which was funded by government and administered by ANSTO, was in place.

In terms of the initial build of beamlines at the Australian Synchrotron, the Synchrotron secured $50M via 10 institutional and consortium funders who each contributed $5M. The 2006 NCRIS Roadmap then contributed $13.9M (exactly 20% of the capital cost of the initial suite of beamlines) to complement the $50M. Included in this spend was $10M for phase 1 of the Imaging and Medical Beamline (IMBL), which included an additional grant from the Victorian Government for $1.5M. In addition to the capital program, the 2006 NCRIS Roadmap funded an international access program for Australian researchers to access overseas synchrotrons with capabilities not available at the Australian Synchrotron, called the Australian Synchrotron Research Program ($3.6M).

Consistent with this model, there is demand from Australian users of neutron scattering capabilities to access neutron beam instruments which are not currently available in Australia. There is high value in developing cohorts of users who are exposed to international facilities, as it would provide an opportunity to include further development for our landmark facilities based on clearly articulated user requirements.

It is therefore proposed that the Australian Synchrotron Research Program model be generalised to an Australian Scattering Sciences International Access Program. This would coordinate and fund user access to synchrotron facilities, neutron beam scattering facilities and specialised electron microscopes not currently available to the Australian research community.

Australia's ability to engage with these global groups comes by virtue of expertise and credibility gained in operation of its current facilities. An example of this is the operation of the OPAL research reactor. The recognition of the OPAL research reactor as one of the leading multi-purpose research reactors in the world has opened many doors for Australia internationally. In particular, it facilitates Australia's engagement with the International Atomic Energy Agency (IAEA), particularly in nuclear technology and technical cooperation (which has spin-off national security benefits for Australia), and has supported Australia in joining international forums such as the Generation IV International Forum (GIF) – a forum on advanced nuclear technologies. Australia's success in gaining membership was based on ANSTO's ability to contribute to the GIF's research and innovation goals using its landmark research infrastructure and world-class research capabilities.

Programs where international engagement with global projects is critical include those related to nuclear, particle and high-energy physics, including but not limited to CERN (particle physics) and ITER (nuclear fusion and high energy physics). ANSTO maintains Australia's relationships with CERN and ITER on behalf of the Australian Government and the Australian research community.

Question 4: What are the conditions or scenarios where access to international facilities should be prioritised over developing national facilities?

Prioritisation of investment in access to international facilities over development of national capability can be guided by the following principles:

- ***Geography & affordability*** – Some facilities require access to a specific geographical location. This leads nations to collaborate to build global research infrastructure (GRI). In such cases, it is attractive for Australia to have access to an international facility that leverages investment by other countries. In other cases, geography is less important but the volume of Australian demand does not justify a national facility – for example in particle physics facilities, some space programs, free electron lasers and spallation neutron sources.
- ***National interest alignment***: experiments and research at international facilities are aligned with Australian research priorities;
- ***Retaining Australian research leadership***: Quality, size and impact of any group or user community needing international facility access;
- ***Industry benefit***: key enabling capability that provides tangible benefit to Australian researchers and emerging new innovation and industries;
  Training and development: will the access help to build competency by training young researchers, reputation, increased networks and collaboration beyond the direct access or single set of experiments that is intended to leverage and accelerate the establishment of national capability.

Question 5: Should research workforce skills be considered a research infrastructure issue?

At the landmark infrastructure level, Australia can develop globally relevant and distinctive workforce skills in the operation of such facilities and in the development of university-based and industry-based research collaborators who become "super-users" and, in some cases, instrument developers and innovators. Landmark infrastructure tends to amplify specialised technical skills that are also highly attractive in sectors such as IT, defence, and specialised engineering industries.

Technical and scientific research support staff within ANSTO's NRI currently provide training to PhD students, post-doctoral fellows and early career researchers. They assist in developing novel approaches to research and link communities of researchers who meet at their facilities. For these reasons, it is essential that ongoing skill and expertise development of the technical and scientific research support staff is recognised as a core activity of NRI investment.

Question 6: How can national research infrastructure assist in training and skills development?

NRI enables training and skills development in a variety of ways.

Research Training of Users

As discussed in the response to Q5 above, research infrastructure, particularly characterisation capability, has an enabling role in the training of a research workforce. This is achieved through the training required to operate instruments confidently and competently, as well as related skills in experimental design, application of techniques, sample selection and data analysis. Facilities can provide this training through a range of channels:

- Pre-access reading and on-line training tools;
- Blended learning (combination of face-to-face, on-line tools and hands-on);
- One-on-one training sessions on instrumentation; and
- Group training: training courses and practical application based workshops or specialist masterclasses.

Training activities are essential to enable the full potential of the infrastructure to be realised and therefore need to be resourced and funded appropriately. Whilst specialist technical and scientific research support staff practically impart training, other costs associated with training need to be included in project planning. These include costs of running courses, the need to fund access to facilities for hands-on elements of the training, and development of resources.

Recently the development of on-line training tools for characterisation- rich research infrastructure facilities, such as MyScope™ (Australian Microscopy & Microanalysis Research Facility), has demonstrated efficiency gains with improved training outcomes. These tools support a blended learning mode of training, linking on-line content with hands- on experience. These tools can also offer virtual instruments to enable researchers to develop skills and competency that can be assessed before accessing actual instrumentation. Further investment in these tools and resources should be considered a part of research infrastructure programs in the future.

