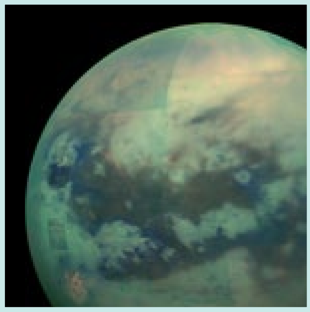
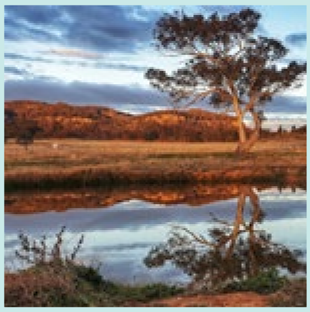
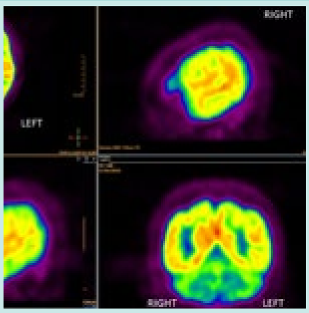
Australian Government

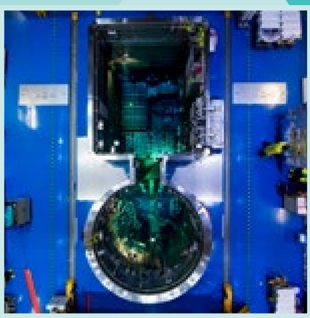
ANSTO

Research Impact Report









Science. Ingenuity. Sustainability.

ANSTO

Research Impact Report

Covers highlights from the period 2016-2022 at ANSTO.

The report was produced in November 2023.

In August 2024, this document was amended to reflect the 2024 Australian Research Priorities

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Introductory Statement from Board Chair

It is with great pleasure that I share our **Research Impact Report**, a document that provides a summary of the impactful scientific work undertaken at ANSTO in recent years to benefit Australia.

It encompasses research that is driven by ANSTO scientists with expertise in nuclear materials, environment and human health. The Report also captures highlights of the significant outcomes of work with collaborators, partners and users who access ANSTO's unique sovereign nuclear capabilities and infrastructure.

This research is a valuable resource for the industry sector and for Australia's economic prosperity.

Nuclear science is essential in the diagnosis and treatment of disease, it can help protect an environment that is threatened by climate change and contribute to a safer and sustainable nuclear industry. ANSTO research is central to such outcomes.

We prioritise our science using Australia's National Research Priorities and other important policy objectives and initiatives set by the Australian Government. ANSTO's science and technology is shaped by a unique nuclear mandate as defined by the **ANSTO Act** and reflects ANSTO's strategic objectives.

The breadth of investigations, the diverse applications, as well as the excellence and depth of the research, are a fitting testimony to the expertise of ANSTO and Australian scientists.

Although there are close to one hundred case studies, there is far more research that has not been showcased. With 400 scientists and thousands of users annually, the total scientific contribution is formidable.

The Hon Dr Annabelle Bennett AC SC FAA FAL

Statement from Group Executive, Nuclear Science and Technology

The **Research Impact Report** shows some of the many ways that science at ANSTO has delivered real world benefits in recent years.

It is important not only to do great science but to be seen to be doing great science, so we deliver this report in the spirit of accountability: to the government; to other funders and supporters who made this research possible; and to the public, who ultimately reap the rewards.

The case studies presented in the report deliver benefit and represent a significant intellectual achievement from ANSTO scientists in collaboration with users, partners, and industry clients.

Our research, and the research of those who access our infrastructure, relies on nuclear science and technology that can only be delivered by ANSTO.

Science at ANSTO brings public benefit to all Australians, in areas of national priority and in alignment with national science and research priorities, through innovation for industry, improving health, protecting the environment, optimising the nuclear fuel cycle, supporting Indigenous cultural heritage, enhancing food and agriculture, and fostering discovery.

When you browse through this library of almost a hundred case studies, you will also find details of ANSTO's advanced capabilities, and, importantly, a list of the individuals who contributed to the research.

Whether it is coming up with the concept or theory, conducting the experiment, interpreting the results or translating the science into a technology, the effort is a shared one.

We applaud these efforts and celebrate the achievements captured in the case studies.

At a time when excellent science is needed to help resolve opportunities and challenges for the nation, ANSTO is proud to have delivered on its mandate in delivering knowledge and advancing prosperity for the benefit of Australia.

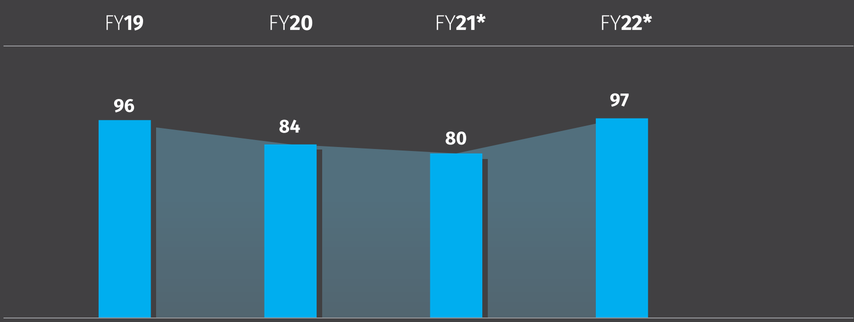
Prof Andrew Peele

Australian Synchrotron (AS)

Utilisation and demand

Australian Synchrotron utilisation performance is measured by the number of hours delivered out of the scheduled number of hours available.

AS utilisation and demand

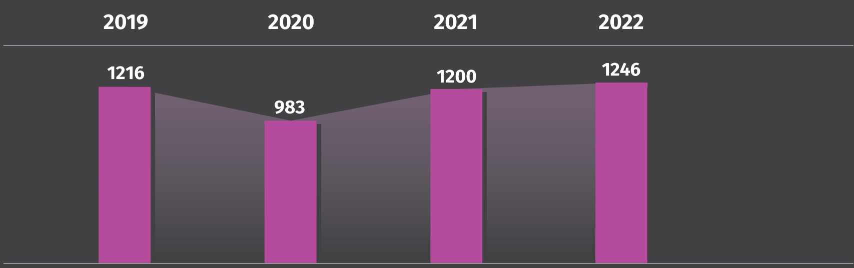


Actual utilisation

* COVID-19 impacted

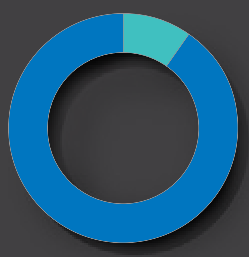
^ Utilisation excluded any experiments cancelled due to COVID-19.

AS approved proposals



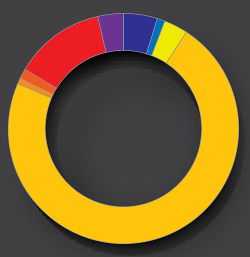
Number of approved proposals

Internal and external users



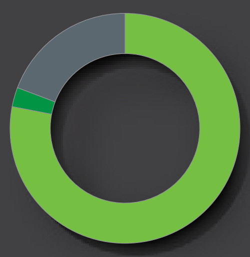
International user visits	5%
Domestic user visits	95%

User organisations



Aust. Res. Inst.	3%
University (Aust)	72%
Non-Aust. Industry	1%
Non-Aust. Res. Inst	1%
Non-Aust. University	13%
PFRA	3%
ANSTO	5%
Aus. Industry	1%
Aus. Gov	1%

User access mode



Merit	78%
User pays	3%
Commissioning	19%

AS user profile. Numbers are averaged for four financial years (FY19-FY22) from a total of 5148 unique users (based on user visits to the Australian Synchrotron).

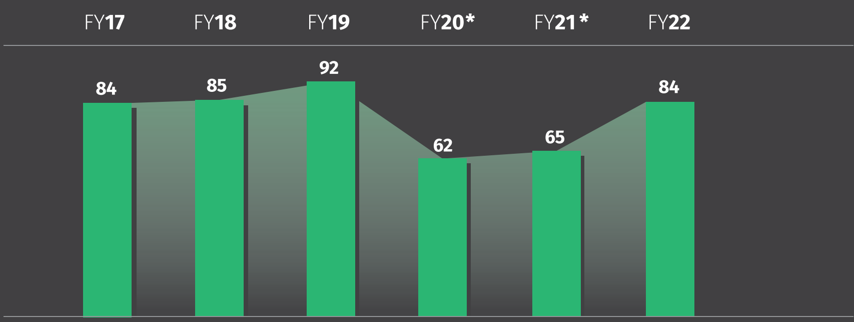
AS user access mode distribution averaged for four financial years (FY19-FY22).

Australian Centre for Neutron Scattering (ACNS)

Utilisation and demand

ACNS utilisation is measured by the number of actual operating days out of the scheduled operating time.