Training of Research Infrastructure Staff

Skill and expertise development of the technical and scientific research support staff within research infrastructure is a core activity of research infrastructure investment. This training may be undertaken wholly within the infrastructure or in collaboration with education providers.

In the establishment of new facilities, specialist expertise may need to be recruited from overseas. However, longer term sustainable operation, at a world-competitive level, requires building up a cohort of local expertise.

Existing infrastructure provides the training ground for future infrastructure projects. For example, a future hadron (particle) therapy facility (including a research activity) will need skills in accelerator science for its successful implementation. ANSTO is one of only three major accelerator installations in Australia with the technical skills and knowledge to develop and maintain operations such as high voltages, radiofrequency, magnetism and vacuum systems.

More broadly, complex and technically intensive research infrastructure contributes to the practical training and establishment of a work force of technical specialists who have skills applicable across multiple sectors. While the intention is to retain these cohorts of expertise to ensure sustainable operation of the infrastructure, it is recognised that opportunities arise within other emerging industries and that skills developed are transferrable. For example, megavolt accelerators and scientific beam lines require unique engineering and technical skills, including high-voltage and high-vacuum engineering, electronic control systems, computer and software engineering and precision mechanical engineering. In the case of nuclear facilities, operating a reactor or a medical cyclotron require high-level radiation and safety skills, as well as nuclear physics and engineering capabilities.

NRI operators could also consider the option of becoming a Registered Training Organisation (RTO) to enable wider work force training of technical specialists. This role could be further enhanced through the establishment of dedicated “education precincts” at national facilities where staff can offer specialist courses as a result of the expertise and experience developed within the facilities. ANSTO is developing a proposal for an Innovation Precinct which will be home to ANSTO’s proposed Graduate Institute, a nuclear science and technology innovation hub and a broader innovation and technology park. The Precinct would bring together scientific partners and businesses to provide a unique environment with opportunities to embrace world class expertise, teaching, research and industry-ready graduates in one location. The aim is to establish a global scale nuclear science and technology centre to train and develop future-scientists, engineers and technologists, fostering innovation with emerging technologically astute experts in an ‘ecosystem’ that is attractive to industrial users.

Question 7: What responsibility should research institutions have in supporting the development of infrastructure ready researchers and technical specialists?

Universities and research institutions are well positioned to support the development of infrastructure ready researchers and technical specialists for the operation of facilities. In the context of collaborative NRI, many university-based core facilities are partners in national infrastructure networks, which means that the integration of research training and facility operations is very closely aligned.

For NRI that is not comprised of university or research institute collaborators, partnerships with education providers that will support career path development can be formed. Activities under such partnerships may include infrastructure staff teaching undergraduate and post graduate courses, and in winter and summer schools. Broader interaction between infrastructure staff and universities should also be encouraged. Under these partnerships, post-graduate students and early career researchers can be incentivised to undertake research training or other career path development within NRI facilities.

By way of example, there is a strong need to develop a collaborative and co-ordinated national radiochemistry training program so that investments in radioisotope/PET tracer development and production, toxicology and dosimetry studies and imaging can be fully realised. The training would take place in a national network of facilities including ANSTO, NCRIS-funded and hospital-based facilities and commercial radiotracer providers, thus offering a diverse range of training experiences career development opportunities and a high quality training environment for suitably qualified scientists.

Question 8: What principles should be applied for access to national research infrastructure, and are there situations when these should not apply?

A broad range of access principles is needed to drive utilisation of the assets for the benefit of the innovation system more widely. It is recognised that a single access policy relevant to all infrastructure projects is not appropriate and that full cost-recovery models are not feasible. Providing financial support for travel and accommodation to users of NRI is key to ensuring optimum utilisation, particularly in the case of landmark infrastructure which is not broadly distributed geographically in Australia.

Relevant access principles that can be applied include:

- ***Merit based - no fee:*** national funding provides national access. This usually applies to landmark level facilities due to the very high incremental costs of access. In some cases for landmark infrastructure, the regulatory regime dictates, for example, that experimental environments have to meet stringent requirements, making it impractical for users to develop these themselves.
- ***Merit based - partial cost recovery:*** This could apply to smaller scale facilities or highly distributed facilities where the incremental and marginal costs are fundable within the ARC and other grant funding envelopes.
- ***National interest programs of research*** – this includes:
    - Longitudinal research programs that require dedicated facility access
    - Risk mitigation such as biosecurity or cybersecurity
    - Ensuring the maintenance of Australia-specific capabilities, particularly related to our oceans, specific flora and fauna and related opportunities for resource utilisation
    - Health and well-being of our population
- Facility-directed ***discretionary access*** for facility strategic purposes.
- ***Access by international researchers***:-
    - may enable reciprocal access rights for the benefit of Australian researchers
    - demonstrates world-leading capability of Australian facilities and positions Australia as a strategic research partner
    - creates new and extends existing international research collaborations
- ***Commercial*** - differential fee schedule for industry.
    - Full cost recovery for large and established industry, but lower rates for SME's or start-ups so as to encourage use of facilities.
    - Commonwealth-funded access scheme - ANSTO strongly supports the establishment of a Commonwealth-funded access scheme for small and medium

enterprises and start-ups. The scheme should have simple rules for access, and should be operated for a significant period to ensure that it becomes pervasive and accessible in the sector. It should be reviewed on the same cycle as Government reviews of NRI programs.

- ***Co-investment*** – access as a result of co-funding of beam lines, instruments or staff. This may be through the provision of capital or operating funds. However, access agreements should not lead to exclusive use of or access to capability.

Question 9: What should the criteria and funding arrangements for defunding or decommissioning look like?

All NRI should be established with a clear funding horizon. There are a range of factors that can be considered during a review of NRI that may eventually result in the cessation of funding or 'defunding' of infrastructure. It is recognised that a decision to no longer fund a NRI facility may not imply the capability is redundant or cannot be used. In many situations it will relate to the transition of the infrastructure to a local or institutional model; funding may be required to enable that transition to take place.

A decision to no longer operate a facility as NRI should be reached in the context of the overall governance of the facility and realised during medium-to-long term reviews of the facility against strategic plans. Criteria to be considered include:

- Operating capability no longer aligned to national research priorities;
- Instrument base, that once provided one-of-a-kind, leading-edge capability has become mainstream, and cost to acquire and operate has reduced;
- Practical working life of asset(s) has been reached;
- Level of funding and value of infrastructure is within the realm of an individual institution to manage;
- Costs of maintain safe and best practice 'state-of-the-art' operation is greater than the cost of new or next-generation capability, aligned to revised research priorities and the needs of users
- Inability to maintain support for the required access models; and
- Poor performance measures, with the facility not meeting key performance indicators as recognised by national and international benchmarks and standards.

For nuclear facilities, the word 'decommissioning' has a particular meaning related to international accounting standards. It is therefore a requirement that ANSTO has fully developed decommissioning plans for its facilities at all stages of their operations and estimates the financial requirements for decommissioning. These are independently audited annually and form part of the statutory accounts of ANSTO. ANSTO therefore does not use the term "decommissioning" in a colloquial way. It is important for Government to ensure that provision for decommissioning in nuclear facilities is made at the institutional level or is accounted for in full in the national accounts.

Question 10: What financing models should the Government consider to support investment in national research infrastructure?

Long-term operation of NRI needs whole-of-life planning. Landmark infrastructure is typically multi-disciplinary and multi-decadal. Therefore, the lifecycles of landmark infrastructure, such as the OPAL reactor and the Australian Synchrotron cannot be planned for within the framework of national research infrastructure at the decadal level, i.e. for reactors or accelerators. However, planning for landmark infrastructure within the decadal framework can provide high leverage through incremental investments in beamlines (for instance at the Australian Synchrotron and the OPAL reactor), specialised experimental environments and the like.

ANSTO also operates national research infrastructure. ANSTO institutionally co-invests in decadal-scale investments, or participates in assembling consortia of users to make appropriate submissions for funding associated with the roadmap process.

ANSTO believes that the bulk of costs for landmark and national infrastructure will need to continue to be funded by the Commonwealth and State governments. This is due to the distributed nature of the returns for investment and the national benefits that accrue in human capital development, knowledge capture in our society and innovation in industry, healthcare and future sustainability of our society. ANSTO has contributed to establishing a set of principles which are embodied in the PFRA submission to the Issues Paper. In relation to that submission, it is important to recognise the very specific nature of decommissioning funding required by ANSTO (see Q9 above).

ANSTO has an integrated asset management framework consistent with ISO55000. ANSTO has a number of particular challenges in this regard. The first is legacy maintenance. ANSTO's Lucas Heights site has significant future costs to ensure that the site meets the minimum requirements of the Australian Building Code. These costs are over and above requirements for funding in landmark and national research infrastructure. Secondly, ANSTO is required to manage facilities within the framework of nuclear licensing. This includes long-term management of radioactive waste facilities and eventual decommissioning. These costs are separate to and over and above the direct costs of operating landmark or NRI.

ANSTO receives what is termed by Government "depreciation funding", which is funding provided for the ongoing asset management of its major facilities and sites. Therefore, ANSTO does not make provision through this current funding for the replacement of the OPAL reactor, for example. ANSTO believes that a carefully developed process is needed to clarify the different elements of financing and the requirements of modern asset management for all infrastructure classes. Although challenging, this will add considerable certainty for the operators of landmark and national infrastructure and should therefore be considered as a priority - but separate to the national roadmap process.

Question 11: When should capabilities be expected to address standard and accreditation requirements?

There are several circumstances in which capabilities should plan to obtain standard accreditations and other regulatory approvals:

- If they are relevant to medical and health research including the development and production of compounds, tracers, or protocols products for human trials.;
- If the facilities undertake significant industry engagement with large companies, SMEs and start-ups. Industry can use the accredited facilities and does not need to obtain their own.
- Accreditation may make the capability more attractive to industry e.g. for facilities producing products or assisting translation of technology into production;
- Significant value is added to the quality of outputs e.g. ensuring regional (international) or world competiveness;
- Where it is required to assure quality of services/capability provided to the Australian science and technology community.