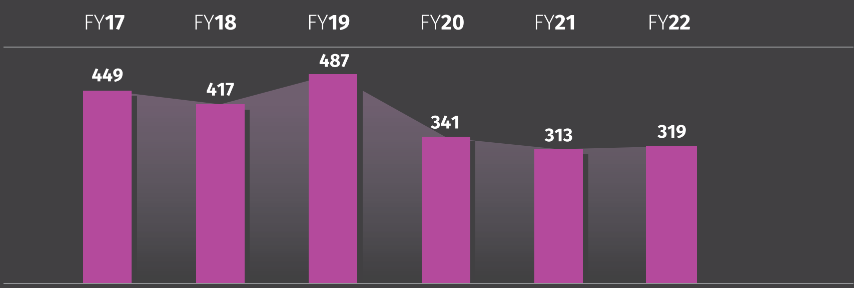
ACNS utilisation



Actual utilisation

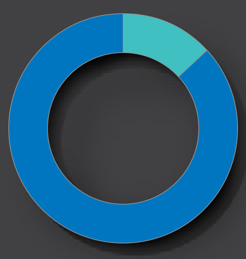
* COVID-19 or OPAL outage impacted

ACNS approved proposals



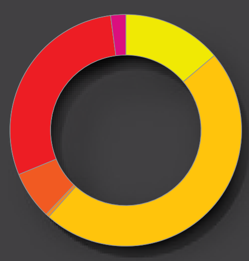
Number of approved proposals

Internal and external users



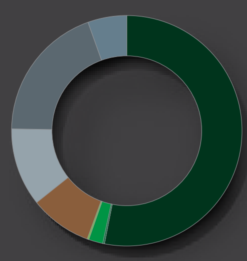
Internal	13%
External	87%

Users by sector



ANSTO	13%
Aust. University	48%
Non Aust. Industry	1%
Non Aust. Res. Inst.	7%
Non Aust. University	29%
PFRA	2%

User access mode



Merit	53%
National Interest	.5%
User Pays	2%
Service Provision to ANSTO	.5%
Discretionary	9%
Development	11%
Maintenance and testing	19%
Reactor System Outage	5%

ACNS User Profile. Numbers are averaged for the six financial years (FY17-FY22) from a total of 2754 unique users (based on usage and user visits to the Australian Centre for Neutron Scattering.

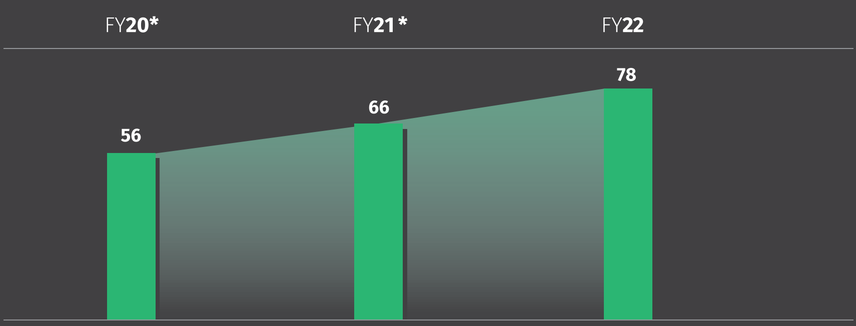
ACNS user access mode distribution averaged for six financial years (FY17-FY22) for neutron beam instruments days utilised across the suite of instruments available. Planned maintenance and testing has also been included.

Centre for Accelerator Science (CAS)

Utilisation and demand

The CAS utilisation is measured by the number of days operating for the user program against the number of days available. The number of days available for the user program is the number of accelerator days (250 business days per year per accelerator) minus the number of days used for planned and unplanned maintenance and system upgrades.

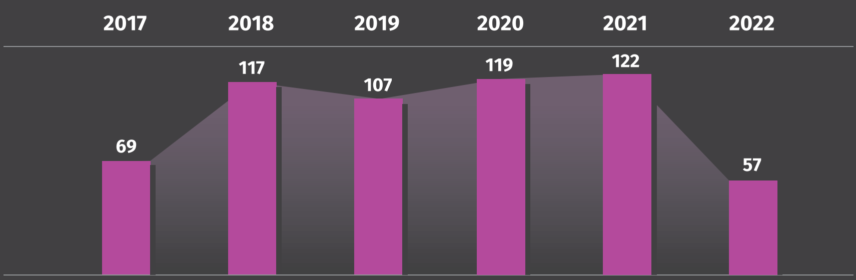
CAS utilisation



Actual utilisation

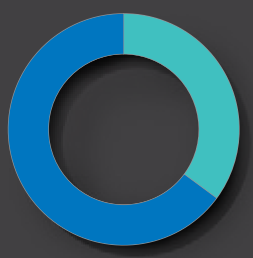
* COVID-19 impacted

CAS approved proposals



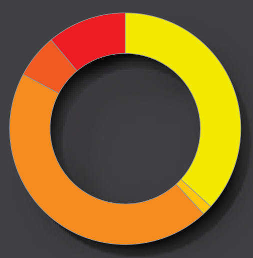
Number of approved proposals

Internal and external users



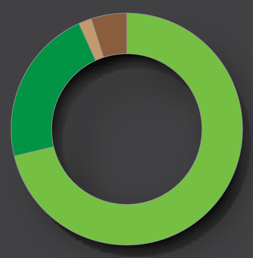
Internal	35%
External	65%

Users by sector



ANSTO	35%
Aust. PFRA	1%
Aust. University	44%
Non-Aust. Res. Inst.	6%
Non-Aust. University	11%

User access mode



Merit	71 %
User pays	22 %
National interest	2 %
Development	5 %

CAS user profile. Numbers are averaged for the six financial years (FY17-FY22) from a total of 1834 unique users from approved proposals.

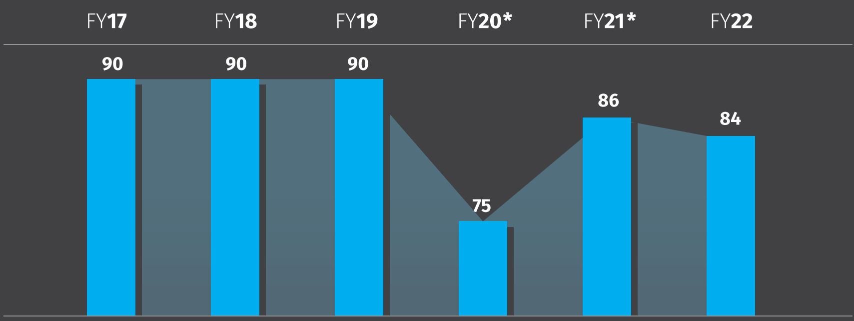
CAS user access mode distribution averaged for six financial years (FY17-FY22).

National Deuteration Facility (NDF)

Utilisation and demand

The National Deuteration Facility utilisation performance is measured by the percentage of the National Deuteration Facility production capacity utilised by the approved user demand.

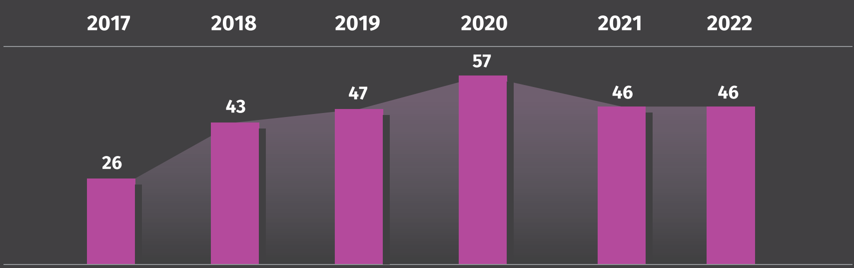
NDF utilisation and demand



Actual utilisation

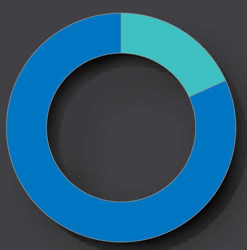
* COVID-19 impacted

NDF approved proposals



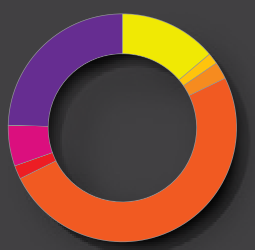
Number of approved proposals

Internal and external users



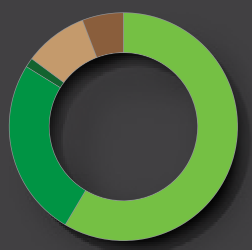
Internal	18%
External	82%

Users by sector



Aust. PFRA	14%
Aust. Industry	2%
Aust. Res. Inst.	2%
Aust. University	50%
Non-Aust. Industry	2%
Non-Aust. PFRA	6%
Non-Aust. University	25%

User access mode



Merit	59%
Merit (cost recovery)	25%
National Interest	1%
Commercial	9%
Development	6%

NDF user profile. Internal and external unique users are averaged for the six financial years (FY17-FY22) from a total of 707 unique users who accessed the National Deuteration Facility (completed and ongoing proposals).

NDF user access mode distribution averaged for six financial years (FY17-FY22) for approved proposals. Commercial indicates full cost access and user pays/cost recovery indicates partial cost contribution from users for collaborative and non-proprietary work. Both access types can be approved through Director's discretion.

Innovation for Industry

Delivering solutions to industry to ensure Australia's economy prosperity and successful competition in international markets is one of ANSTO's core strategic objectives.

Nuclear and accelerator techniques are powerful because they can reveal information about structure, electronic properties and dynamics at the molecular and atomic scale.

Our nuclear capabilities and expert scientists work with businesses to solve challenges and develop and improve new products.

This support crosses a variety of sectors, but there are significant contributions in energy, defence and security, light and heavy manufacturing and infrastructure.

This report also provides case studies of progress in more niche areas, such as advanced materials for quantum computing, superior and environmentally-friendly materials and the resources sector.

Building better batteries

The search for cheaper and safer lithium-ion batteries

At present, the highest-performing lithium-ion batteries cannot compete with petrol in terms of their driving range. In a lithium-ion battery, the positive electrode material (e.g., cobalt oxide) is the roadblock in extending the upper limit of how much energy a battery can hold, such as energy density (Wh/kg).

THE CHALLENGE

Electrode materials that contain cobalt currently offer the highest energy density in commercial lithium-ion batteries. However, cobalt is an expensive and toxic element. There is a need to find lithium-ion battery electrode alternatives that are efficient, economical, and safe. Spinel-structured electrode materials ($LiNi_{0.5}Mn_{1.5}O_4$) are a safer and more economical alternative to existing commercial materials that contain cobalt. However, spinel electrodes lose charging capacity over time, known as capacity fade, and so are not currently a competitive alternative. This work aimed to balance battery power and life with reduced cost and toxicity.

THE SOLUTION

Rapid 'capacity fade' or loss of charge of unmodified spinel-type material ($LiNi_{0.5}Mn_{1.5}O_4$ (LNMO)) was first addressed by using aluminium fluoride coatings. The team then made a series of atomic-level material modifications. They assessed their modifications using beamlines at the Australian Synchrotron and neutron diffractometers on the Wombat and Echidna instruments. Neutron scattering allowed real-time observation of the mechanisms behind their improvements. Each experiment provided a leap in the cycle stability of the material. Most notable is the modified version of spinel-structured electrode material with the formula $LiNi_{0.5}Mn_{1.48}Ge_{0.02}O_4$, containing only 1% germanium. This version achieved an extraordinarily stable battery performance of 71% battery retention after 2000 recharges. The team achieved 800 mWh/g with a high operating voltage of 4.7 V, which is close to that of the best lithium-ion batteries e.g., NMC 811 generates 927 mWh/g. This excellent cyclability is outstanding for this type of material, which is Co-free and has less nickel. Cyclability is the key to the longevity of the battery.

THE IMPACT

This work developed a competitive replacement for the current best-in-class lithium-ion batteries. Modified spinel-type electrodes ($LiNi_{0.5}Mn_{1.5}O_4$) have the high energy density needed for electric vehicle applications with driving ranges and other features. These batteries retain excellent charging capacity, are non-toxic, and are much cheaper to manufacture using less nickel and no cobalt.

Research Priorities

Net zero future

ANSTO Capabilities

- Synchrotron X-Ray Powder Diffraction and Spectroscopy
- Neutron Scattering

ANSTO Instruments

Wombat
High Intensity Diffractometer
Echidna
High Resolution Diffractometer
Soft X-ray Spectroscopy (SXR) Beamline
Powder Diffraction (PD) Beamline

Collaborators/Client

University of Wollongong

ANSTO Contributors

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Dr Lars Thomsen
Dr Bruce Cowie

Publications

doi.org/10.3389/fenrg.2018.00089
doi.org/10.1002/anie.202001454
doi.org/10.1002/adma.202101413
doi.org/10.1002/ange.202201969

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Most electric cars use lithium ion batteries

Advanced quantum technology

Innovations for ultra-small and sensitive sensors to map brain activity

Weak electrical currents naturally produced in the brain produce magnetic fields in the nano-Tesla strength range. The precise measurement of these magnetic fields allows detailed mapping of brain activity, which enables the diagnosis and treatment of neurodegenerative disorders.

THE CHALLENGE

Engineering and fabricating biocompatible devices and sensors for observing and detecting stimulated neuron cell activity with excellent magnetic sensitivity requires customised material modification at the nanoscale.

THE SOLUTION

A team of researchers from the Instituto Nazionale il Ricerca Metrologica and the University of Torino in Italy, and ANSTO's Centre for Accelerator Science used precision ion beam implantation to develop an experimental apparatus, with nitrogen-vacancy centres in synthetic diamond, that can measure magnetic fields with unprecedented sensitivity at the nanoscale. Precision ion beam implantation for materials modification is a unique capability made possible at ANSTO's Centre for Accelerator Science.

THE IMPACT

This innovative method has been used to produce sensors with excellent magnetic sensitivity at an ultra-small scale and with full biocompatibility. This method shows unprecedented potential for nanoscale magnetic sensing in biological systems at the cellular level.

Research Priorities

Net zero future

ANSTO Capabilities

- Surface engineering and materials modification

ANSTO Instruments

Low-energy ion implanter

Collaborators/Client

Instituto Nazionale Di Ricerca Metrologica
Universita Degli Studi Di Torino

ANSTO Contributors

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Publications

doi.org/10.1140/epjqt/s40507-020-00088-2
doi.org/10.1038/s41598-020-78436-6

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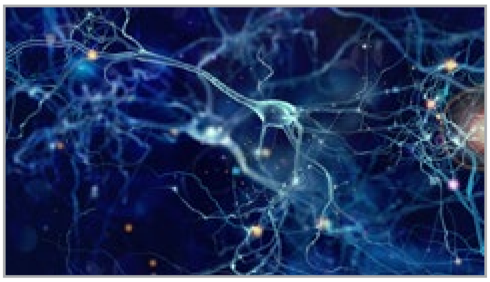

Neurons in the brain

Radioisotope production

Developing and standardising mercury-203 for environment and human health research

Mercury-203 has been identified as a potential research tool in tackling environmental and human health challenges. Currently, the only pathway to produce mercury-203 in Australia is via the Open Pool Australian Lightwater (OPAL) multi-purpose research reactor at ANSTO.

THE ENVIRONMENTAL CHALLENGE

Australia's marine industries were valued at over $81 billion a year in 2017-2018. The largest contributor is the oil and gas industry, valued at approximately $37 billion a year. By 2026, over 65 offshore installations around Australia's coast will require some form of decommissioning. The fate of contaminants such as mercury associated with subsea pipelines remains unknown. Understanding the behaviour of mercury leached from such infrastructure into the marine environment is key to managing the decommissioning process and protecting marine life and its consumers.

THE HUMAN HEALTH CHALLENGE

Theranostic radiopharmaceuticals are nuclear medicines used in both the diagnosis and treatment of disease, typically a cancer cell or tumour mass. A radioactive medicine is attached to a specific biomarker, known as a bifunctional chelator, that facilitates the delivery of the medicine to a target site. Biomarkers can be bulky and impair binding to the biological target. This limits the development of new theranostic radiopharmaceuticals. Developing theranostic radiopharmaceuticals based on radioactive mercury will allow for its simple insertion into a range of new peptide-based biomarkers for radiopharmaceutical use.

THE COMBINED SOLUTION

To enable this environmental and medical research, the ANSTO team developed and deployed reliable production of mercury-203. Irradiation of enriched mercury oxide (mercury-202) in the OPAL multi-purpose research reactor produces mercury-203.

Our researchers then used ANSTO's unique capabilities in radioisotope processing and tracing under controlled laboratory conditions to generate novel data on the chemical and biological fate of mercury during subsea pipeline decommissioning. They also used mercury-203 molecules for the development and evaluation of novel theranostic radiopharmaceuticals.

THE IMPACT

In developing and standardising the production of mercury-203, ANSTO is assisting with decommissioning plans of offshore seabed infrastructure with mercury contamination. This work has the potential to reduce decommissioning liabilities for both industry and government, whilst ensuring the best practice environmental protection is followed.

ANSTO has facilitated cutting-edge radiopharmaceutical design and testing in Australia by providing ongoing production of nuclear medicines such as mercury-203 for Australian researchers with higher radioactivity per unit mass and a lower market cost.

Research Priorities

Environment | Health

ANSTO Capabilities

- OPAL reactor
- Radioisotope development and provision

Collaborators/Client

Australian oil and gas producers
National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA)
Department of Industry, Science, Energy and Resources (DISR)
Mercury Australia
Monash University
International Atomic Energy Agency (IAEA)
Helmholtz-Zentrum Dresden

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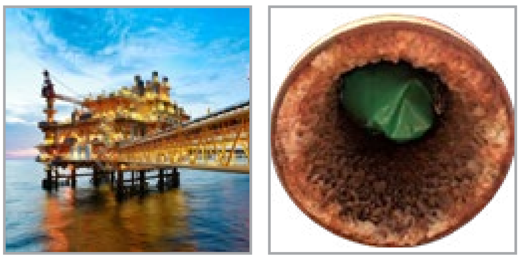

FIGURE 1:
Offshore infrastructure (oil rig, left) with an example of subsea pipeline (right) where contaminants such as mercury can build up and may have the potential to cause harm to the marine environment.