Infrastructure plans need to take into account the cost of achieving and maintaining regulatory or standards accreditation. These costs should be included in the infrastructure funding model.

Health and Medical Sciences

Question 15: Are the identified emerging directions and research infrastructure capabilities for Health and Medical Sciences right? Are there any missing or additional needed?

ANSTO operates a variety of NRI that supports health and medical research, translation and clinical application. ANSTO enables research from the molecular and cellular level through to the organelle, small animal and eventually the whole body, in a clinical setting. Capabilities include neutron and X-ray scattering, and molecular deuteration facilities that enable structural biology studies. Approximately 65% of all protein structures discovered in Australia and New Zealand are currently solved at the Australian Synchrotron.

Planned new beamlines to support health and medical science at the Australian Synchrotron are required for structural biology and for protein scattering. The Imaging and Medical Beamline at the Australian Synchrotron is a world-leading beamline for medical research and is an example of enhanced imaging capability that is unique in Australia. New imaging modalities are emerging here along with novel forms of radiotherapy.

For investigation of the interaction of multiple proteins, which is relevant to a range of fundamental science such as nerve impulse propagation and DNA replication to understanding degenerative (Alzheimer’s, Parkinson’s, cataracts) and other diseases and their treatment, the use of deuterated protein produced by the National Deuteration Facility enables investigations at the OPAL Reactor that resolve structure and behaviour under physiologically relevant conditions. Likewise, the penetration of pharmaceuticals, antibiotics, or toxins through human cell membranes can best be studied using deuterated lipids and/or proteins.

Facilities and expertise for molecular and preclinical imaging capabilities, including substantial infrastructure for the development and production of radioisotopes (reactor- and cyclotron-based) and associated radio chemistry to bind isotopes (radiolabelling) to molecules, are also operated as NRI. ANSTO operates a medical research cyclotron that has GMP capability for the purpose of developing and producing novel radiotracers for pre-clinical and clinical research programs. This capability forms a node of the National Imaging Facility (NIF).

ANSTO agrees that PET tracer development and associated infrastructure (cyclotrons, hot cells, etc.) and imaging is an emerging capability need. The capability should be prioritised for further new and incremental investment to enable greater integration and drive productivity of existing infrastructure and also for new instrumentation and expertise to fill gaps.

In Australia, there is an existing cyclotron network, which is currently focused on operations. It would provide a great strategic benefit for the network to become a throughput network with a focus on the value chain of creating new ligands and peptides and radiotracers. The establishment of a more integrated network system would enable better utilisation of current infrastructure; it would enable the community to leverage the network of cyclotrons, focusing efforts of some cyclotrons on research and development which would enable scope for production of new tracers. A national collaborative network of user-focused, open access facilities spanning fundamental research and pre-clinical capabilities through to clinical settings would provide an important framework for ongoing investment in the following priorities:

- A strategic collaborative network of cyclotrons and infrastructure (hot cells) for PET and SPECT radiotracer development (including reactor-produced). These facilities would be used to develop and manufacture novel and specialist radiotracers for research and pre-clinical and diagnostics research. Microfluidic radiochemistry techniques can accelerate development and optimisation of novel radiotracers. Establishment of GMP and ISO9001 accreditation in strategically targeted facilities should also be considered;
- Development of radiotracer and imaging capability to enable new research into diseases not previously imaged;
- Development of translational capability (in partnership with other dedicated capabilities focussed on translation) for new molecules, nano-devices, and theranostics from pre-clinical research outcomes to clinical trials;
- Development of networked pre-clinical SPECT imaging facilities and more broadly co-ordination of imaging capability, data analysis methodology and collection of additional data, which are critical to realise the full potential of molecular imaging; and
- Correlative imaging modalities across a broad spectrum of resolution and size. Imaging across the spectrum from cell ultrastructure, organelle through to whole body imaging using correlative techniques is an emerging trend for research into disease causes, diagnosis and therapy. Correlative modalities include super resolution advanced light microscopy and high-resolution cryo-electron microscopy techniques in collaboration with national microscopy capability such as the Australian Microscopy and Microanalysis research facility.

The future mission of the national imaging capability is to address the needs of a diverse research community that includes users (including students) from universities, hospitals, industry, medical research institutes and PFRAs. It is important that the needs of researchers drive the strategic development of the capability. This framework is essential to: 1) realise the benefit from prior investment; and 2) expand and install new capability; and 3) ensure maximum impact of ongoing investment through maximum utilisation of infrastructure.

Question 17: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Health and Medical Sciences capability area?

Next generation whole body PET imaging

There is a need for whole body, multi-organ imaging capability that allows simultaneous study, rather than imaging of organs in isolation. Next generation whole body PET systems are being developed that have greater sensitivity and spatial resolution with lower dose requirements e.g. PET EXPLORER. This type of capability will enable researchers to acquire more imaging time points at a lower effective radiation dose, combined with more accurate localisation of pathological processes.