Safely decommissioning offshore infrastructure

Managing residual contaminants in subsea pipelines

Once an oil or gas field reaches the end of its production life, the associated infrastructure (assets) will need to be decommissioned. Current Australian legislation requires the operator to remove all offshore infrastructure post-decommissioning. The cost of decommissioning and removal of offshore infrastructure around Australia is estimated at $52 billion over the next 30 years.

THE CHALLENGE

There is an opportunity for some assets, such as subsea pipelines, to remain in the ocean (known as in situ) if deemed environmentally acceptable. However, assessment of the ecological impact of in situ decommissioning typically fails to consider the long-term effects of contaminants, such as mercury and naturally occurring radioactive material (NORM)s that may have accumulated in assets during operation. Because of this, there is a need to develop a multi-phase approach when assessing subsea pipeline contaminants to ensure the highest level of environmental protection while potentially minimising decommissioning costs.

THE SOLUTION

This work drew upon ANSTO's cutting-edge testing capabilities at specialist laboratories at the Lucas Heights campus and the Australian Synchrotron to provide a detailed characterisation of any potential contamination and its long-term effects on the Australian marine ecosystem. Specific investigations were undertaken to understand the potential for the contaminants to dissolve and mobilise in the surrounding seawater, impact the ecology, and be taken up and transferred through the marine food web to humans.

THE IMPACT

Research findings have informed both operators and government regulators, providing critical information about the long-term impacts of residual contaminants from decommissioned subsea pipelines. Operators can better plan the decommissioning process, while regulators can accurately assess potential impacts of contaminants within the offshore infrastructure. The team is currently coordinating with international bodies including the International Atomic Energy Agency (IAEA) to develop technical reports outlining best practice management of NORM-contaminated offshore infrastructure.

Contaminants can build up in offshore infrastructure

WATCH THE VIDEO

Research Priorities

Environment

ANSTO Capabilities

- Scanning Electron Microscopy (SEM)
- Transmission Electron Microscopy (TEM)
- Synchrotron X-Ray Fluorescence
- Aquatic Laboratory
  Vivarium Facility
- Radioisotopes and Radiotracers
  Production and formulation of mercury and other key Radioisotopes

ANSTO Instruments

X-ray Fluorescence Microscopy (XFM) Beamline
Gamma and Alpha Spectrometry
Elemental Analysis (ICP-MS)

Collaborators/Client

National Decommissioning Research Initiative
CSIRO
The Australian Institute of Marine Science (AIMS)
International Atomic Energy Agency (IAEA) ENVIRONET Working Group

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Dr Sue Brown and Team
Ken Short
Dr Daniel Oldfield
Dr Peter Kappen
Dr Jess Hamilton

Publications

doi.org/10.1071/AJ20024
doi.org/10.1071/EN22048
doi.org/10.1016/j.jenvrad.2022.107093
doi.org/10.1016/j.jhazmat.2022.129348
doi.org/10.1016/j.jenvrad.2021.106774
doi.org/10.1080/10643389.2021.1917949
doi.org/10.1016/j.jenvrad.2022.106979
doi.org/10.1016/j.scitotenv.2023.163015
doi.org/10.1071/AJ22173

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Deuterated molecules

Improving and stabilising materials using deuteration

Degradation and instability of materials are the enemy of nearly everything in life, from biology to chemistry, including industrial products. Materials such as healthcare products, lubricants, electronics, and food can oxidise, and enzymes in the body act similarly to oxygen by breaking the molecular bonds of materials such as drugs.

THE CHALLENGE

These natural processes are often detrimental to the intended performance and effectiveness of materials. To slow down degradation and instability effects while retaining the original functionality and quality of the product, chemists endeavour to design better-performing molecules, additives, and preservatives.

THE SOLUTION

ANSTO has deuteration facilities which can produce molecules where all or part of the molecular hydrogen (99.98% hydrogen-1 in nature) is replaced with deuterium (hydrogen-2). Deuteration can reinforce weak bonds in molecules of a material without changing its chemical nature, making the material more resistant to damage by oxygen or enzyme action. Through the deuterium kinetic isotope effect, this can result in materials with improved physical properties and enhanced performance.

THE IMPACT

ANSTO's National Deuteration Facility enables innovation across diverse sectors, including pharmaceuticals, cosmetics and personal care products, optoelectronics, advanced manufacturing, and mRNA technology. For example:

- Medical imaging agents - deuterating the ANSTO-developed radiotracer [^{18}F]PBR111 has been demonstrated to improve image quality by slowing the breakdown of the molecule in vitro and in vivo,
- Manufacturing - deuteration of mineral oil for a Japanese chemical manufacturer promoted R&D into new polymeric products and higher thermo-oxidative resistant oil for potentially better-performing lubricants.
- Photonics and semiconductors - demonstration of a better performing organic solar cell material in photovoltaic cells and semiconductors for molecular electronics by using deuteration, and
- Skin care products - deuteration of the sunscreen ingredient avobenzone (cause of poor performance of sunscreen products) enabled evaluation and understanding of the degradation of this compound.

Research Priorities

Health

Net zero future

ANSTO Capabilities

- Chemical deuteration
- Human Health

Collaborators/Client

Mitsui Chemicals
UNSW
Eurofins Dermatest

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Publications

dx.doi.org/10.1016/j.aca.2019.02.025
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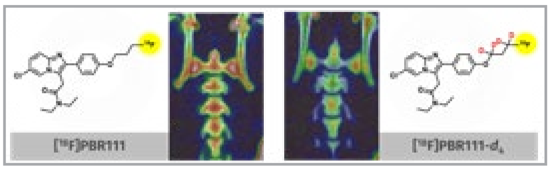

FIGURE 1:
Reduction in bone uptake of radioactivity due to the deuterium stabilized [^{18}F] PBR111-D$_4$ radiotracer used in PET imaging of neuroinflammatory disease.

Supporting advanced manufacturing in Australia

Establishing quality control and failure analysis for Conflux Technology

The Australian-based company, Conflux Technology, uses additive manufacturing to produce high-performance heat exchangers. Heat exchangers are used to transfer heat between two different mediums, typically to lower or raise temperatures, in a specific area of machinery. These devices have a range of advantages that include saving energy and improving performance by cooling engines. Conflux Technology produces heat exchangers for demanding applications across the aerospace, automotive, oil and gas, defence, and microelectronics industries. Over 90% of their production is exported overseas.

THE CHALLENGE

Additive manufacturing techniques like 3D metal printing allow manufacturers to produce complex parts that would not be possible using traditional methods such as casting and extrusion. Due to the small feature sizes and the large number of production variables associated with engineering such complex parts, quality control and failure analysis is paramount.

THE SOLUTION

With access to ANSTO's Australian Synchrotron, Conflux has been able to non-destructively inspect the internal structure of various manufactured parts in high resolution. To perform quality control, Conflux has been able to identify and eliminate defects and optimise the performance of manufactured parts. Conflux is also using the Australian Synchrotron for R&D on new part designs and to optimise manufacturing processes.

THE IMPACT

This work highlights the significant role ANSTO's Australian Synchrotron plays in supporting the Australian engineering industry and innovation. Supporting Australian industries, particularly those like Conflux Technology which supply international markets, is an important part of developing and sustaining our economy through advanced manufacturing practices.

Research Priorities

Secure nation

ANSTO Capabilities

- Synchrotron X-ray CT imaging

ANSTO Instruments

Imaging and Medical Beamline (IMBL)

Collaborators/Client

Conflux Technology

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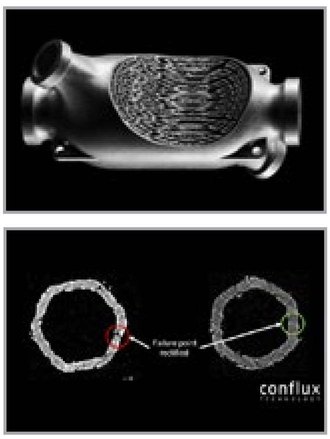

FIGURE 1:
Complex 3D printed structures inside the heat exchangers (top image – cutaway of heat exchanger), as well as observation of failure points that have been rectified (bottom image).

Sustainable nuclear medicine production

Reusable molybdenum-99 targets to lower costs and decrease nuclear waste

Molybdenum-99 (Mo-99) is a radioactive element that naturally decays to form the nuclear medicine technetium-99m (Tc-99m). Tc-99m is used worldwide to image and diagnose a range of illnesses, including heart disease and cancer). Every year, Tc-99m is administered to approximately 40 million people. The production of Mo-99 is part of ANSTO's core mission. ANSTO produces approximately 8-10% of the world's doses, which are packaged in Gentech Generators and shipped both nationally and internationally every week.

THE CHALLENGE

The current process of making Mo-99 was derived from technology developed in the 1950s and 1960s. The technology relies on a complex method of fully dissolving 'molybdenum targets'. These targets are metal plates containing uranium enriched with 19.75% uranium-235, which are irradiated in ANSTO's OPAL research reactor to produce the fission product, Mo-99. However, this process can lead to a relatively low yield of Mo-99 and produces undesirable nuclear waste in the form of other fission products. The challenge is to make Mo-99 more economical, use less U-235, and decrease waste.

THE SOLUTION

Current and previous work focused on neutronics modelling to determine yields from a porous reusable Mo-target. The team has gained a provisional patent and proof-of-concept experiments have begun. Experiments involve the fabrication and irradiation of simulated Mo-targets. The porous targets aim to use a smaller fraction of uranium-235, only 1-2%, compared with the current 19.75%. Following proof-of-concept, the team will work on implementing the technology for accelerator-based systems. By doing this, the technology could then be applied on a much smaller scale than current reactor-based systems.

THE IMPACT

This project protects Australia's sovereign capability to produce Mo-99. ANSTO will be able to produce Mo-99 more sustainably, at lower costs, while also decreasing its nuclear waste. The possibility of producing these improved Mo-targets at ANSTO's Lucas Heights facility will significantly reduce costs and give ANSTO a competitive advantage in the marketplace.

Research Priorities

Health

ANSTO Capabilities

- Neutron irradiation
- Neutron Activation Analysis
- Ion irradiation
- Scanning Electron Microscopy
- Thermogravimetry-Differential Scanning Calorimetry

ANSTO Instruments

OPAL Multi-Purpose Research Reactor
Particle Accelerators

Collaborators/Client

University of Wollongong

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Publications

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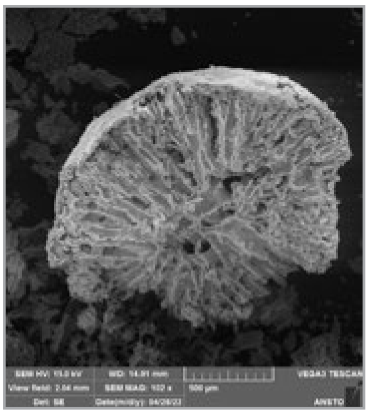

FIGURE 1:
Porous reusable molybdenum target that will hold a much smaller amount of uranium-235, producing cheaper molybdenum-99 and reducing nuclear waste.

Optimising steelworks operations

Understanding the inner workings of blast furnaces

To make steel, raw iron ore is smelted in a blast furnace with metallurgical coal. This process of smelting is complex and has led companies such as BHP to pursue better practices for optimal operational stability and productivity.

THE CHALLENGE

For the efficient operation of a blast furnace, operators need to understand the internal void structure of the iron ore lump and sinter, which influences the permeability of the iron layer during smelting. Previously, the internal structure of the iron layer has been estimated because typical computed tomography (CT) scans that use X-rays are blocked by the iron content. Therefore, more powerful techniques are needed to directly study the internal structures of the iron layer to improve blast furnace operations.

THE SOLUTION

Researchers utilised the Australian Synchrotron's Imaging and Medical Beamline (IMBL) because it offers very intense, very high-energy X-rays that can pass through the thick iron layers of the test samples. This powerful X-ray analysis was combined with neutron imaging using the Dingo instrument at ANSTO, which also offers very high penetration through metallic iron layers. The results allowed BHP to successfully visualise how iron ore lump and sinter were melting, and how networks of voids formed inside the melted iron. The work determined how different mixtures of lump iron ore and sinter behave together to better inform blast furnace operation.

THE IMPACT

This research was critical in developing more efficient steelworks practices. By using ANSTO's unique facilities, BHP was equipped to better understand the inner workings of blast furnaces. These investigations have helped to save energy as well as increase productivity and profitability.

Research Priorities

Net zero future

ANSTO Capabilities

- Neutron Scattering
- Synchrotron X-ray CT imaging

ANSTO Instruments

Imaging and Medical Beamline (IMBL)
Dingo
Neutron Imaging

Collaborators/Client

BHP
University of Newcastle

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Publications

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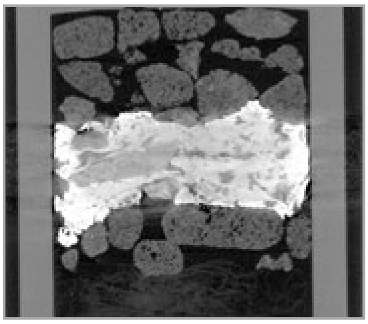

FIGURE 1:
Visualising voids in iron ore and coking coal layers during softening and melting (S&M) under load testing with ANSTO's Australian Synchrotron and Dingo instruments.

Lightweight fire-fighting suits

Innovative nanosheet technology improves firefighter mobility and safety

Thermoplastic polyurethane (TPU) and polyurethane foam (PUF) are widely used in manufacturing because they can be easily crafted into different shapes and forms, including heavy duty fire-fighting uniforms. However, easily the ignitable and highly flammable TPU and PUF, can also release toxic fumes and soot. Flame retardants are added to materials to reduce flammability and toxicity. However, the Australian fires suits made with traditional fire retardant are heavy and cumbersome. The materials can contribute to life-threatening dehydration and fatigue

THE CHALLENGE

Nanosheets containing transition metals, such as titanium, have emerged as a new option for lightweight flame-retardants. MXenes are 2D nanomaterials (nanosheets) that contain titanium and carbon (Ti_3C_2), which possess excellent fire and heat-resistant properties. When MXenes are combined with certain compounds (chitosan extract from prawn shell and phytic acid), an ultra-thin, durable, and strong fire-resistant coating is produced. Among existing flame-resistant materials, the ultra-thin Ti_3C_2 nanosheets provide better fire safety performance. The coating can also be used as a surface treatment for existing fire suits. However, there have been very limited studies exploring the potential of MXenes in the manufacture of fire suits to produce lightweight, protective equipment.

THE SOLUTION

Most experimental studies on MXenes utilised techniques that focused only on single- or few-layer Ti_3C_2 ultra-thin nanosheet technology. Researchers used small-angle neutron scattering on the Bilby instrument to characterise the interlayer structure of Ti_3C_2 ultra-thin nanosheets. The nanometre (10^{-9} m) to the micrometre (10^{-6} m) length scale was investigated to obtain structural information, such as average size, shape, and orientation, on the bulk material. Bilby data provided a deeper understanding of the fundamental properties by revealing the morphological structure and elemental distribution of chemically etched Ti_3C_2 ultra-thin nanosheets; and providing critical information on structural changes under temperatures between 20°C and 60°C.

THE IMPACT

This technology will alter the landscape of firefighting, by providing lightweight, fire-resistant safety suits. The new super-thin 2D nanosheets are far more effective flame-retardants than previously used materials. The nanosheet technology can be applied as a post-treatment on top of existing safety suits, as well as potentially in the manufacture of efficient lightweight protective equipment with anti-microbial features. Lightweight fire safety suits will lead to better health, safety, and decision-making, increasing firefighter mobility, and most importantly, saving more firefighter's lives.

Research Priorities

Environment

Net zero future

ANSTO Capabilities

- Small angle neutron Scattering

ANSTO Instruments

Bilby
Small Angle Neutron Scattering

Collaborators/Client

University of New South Wales

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Publications

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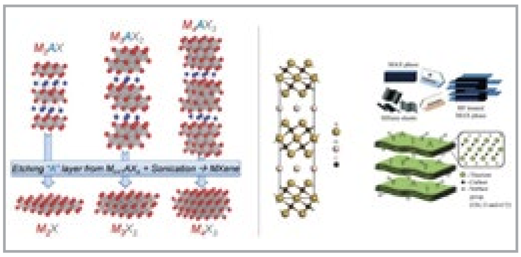

FIGURE 1:
Synthesis of MXenes from MAX phase Ti_3AlC_2.

Sustainable cooling and refrigeration

Advancing refrigerant materials with novel plastic crystals

Between 25-30% of the world's electricity is used for cooling and refrigeration. Current mechanisms of refrigeration use materials that are not environmentally friendly because of their potential to contribute to global warming.

THE CHALLENGE

Solid-state caloric effects are an alternative method of refrigeration. These employ a solid material as a refrigerant, which can dissipate heat and cause cooling. However, the application of these solid-state refrigerants is limited by the performance of current materials. To optimise these alternate refrigeration materials, a fundamental understanding of this cooling method is necessary.

THE SOLUTION

The team used neutron scattering instruments Pelican and Sika at ANSTO to investigate the properties of plastic crystals identified as a promising solid-state refrigerant material. They discovered the mechanism behind the colossal barocaloric effects from plastic crystals, which would allow significant cooling to occur under low pressure.

THE IMPACT

This investigation has led to a new class of materials, plastic crystals, with the potential to be used as an advanced, high-performing, environmentally friendly, and economical form of refrigeration.