These systems will transform pre-clinical and clinical research by opening up the study of disease in paediatrics and enabling safe longitudinal studies. Investments in leading edge instrumentation such as these systems should be made in the context of an overarching strategic plan for the NIF. Investment in next generation technology also requires support for technical and scientific research support staff.

Adoption of leading edge technology would leverage existing infrastructure, for example our excellent national radiotracer capability that would provide a range of novel and specifically developed tracers. There is also a research community surrounding the state-of-the-art PET EXPLORER that will drive adoption and application of the techniques while further developing methodologies and underlying techniques. Adoption and adequate resourcing of leading edge imaging technology will enable Australia to develop a leadership position in the development and application of the technique as well as enable world-class clinical research outcomes.

Carbon Cancer Research and Therapy Capability

There is an opportunity to establish a National Carbon Cancer Therapy and Research facility for Australia. Carbon-ion therapy is at the cutting-edge of cancer treatments that can potentially be applied to a wide range of patient groups including children with intractable and otherwise untreatable forms of cancer. The use of accelerated carbon ions, a technique that delivers a precisely targeted dose of energy with minimal side effects, has the potential to improve patient health outcomes and quality of life during and post treatment.

Carbon-ion therapy is emerging as the premier next generation cancer treatment, with a number of facilities already established in Western Europe, Japan and China. While Australia has begun to investigate more mature technologies such as proton therapy, we lag significantly behind the many advanced nations now adopting cutting edge carbon-ion technology. International experience demonstrates the potential that carbon-ion treatments are a cost-effective addition to traditional therapies.

In addition to making a sustained commitment to improving the health of Australians by providing world-leading cancer treatment, this capability would boost ongoing health research and deliver innovation in the physics and associated technologies that underpin carbon therapy.

The development of such a capability is supported in Australia by significant clinical groups – the Faculty of Radiation Oncology Council at the Royal Australian and New Zealand College of Radiologists as well as the National Particle Therapy Collaboration Group – which have a broad stakeholder community including nuclear medicine professionals, industry oncologists, universities, hospital administrators. This group has met regularly over the past 5 years to progress this capability area and is advanced stages of planning.

Like the OPAL reactor is able to leverage both clinical and research outputs from the one multi-purpose facility, carbon therapy facilities would similarly deliver great outcomes supporting the research as well as the clinical community treating patients. Research can be undertaken into improving radiotherapy outcomes and understanding interaction of particles with human tissue and developing optimum mechanisms for diagnostic delivery.

A national research and clinical centre would develop and lead a collaborative national network for clinical practice, education and research using heavy ions. A research facility would also provide an opportunity to join an international network of collaborative research centres, whose investigations in medicine, biology and physics have applications in many high-technology industries. The facility would generate clinical trials, further medical research on the interaction of radiation with living matter, lead to improvements in particle therapy techniques and become a centre for advanced training and education.

Early stage clinical and research platforms require a sustained research effort to understand the physics and biological mechanisms of absorbed radiation dose at the cellular level and their effect on patient outcomes, particularly in the case of heavy ion therapy. Australia is well placed to tackle these challenges with its strong track records in medical physics and radiation oncology. This is a natural area for collaboration between ANSTO and the radiation physics/oncology communities.

Environment and Natural Resource Management

Question 18: Are the identified emerging directions and research infrastructure capabilities for Environment and Natural Resource Management right? Are there any missing or additional needed?

Several landmark and national infrastructure facilities operated by ANSTO provide uniquely sensitive tools for characterisation for environmental and natural resource based research. These include the Australian Centre for Neutron Scattering, the Australian Synchrotron and the Centre for Accelerator Science. In addition, ANSTO operates facilities for isotope tracing in natural systems that enable dating and determining isotopic signatures of groundwater, as well as tall tower-mounted infrastructure tracking air mass and with a capability for radon measurements which contributes to an understanding of near-surface atmospheric mixing.

Australia would benefit from the establishment of an overarching framework for environmental and resource research described by a profile including deep ocean – coast – urban fringe – terrestrial interior domains – atmosphere. The fundamental tools required by researchers active in these domains fall into the categories of precision research infrastructure for measurement, observations, integrated modelling and interoperable data underpinned by eResearch capabilities.

National Environmental Tracing Facility

The Issues Paper correctly identifies the critical priority for an understanding of ground-water systems. A quantitative understanding of our groundwater resources and their interaction with surface water and ecosystems is essential to support research challenges in conservation, agriculture, mining, aquaculture, urban development and climate change. A critical and emerging capability in this area would be a national capability for environmental tracing. The capability would integrate high precision environmental measurement, systems modelling and interoperable data by leveraging institutional investments across Commonwealth agencies and universities as well as providing a user-focused platform for new investments to be made. This capability would support the responsible development and management of the nation's natural and primary resources: in–on–under air, land, water or ocean.

Environmental tracers are natural and man-made compounds that can be used to track the origin and transport of water across the landscape. In particular, age-dating environmental tracers in groundwater are essential to evaluate the sustainability of this resource. A diverse toolkit of tracers is required because groundwater age in the Australian context can vary from days to millions of years.

The capability will be a world-class facility that scientists and natural resources managers can use to create solutions for nationally significant resource development and management challenges, such as mine remediation and management.