Research Priorities

Net zero future

ANSTO Capabilities

- Neutron Scattering

ANSTO Instruments

Pelican
Time-of-flight Spectrometer

Sika
Cold Triple Axis Spectrometer

Collaborators/Client

Chinese Academy of Science
J-PARC
Osaka University
University of California Irvine
Central South University
Florida State University
National Institute for Materials Science
Spring-8
Centre for High-Pressure Science
and Technology Advance Research
National Synchrotron
Radiation Research Center
Shanghai Jiao Tong University

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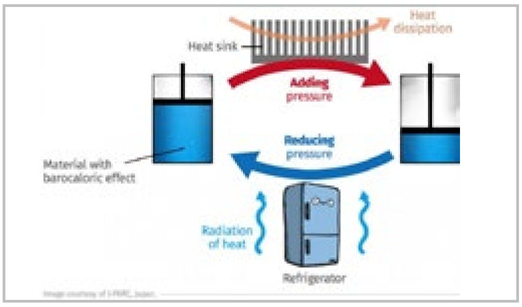

FIGURE 1:
The barocaloric effect.

Optimising high-strength low-alloy steel

Understanding the effect of steel structure on mechanical properties

The addition of carbides into high-strength low-alloy steels is known to improve steel strength. Carbides are compounds of carbon and a metal. An example is titanuim carbide. Carbon-metal combinations could be selectively chosen to improve the properties of steel for specific applications. This is particularly relevant to direct strip casting, which is a technique used to produce thin steels directly from a melt. Strip casting is one of the most environmentally friendly casting techniques.

THE CHALLENGE

Studies have shown that the addition of molybdenum favours the precipitation of finer interphase carbides, which improves the mechanical properties of steel. What remained poorly understood was clarifying how using different amounts of molybdenum-bearing carbide additives, and varied cooling temperatures and durations could affect the structure and mechanical properties of steel.

THE SOLUTION

To investigate how variable additions of molybdenum and varied cooling conditions influence the quality of high-strength low-alloy steels, the team used ANSTO's small angle neutron scattering instrument Quokka, in combination with atom probe tomography and electron microscopy. Together these techniques revealed detailed atomic scale (100 nm) structural information that was vital in understanding the mechanical properties of steel varieties.

THE IMPACT

This work demonstrated how a combination of advanced techniques, including ANSTO's high-powered Quokka instrument, can reveal structural details and their relationship with mechanical properties in different steel samples. By understanding the effect of structure on steel mechanical properties, it is possible to optimise industrially relevant materials for specific applications. This expertise has extended to research on the recycling of aluminium alloys.

Research Priorities

Environment | Net zero future

ANSTO Capabilities

- Neutron Scattering

ANSTO Instruments

Quokka
Small Angle Neutron Scattering

Collaborators/Client

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Publications

doi.org/10.1016/j.matchar.2020.110444

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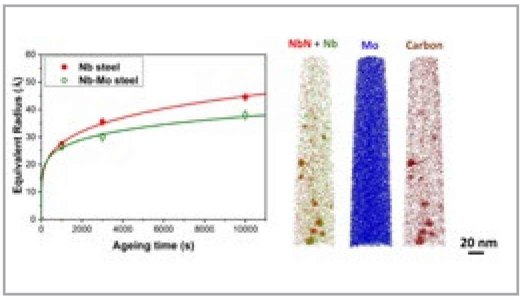

FIGURE 1:
Small angle neutron scattering on Quokka allows us to extract the average radius of the inclusions in the two different steels from the whole sample (left). Atom probe tomography (right) provides atomic structures of small section of the sample. The results are correlated with strength measurements to understand how the mechanical properties can be tuned by changing the structure.

Quantum technology

Enhancing the design of lanthanoid single molecule magnets

Single molecule and single ion magnets are an intriguing class of materials, which show unusual magnetic and chemical properties on a molecular level. This has made them obvious candidates for high-density data storage and as qubits for quantum computers, as well as potential use in spintronic applications.

THE CHALLENGE

While useful properties have been observed in single molecule magnets, many questions about their design and the fine-tuning of their properties remain unresolved.

THE SOLUTION

ANSTO scientists have had a long-standing collaboration to measure the ground state splitting of these molecules and have used structural analysis, by ab initio calculations to understand this quantum property. This information can guide the design of new materials.

Inelastic neutron scattering is the most direct and highest resolution way to determine crystal field splitting; it is vital for understanding the stability of single molecule magnets. The team used Pelican, a time-of-flight spectrometer, to obtain high-quality and high-resolution data which determined the ground state splitting with an accuracy that was not possible with any other technique. The National Deuteration Facility provided essential deuterated materials for this project. This work also made extensive use of the physical properties measurement system at the Australian Centre for Neutron Scattering to characterise the bulk magnetic properties and complement the inelastic data.

THE IMPACT

The combination of high-quality and high-resolution measurements on unique samples coupled with state-of-the-art ab initio calculations elucidated magneto-structural correlations in a range of single molecule magnets.

Scientists have also started to investigate the vibrational properties of single molecule magnets and are now in the process of using the same combined theoretical and experimental approach to understand vibrational relaxation in quantum states.

Understanding the vibrations allows the separation of them from the interesting magnetic signal and the pathways for a signal to relax, which could fundamentally limit the technological usefulness of these materials. With an enhanced design of single molecule magnets, other potential technological applications can be investigated.

Research Priorities

Net zero future

ANSTO Capabilities

- Neutron scattering
- Chemical deuteration

ANSTO Instruments

Pelican
Time-of-flight Spectrometer

Collaborators/Client

University of Melbourne

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Publications

doi.org/10.1071/CH21306
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doi.org/10.1002/ejic.201801306

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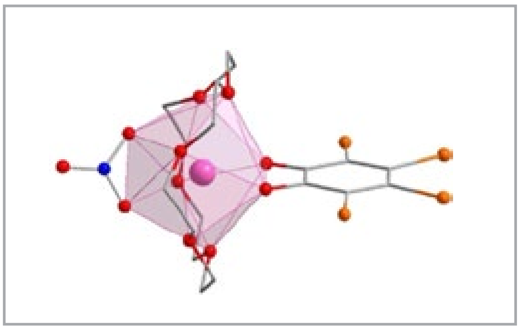

FIGURE 1:
An example of a single molecule magnet and analogous compounds studied. This example is $[Ln(18\text{-}c\text{-}6)(NO_3)(Br_4Cat)]\cdot CH_2Cl_2$ 18-c-6 = 18-crown-6; $Br_4Cat_2^-$ = tetrabromocatecholate.

Maintaining water utility infrastructure

Detecting and mitigating acid corrosion in sewer pipe concrete

Acidic conditions in sewer systems cause microstructural changes including dissolution and leaching by corrosion of the concrete pipes. The changes are attributed to the bacterial activity or mineral acids present in wastewater, which can lead to corrosive acidic solutions. Monitoring and mitigation of the corrosion experienced by concrete sewer pipes come at a significant cost, approximately millions of dollars per annum, to water utilities around the world.

THE CHALLENGE

To better understand, monitor, and detect corrosion in concrete sewer pipes, researchers conducted accelerated experiments using sulfuric acid (pH 1) on test concrete samples. They observed the formation of a distinct golden-brownish layer concentrated in iron. The iron-rich layer was not due to the presence of iron-oxidising bacteria or an iron-containing reinforcement bar (rebar). Rather, the iron-rich layer was found to be associated with the corroded area, a corrosion front, in all samples. To better enhance our understanding of this iron-rich layer and its relationship to the development of corrosion fronts in rebar-free cement, the internal structure of these cement samples needed investigation.

THE SOLUTION

The team used ANSTO's high-powered neutron tomography capability (DINGO) to non-destructively reveal the internal structure of the cement samples. Analysis showed the distribution of aggregates and sand grains within the cement, the presence of cracks and voids, and the thickness of the corrosion front. This technique is so powerful that it can distinguish between corrosion effects and irrelevant defects introduced during sample preparation. Results showed that the thickness of the corroded layer and the depth of the iron-rich layer depends on the amount of time the cement was immersed in acid. The detection of an iron-rich layer relates to the depth of concrete corrosion due to sulfuric acid attack.

THE IMPACT

This research developed a method for the early detection of acid corrosion in cement. Using ANSTO's DINGO instrument, researchers could automatically detect and locate the iron-rich layer and crack lines associated with a corrosion front to estimate the remaining service life of concrete sewer pipelines. This work facilitates timely corrective actions and could save water utilities millions of dollars each year.