National Ice Core Archive

Among a number of techniques being used to study past climate history and how this might shed light on future impacts, is the study of ice cores. Studying elements archived within ice cores offers researchers valuable information on climate variability, sea level rises, global warming and extreme weather changes. Microscopic bubbles and elements trapped in ice reveal a great deal about past climate and the dramatic impact humans may have on future climate. Australia has a long history of collecting ice cores from Antarctica. This collection and characterisation of the cores is expensive, and the cores need to be returned to Australia for analysis and storage in a variety of freezer facilities. Access to the archived cores is limited, and the full potential of the resource is not being utilised. The establishment of a National Ice Storage Archive would enable greater utilisation of the cores and guarantee long-term storage. It would also facilitate a capability in ice core analysis. In the short term, an update to current facilities is needed to enable specialist measurements for ice cores. ANSTO's facilities have been recently redeveloped and rebuilt but there is a requirement for a new carbon dioxide analysis capability from 2022 when the new ice breaker is commissioned. The ice breaker mission is to get a million year ice core high resolution record, but at present there is no designated facility in Australia that could process this adequately.

Advanced Physics, Chemistry, Mathematics and Materials

Question 21: Are the identified emerging directions and research infrastructure capabilities for Advanced Physics, Chemistry, Mathematics and Materials right? Are there any missing or additional needed?

ANSTO operates a broad range of national and landmark research infrastructure that is included in this capability area and can also be categorised as characterisation research infrastructure. The issues paper correctly identifies X-ray techniques at the Australian Synchrotron, accelerator facilities within the Centre for Accelerator Systems Science that provide ion beam analysis and accelerator mass spectroscopy capabilities and neutron beam facilities located at the Australian Centre for Neutron Scattering as highly relevant in this regard. Further discussion regarding the Australian Synchrotron, CAS and ACNS will appear in the response to Q30.

Existing: National Deuteration Facility

Once molecular deuteration was the province of researchers investigating material structure but now companies around the world seek to capitalise on the improved performance that deuteration can confer on their products. Key developments using deuterated molecules in the US and Europe include trials of more effective pharmaceuticals for diabetes and AIDS that have fewer side effects. In Australia, ANSTO is developing more stable radiotracers for imaging disease states and neurotransmitters in the brain, and we have collaborated in proving deuterated chemicals are more efficient solar cell components (in photovoltaics). Potential applications also include optoelectronics and lubricants and friction modifiers.

ANSTO's National Deuteration Facility (NDF) currently provides labelled molecules for investigations of the molecular structure of complex multicomponent systems using neutron scattering and various spectroscopic techniques which enable Australian and international researchers to solve design and function questions. In medicine, deuterated molecules are used to study the causation, detection and treatment of disease and development of biopolymers for tissue engineering. In the energy sector, deuterated compounds facilitate design of improved gas storage and new generation batteries, new catalytic materials for green chemistry, and improved mineral processing.

This paradigm shift where the value of deuteration now encompasses both high value research on molecular structure as well as the design of new materials and products with enhanced functionality requires further investment to provide sufficient capacity and capability to service both user communities. This investment would catalyse stronger and closer engagement with industry and would attract national and international demand focused on product delivery.

Existing: Centre for Accelerator Science

ANSTO does not agree with the commentary in the Issues Paper that accelerator science facilities are generally meeting demand and that ongoing maintenance funding can continue to operate at current levels.

The Centre for Accelerator Science (CAS) is creating the capacity for increased utilisation (up to an additional 25% beam time). This is necessary as there is clear evidence that, due to current limited CAS capacity to satisfy demand, a number of requests from Australian users went overseas, to other labs in US and Europe.

The main drivers of this increased demand are an expansion in utilisation of accelerator science techniques for answering questions such as water dating for managing of aquifers (see response to Q 18 above). Sustainable use of aquafers is a critical issue for Australia. In addition, due to the emergence of new technologies such as fracking, there is an increased demand to analyse gas samples extracted from ground water, and to discriminate between the carbon content from fossil and biogenic sources. There is also increased demand for better analysis of nuclear materials samples to distinguish specific isotopic signatures (see response to Q 27).

Emerging: Electron Accelerator irradiation facility

An electron beam research facility would complete the full suite of state-of-the-art radiation capabilities for researchers enabling a wide range of applications including agriculture, healthcare manufacturing and advanced materials. The gamma irradiation capability currently available at

ANSTO will cease to operate in the next two years. This will create a gap in capability, leaving the nation without a precision high-flux irradiation technology that has accurate dose and temperature control for research and commercial irradiation services.

Irradiation is essential for the sterilisation of medical products including catheters and medical devices such as knee implants, as well as tissue-based transplant materials such as tendons and bones. Radiation resistance of materials remains a significant fields of research in the space, nanotechnology, medical, manufacturing and electronics industries.

The research application of a high-powered electron accelerator would also allow studies on radiation-accelerated degradation and hardening of new materials.

Emerging: Underground Physics Laboratory

In many new areas of physical, astronomical, material and life sciences, background cosmic radiation at sea level or above is not optimal for carrying out experimental work. A facility deep underground (more than 800 m) provides an ultra-low-background radiation environment, making it perfect to house sensitive experiments such as dark matter direct detection, as well as future projects in neutrino-physics, geophysics (muon tomography), materials science (high purity materials and purification systems), and astrobiology. An example of such a laboratory planned for Australia is the Stawell Underground Physics Laboratory (SUPL) located 1025m underground in the operating Stawell Gold Mine, Victoria. SUPL will be the first laboratory of its kind in the southern hemisphere, and will join an international network of underground ultra-low background radiation laboratories such as the Gran Sasso facility in Italy and SNO-LAB in Canada. Once operational, it will be made available to Australian researchers as a national user facility.

A major science programme at SUPL will be participation in the global search for the unidentified dark matter that constitutes about 25% of the Universe and about 85% of the total matter in the Universe. The identity and detection of dark matter is one of the major questions in modern physics and astronomy, comparable to the search for the Higgs Boson. The wider Australian science community would benefit from SUPL's underground ultra-low background environment, including development of ultra-sensitive radiation measurement instrumentation, environmental science, health, biology, geology, mining and deep sub-surface life.

Question 22: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Australia should appropriately engage with large multi-national science endeavors such as continued engagement with particle physics and other research at CERN, near Geneva. The Australia fusion research community will be able to have enhanced access to the ITER Fusion Power Demonstration Program. ANSTO, representing Australia and the Australian research community, has negotiated a cooperation agreement with the ITER International Fusion Organisation. This will leverage access to ITER research & development for Australian researchers in areas such as plasma physics, new superconducting materials and materials under extreme conditions, and additionally will open avenues for Australia to supply specialized components. For example, ITER has allocated a port for an Australian-conceived plasma diagnostic system developed by the ANU's Australian Plasma Fusion Research Facility.

Whereas Australia generally cannot afford full membership participation in projects of this scale, we can engage at lower levels via national organisations such as ANSTO, and achieve significant access, impact and international recognition for modest investment. Such links can leverage disproportionately large returns compared to the scale of investment, both in science and technology outcomes, and in building Australia's international profile.

Understanding Cultures and Communities

Question 24: Are the identified emerging directions and research infrastructure capabilities for Understanding Cultures and Communities right? Are there any missing or additional needed?

Existing capability:

ANSTO operates X-ray, neutron beam, neutron activation analysis and accelerator capabilities that are used for a range of cultural heritage projects. These include provenance of art works, materials characterisation of ancient materials and non-destructive imaging via X-ray and neutron computed tomography of natural and man-made artefacts.

National Security

Question 27: Are the identified emerging directions and research infrastructure capabilities for National Security right? Are there any missing or additional needed?

There are a number of activities in which ANSTO undertakes nuclear stewardship on behalf of Government to ensure that Australia's reputation and leadership in the peaceful use of nuclear technology develops over time. For example, ANSTO operates Australia's only Nuclear Forensics Research Facility (NFRF) which undertakes research and development into forensic capabilities to assist Australia's policing services in radiological crime scene matters. The NFRF also provides nuclear forensics operational support to Australia's policing services in the prosecution of criminal offences involving nuclear and other radioactive materials. ANSTO's leadership in the field of nuclear forensics is recognised internationally as evident by our appointment to chair the Nuclear Forensics Working Group of the Global Initiative to Combat Nuclear Terrorism (GICNT), on behalf of the Department of Foreign Affairs and Trade, facilitating the sharing of technical developments in nuclear forensics with the 86 partner nations of GICNT.

ANSTO also operates the Centre for Accelerator Science, which provides a capability to detect trace amounts of a range of elements and isotopes. In the nuclear safeguards field, human activities involving nuclear materials, such as handling uranium and plutonium, leave tiny but detectable traces in the neighbouring environment. From these traces, the nature of the activities, whether legal or illegal, can be determined. The IAEA uses environmental sampling as part of its strategy for monitoring compliance with the Nuclear Non-proliferation Treaty, enlisting the help of a number of laboratories from around the world, including ANSTO, to analyse these samples. The same sampling and analytical techniques are applied by other agencies, for example those responsible for detection of illicit trafficking of nuclear and radioactive materials.

ANSTO's NRI is also used in the development of high performance armour materials for use in armoured vehicles. Many projects are multidisciplinary and utilise ANSTO's NRI, with particular emphasis on two neutron beam lines, Kowari and Dingo, which are used for stress evaluation, texture measurements and neutron tomography.

Underpinning Research Infrastructure

Question 30: Are the identified emerging directions and research infrastructure capabilities for Underpinning Research Infrastructure right? Are there any missing or additional needed?

Neutron and X-Ray Scattering (Reactor and Accelerator Technologies)

ANSTO operates the OPAL research reactor, the Australian Centre for Neutron Scattering (ACNS) and the Australian Synchrotron as the landmark infrastructure that provides neutron and X-ray scattering capabilities for the nation. The Issues Paper correctly identifies that these capabilities enable world-class research outcomes across a broad range of scientific and engineering domains. These facilities have extensive international networks; and access to complementary X-ray scattering capabilities overseas via an international access scheme which provides an important addition to the synchrotron user program in Australia, enabling researchers to access a wider range of techniques.