Research Priorities

- Environment
- Net zero future

ANSTO Capabilities

- Neutron Scattering

ANSTO Instruments

Dingo
Neutron Imaging

Collaborators/Client

Macquarie University
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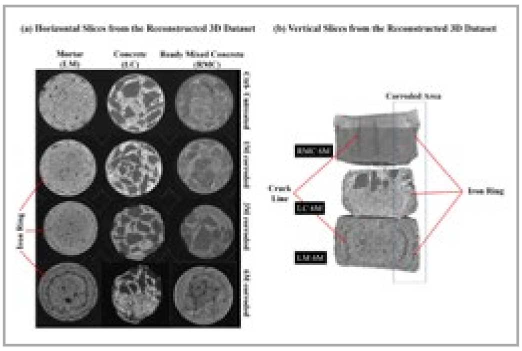

FIGURE 1:
Reconstructed 3D neutron tomography datasets of specimens (a) uncorroded and immersed in an acid bath for 1, 3, and 6 months, and (b) the corresponding vertical slices of 6 month corroded samples. The variations in the intensity of the lighter grey areas are due to chemical and/or physical density changes in the cement paste. Black areas are due to crack lines and voids within the samples. A dark greyish ring is observed in the images which contains a high concentration of iron, indicating the corrosion front.

Optimised nutritional supplements

A step toward better storage and delivery methods for fish oil

Fish oil is packed with omega-3 polyunsaturated fatty acids that have scientifically proven health benefits, such as lowering cholesterol and blood pressure and reducing the risk of heart attack and stroke. Omega-3s cannot be synthesised in the body, therefore the Heart Foundation recommends Australians consume between 2-3 servings of fish per week. Omega-3 supplements are also a popular method of reaching the recommended dose.

THE CHALLENGE

Major challenges in harnessing the benefits of fish oil include overcoming its unwanted flavours and strong odours while reducing oxidation to optimise the nutritional benefits. A key to enhancing fish oil for both storage and fortification of foods is efficiently encapsulating fish oil in nanoparticles. Although this has been broadly studied, the current methods of encapsulating fish oil vary in their effectiveness.

THE SOLUTION

The team efficiently encapsulated fish oil in nanoparticles using a vortex fluidic device (VFD). This device has diverse applications and can generate nanoscale particles more consistently and efficiently than traditional processing. Once this process to enhance the stability of the fish oil particles was achieved, researchers utilised small-angle neutron scattering on the Bilby instrument to understand the structure of the particles. This is an ideal technique to study this system as the VFD can be installed in the sample position and operated during Bilby analysis. Results showed that this technique produced highly homogeneous nanoparticles compared to conventional fish oil emulsions. This homogeneity appears to be the driving reason for the stability of the nanoparticles.

THE IMPACT

This work provides a huge step toward better storage and delivery methods for fish oil, in addition to other nutritional supplements. The encapsulated omega-3s were successfully shielded from oxidation, and effective in enriching the omega-3 in liquid food. Using a VFD, omega-3 nanoparticles were successfully created and blended into apple juice without a fishy taste. This research improves our ability to enhance the nutrient profile and preserve nutrients in food important for human health.

Research Priorities

Health

ANSTO Capabilities

- Deuteration
- Neutron Scattering

ANSTO Instruments

Bilby
Small Angle Neutron Scattering

Collaborators/Client

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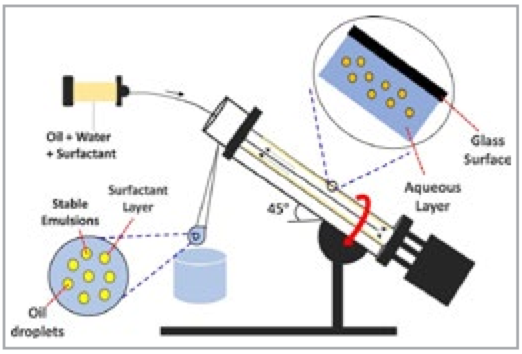

FIGURE 1:
The figure shows how a mixture of fish oil and surfactant in water are injected into the Vortex Fluidic Device (VFD). The spinning tube creates a thin layer of mixture under shear which homogenises the sample. As more sample is added the homogenised mixture is driven to the top of the tube where it is collected. The resulting nanoparticles have a narrow size distribution that are more stable than conventionally homogenised fish oil emulsions.

Maintaining critical transport systems

A new laser cladding maintenance strategy for light rail repairs

Melbourne is home to the world's largest light rail system, which is heavily relied upon for sustainable passenger transit in urban areas. The continued rise in passenger numbers heightens the operating conditions by requiring increasing speeds, loads, and service frequency. These increasing operations cause the low-carbon rail grades commonly used in Australia to undergo premature wear, rolling contact fatigue, and plastic deformation.

THE CHALLENGE

Maintaining rail components typically involves either grinding to remove damaged surface layers – a short-term fix, or welding which introduces tensile stress. These are expensive rail replacement procedures and are highly disruptive to network operations. Laser cladding is an alternative repair technique that uses a laser to melt a metallic powder at the rail surface to improve wear performance. However, the heat used to melt the cladding powder affects a small region below the cladding substrate, introducing tensile residual stresses detrimental to the operation lifetime. To determine rail wear and fatigue, it is essential to understand residual stress generation after laser cladding repairs.

THE SOLUTION

The team used neutron diffraction techniques to develop an improved laser cladding-based maintenance strategy to prolong the operational lifetime of light rail components. This work established the influence of various cladding alloys, railway curvature, and finishing procedures such as grinding effects, on internal stress. Comprehensive and accurate stress analysis was essential to determine the optimum cladding alloys and parameters, microstructure and mechanical properties, that match the rail substrate while minimising residual stress. Neutron data non-destructively determined useful microstructural information on full-scale rail components.

THE IMPACT

This work provides the foundation to develop an in-situ maintenance and repair strategy that can be safely, efficiently, and economically applied to a variety of light rail components. The criteria will help to improve the operational lifetime of a variety of rail components and can be applied to other industries utilising laser cladding technology — helping to meet the challenges of maintaining critical infrastructure for the future.

Research Priorities

Net zero future

ANSTO Capabilities

- Neutron Scattering

ANSTO Instruments

Kowari
Strain Scanner

Collaborators/Client

Monash University
Laser Bond Limited
Yarra Trams

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doi.org/10.3390/ma16010232

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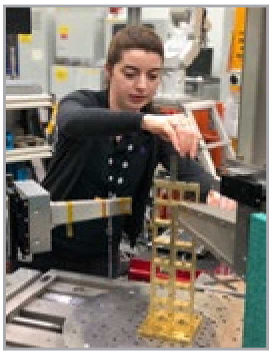

Researcher Olivia Kendall using the Kowari strain scanning instrument to undertake rail cladding investigations.

Multiscale modelling

Developing carbon/carbon composites and graphite for high-temperature systems

The need for materials with excellent mechanical properties at high temperatures has increased with the development of Generation IV nuclear reactors. Carbon/carbon (C/C) composites (graphite reinforced by carbon fibres) have been identified as candidate materials for use in control rods, hot duct assembly, or heat exchangers, particularly for the Very-High-Temperature Reactor (VHTR) and the Molten Salt Reactor (MSR). C/C composites and structural graphite are also being investigated as in-core materials for future fusion- and fission-based small modular energy-generation systems. Structural graphite has high thermal and chemical resistance and good mechanical properties suitable for components in fission-based systems.

THE CHALLENGE

To design safe C/C composite and graphite components for nuclear applications, it is crucial to understand the mechanical behaviour, damage resistance and failure mechanisms under different loading conditions and temperatures, and the effect of imperfections resulting from the manufacturing process.

THE SOLUTION

Multiscale finite element (FE) simulations can build numerical models to capture C/C composite and graphite's mechanical and fracture behaviour at different operating temperatures. The team devised C/C composite and graphite models to assess the effect of porosity and imperfections on mechanical performance based on an analysis of microscopic images. These models can be used to predict the macroscale behaviour, plastic damage, and onset of cracking and crack development of C/C composite and graphite.

THE IMPACT

This work developed multiscale simulations (numerical models) that can predict the mechanical behaviour of C/C composite and graphite operating in high-temperature conditions, ensuring safe and reliable performance when used in energy generation systems. These models can replace time-consuming experimental testing and speed up the development and deployment of novel high-temperature systems. The models developed in this collaboration with ANSTO could also have aerospace and defence applications.

Research Priorities

Net zero future

ANSTO Capabilities

- Computing Facilities
  High Performance Computing Clusters
- Materials Characterisation
  Mechanical Testing, Microscopy

Collaborators/Client

Idaho National Laboratory
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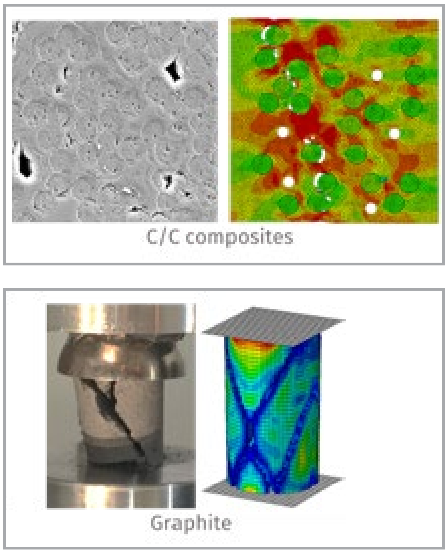

FIGURE 1:
Microstructure and FE simulation of C/C composite (top); mechanical testing and FE simulation of graphite (bottom).