As previously described, ANSTO also operates the Centre for Accelerator Science and the National Deuteration Facility (NDF), both of which enable a broad range of research programs spanning the environment, health and medical science, material science, nanotechnology, minerals and resources, and cultural heritage. These two facilities should be added to the list of existing underpinning research infrastructure.

The ACNS and Australian Synchrotron facilities are over-subscribed; and this demand coupled with new and emerging instruments that will create opportunities for new research programs is driving campaigns to expand and install additional capability over the next five years. Investing in well-performing infrastructure such as the Australian Synchrotron and OPAL/ACNS leverages previous investment and takes advantage of the world-best practice already established. Expansion of ACNS by way of a second guide hall adjacent to the OPAL reactor would provide a foundation for an additional suite of neutron beam instruments. The development of more capable and more flexible neutron delivery systems will allow ACNS to develop instrumentation around a variety of equipment that can place the sample in extreme environments such as those experienced during industrial processes.

Neutron imaging is emerging as an indispensable tool for a variety of new technologies such as fuel cells for automobiles. With a second guide hall and making full use of the advances in neutron optics, ANSTO would be able to build the world's first neutron microscope enhancing neutron imaging capability.

To solve challenging problems in protein structure and dynamics as well as in sub-cellular imaging and to provide needed *in situ* capability for materials science, advances in detector, experiment and synchrotron light source technology are required. These will provide better access to the time domain for experiments with a dynamic component, better spectral resolution and better spatial resolution.

Emerging directions that can meet these needs include the development of new light sources. In the ten year timeframe, upgrading the Australian Synchrotron's storage ring or constructing a new facility to take advantage of new lattice designs will improve beam properties sufficiently to help solve current challenges. In the short term some existing capability gaps can be filled by building new beamlines. The Australian Synchrotron plan for new beamlines will deliver capability in health and advanced materials and resources to keep Australian research infrastructure at world-class levels.

eResearch Infrastructure

The landmark and national research infrastructure operated by ANSTO provides characterisation capabilities required by more than 5000 researchers in Australia annually. Discovery and innovation in a data-rich and intensive science environment like ANSTO is enabled by quality eResearch infrastructure.

ANSTO utilises an integrated eResearch capability comprising networks and connectivity; data storage; cloud-based integrated analysis tools and data services. This capability has been built to meet researcher needs across the entire user experience, combining internal ANSTO-designed and operated systems as well as co-investment and subscriptions that leverage NCRIS and SuperScience funded national eResearch capability such as AAF, AREN, NCI and Pawsey, RDS/NeCTAR/ANDS.

Users of extremely data-intensive capabilities such as neutron and X-ray tomography, X-ray fluorescence microscopy and the imaging and medical imaging beam line (IMBL) at the Australian Synchrotron are highly dependent on underpinning eResearch infrastructure. For example, the IMBL provides medical researchers dynamic 3D x-ray imaging at incredibly high resolution so as to reveal minute differences at the interface of air, tissues and bones: the starting point of many diseases. It can visualise blood vascularisation, air movement in the lung, and tissue and organ structure in far greater detail than that possible with MRI. The beamline provides an exciting discovery space for accelerated research into treating tumours, chronic lung disease, haemorrhage and inflammation of the brain, bone growth and replacement, and various heart-related conditions. An integrated eResearch capability is therefore critical for researchers using IMBL. Typical work flows comprise capture of high volumes of data, process and visualisation in real time so as to optimise experimental conditions. Such workflows are characteristic of advanced imaging modalities and assist users to apply correlative and complementary characterisation approaches to their research.

Ongoing investment in national eResearch capabilities is essential for ANSTO's ability to adequately support its user community. Identified needs include:

- AREN (through AARNet) is a critical service and needs to continue to be funded to match the growth in international standards in how data is transported and used. AREN needs to continue to build high speed resilient and reliable networks into new campuses and instruments over the next decade.

- The AAF has successfully delivered a national authentication framework but now needs to tackle authorization across all AAF members.
- RDS/NeCTAR/ANDS - The Virtual Laboratories program (VLs) has been successful, and further investment will enable ANSTO to establish cloud- based analysis environments that support user workflows. The VLs can also assist with integrative high performance computing. Projects that can bring together capability from a variety of disparate (and often off-the-shelf) components should be supported. For example, MASSIVE is a program that has provided value to users through integration of data storage, visualisation, high performance computing and access to commercial software tools.

Question 32: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Underpinning Research Infrastructure capability area?

New beamlines at the Australian Synchrotron are an essential component of keeping Australia's characterisation capability world-class. As part of the National Innovation and Science Agenda, the Government committed $520 million to operate the Australian Synchrotron over ten years. Importantly, that Government funding package includes operational funding for new beamlines, with the capital funding to now be secured. This commitment means that ANSTO can expand the capacity and capability of the Australian Synchrotron to ensure research undertaken there remains cutting edge. The facility has identified eight new beamlines to be built to meet current and anticipated demands of Australian research and industry. It is proposed, in order to show support from stakeholders, that the capital funding package would include significant contributions from other research organisations (including ANSTO), universities, and state and overseas governments and New Zealand. As noted above, a further component of capital funding from a national research infrastructure scheme would strengthen the impact of the facility.