Advanced materials characterisation

Assessment of material degradation in operating conditions

To maintain safe and reliable operations in industrial settings, it is crucial to assess material behaviour and degradation under operating conditions. This assessment is particularly vital for critical national infrastructure, including power stations, where in-service material inspection and surveillance programs play a pivotal role. By continuously analysing material behaviour, engineers can develop advanced materials and design resilient infrastructure systems capable of withstanding extreme conditions, ultimately enhancing performance and ensuring the longevity of critical infrastructure.

THE CHALLENGE

Any high-temperature engineering system operating under constant or varying stress and temperature conditions is vulnerable to high-temperature creep and fatigue damage, leading to premature failure of engineering components. The detrimental effects of high-temperature creep and fatigue damage, such as component distortion, misalignments, and catastrophic failures, underscore the critical importance of implementing robust monitoring and maintenance protocols within high-temperature engineering systems.

THE SOLUTION

ANSTO's researchers used world-class diffraction-based techniques to gain a detailed understanding of material microstructure and its degradation in service conditions. The team has also developed several advanced analysis and modelling tools which provide an in-depth understanding of a materials' behaviour in operating conditions and modelling of microstructural evolution at high temperatures. ANSTO's researchers have made significant strides in unravelling the intricate details of material microstructure and degradation mechanisms.

THE IMPACT

This work has profoundly impacted our understanding of material behaviour in operation. This knowledge is pivotal for engineers, providing the necessary insights to ensure the safe and reliable operation of high-temperature engineering systems, such as power plants. The ability to accurately assess high-temperature material damage in engineering components, this work empowers engineers to strategically plan outages, avoid unexpected shutdowns, and prevent catastrophic failures. Through continuous monitoring, early signs of degradation can be promptly identified, allowing for timely preventive actions. Moreover, these findings offer invaluable data that enable the evaluation of remaining useful life, optimisation of maintenance strategies, and efficient allocation of resources.

Research Priorities

Net zero future

ANSTO Capabilities

- High temperature creep testing
- Electron Backscatter Diffraction
- Energy Dispersive Spectroscopy
- Transmission Electron Microscopy

Collaborators/Client

University of New South Wales
University of Sydney
Shanghai Institute of Applied Physics (SINAP)

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Publications

doi.org/10.1016/j.mtla.2021.101069
doi.org/10.1016/j.mtla.2019.100513
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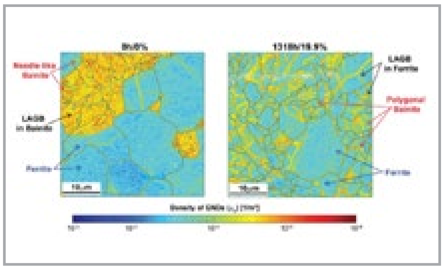

FIGURE 1:
High-resolution maps showing the distribution of geometrically necessary dislocations in the as-received microstructure (0 h/0%) and crept microstructure (1318 h/19.9%).

Mitigating welding induced distortion

Computational welding mechanics provides solution

Weldments are subjected to large shrinkage forces which might lead to significant distortions when joining thin plates (e.g. during ship building). These might then negatively impact further assembly and overall in-service performance of a welded part or an assembly.

THE CHALLENGE

To mitigate distortion, the manufacturing industry typically adopts an expansive trial-and-error approach to find an optimum weld sequence to minimize the welding distortion. This is a time-consuming process due to the repeated reworks as a result of the misalignment of distorted panels. Even if a panel's distortion is somewhat reduced after finding an optimal weld sequencing, the implication of these changes on the residual stress field and the weld microstructure are not well understood.

THE SOLUTION

A sequentially coupled multi-physics numerical weld modelling was developed to investigate and mitigate welding distortion. A validated welding model is used to assist in further optimization by calibrating a less complex fast-to-solve numerical model. ANSTO's research team was able to accurately predict the welding-induced distortion and residual stresses while shedding light on the effect of the weld sequencing on the weld microstructure. Developed numerical models provide an insight into underlying thermo-physical, thermo-metallurgical and thermo-mechanical processes taking place during the welding process and thus helping the manufacturing industry to further optimise their welding practices. ANSTO jointly works with BAE Systems Australia and the University of Wollongong under the auspices of the Defence Materials Technology Centre (DMTC) on improving welding practices in shipyards through numerical simulations.

THE IMPACT

ANSTO's multi-physics welding simulations can accurately predict welding-induced distortion and residual stress as well as resulting weld microstructure which governs the performance of weldment or a welded assembly in-service conditions. By employing a developed modelling framework it is possible to eliminate an expensive trial-and-error approach and mitigate the welding-induced distortion while also gaining an understanding of the residual stress field, and weld microstructure for optimal performance of welded structures.

Research Priorities

Net zero future

ANSTO Capabilities

- Materials testing, Residual stress measurements (Synchrotron X-ray, neutron and contour)

Collaborators/Client

BAE systems Australia
University of Wollongong
Defence Materials Technology Centre (DMTC)

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Publications

doi.org/10.1016/j.commatsci.2011.10.026
doi.org/10.1016/j.ijsolstr.2011.07.006
doi.org/10.1016/j.ijpvp.2017.04.006
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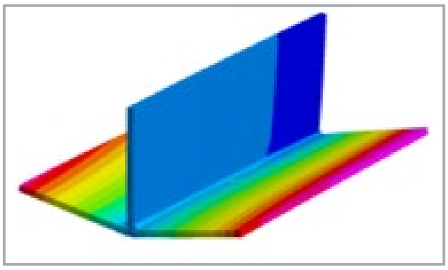

FIGURE 1:
(Top) Distortion in welded panel of frigate.

FIGURE 2:
(Bottom) Welding induced distortion.

Novel solar solutions

Flexible organic solar cells for superior energy performance

With increasing energy requirements, solar represents a vast renewable energy resource. Current photovoltaic (PV) solar panels are expensive to process and limited in functionality. They are primarily manufactured from silicon, which is heavy and rigid. Organic solar cells present an easier and cheaper alternative. They are ultralightweight and flexible, and less difficult to manufacture, with an expanding range of applications.

THE CHALLENGE

Before organic solar cell materials can be commercially viable, higher power conversion efficiencies and better mechanical properties must be developed.

THE SOLUTION

This work developed ultra-flexible, ultra-thin (0.003 mm) organic solar cells (OSCs) that achieved a record power conversion efficiency (12.3%). The OSC showed minimal degradation over 1000 cycles of bending and compression-stretching. The team used the small and wide-angle X-ray scattering (SAXS/WAXS) beamline at the Australian Synchrotron in combination with the soft x-ray (SXR) beamline to characterise the structure and orientation of molecules within the organic thin film of the solar cells and demonstrate how these features can improve the properties and activity of the solar cells.

THE IMPACT

This work developed new flexible solar cells with superior energy performance. The challenge now lies in the process of up-scaling these solar cells and combining them with other components to develop advanced devices for commercial applications.

Research Priorities

Net zero future

ANSTO Capabilities

- Synchrotron X-ray scattering
- Synchrotron X-ray spectroscopy

ANSTO Instruments

Small Angle X-ray Scattering (SAXS) Beamline
Wide Angle X-ray Scattering (WAXS) Beamline
Soft X-ray Spectroscopy (SXR) Beamline

Collaborators/Client

Monash University

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Publications

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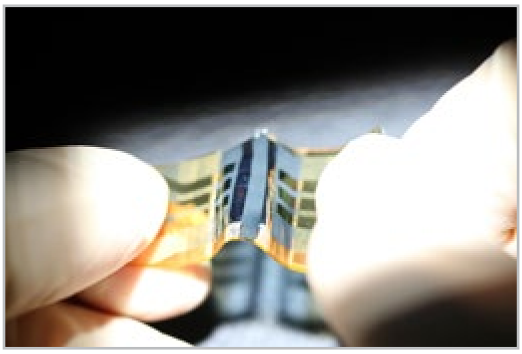

FIGURE 1:
Flexible organic solar cell.

Green hydrogen

A simple and low-cost method to generate hydrogen

As a clean burning fuel, hydrogen is a promising alternative to fossil fuels and can be used for energy transport and storage. However, current methods of generating hydrogen such as extracting it from water (H_2O) or natural gas is an energy-intensive process that negates the reduction in carbon emissions. Clean, energy-efficient methods such as using renewable energies can produce 'green' hydrogen fuel.

THE CHALLENGE

Photo-generated hydrogen would allow the capture of the sun's energy in chemical bonds to split water (H_2O) and generate hydrogen. Several research groups in Australia are studying the production of advanced catalytic materials to help trap energy in sunlight. The active component of catalysts is often metals. The finer a catalyst is dispersed, the more active it becomes. Current methods rely on costly precious metals and can be highly energy intensive.

THE SOLUTION

Researchers at the University of Adelaide are working on catalysts with particles comprising only one or a few atoms to achieve ultimate dispersion. Using highly specific spectroscopies at the Australian Synchrotron (X-ray absorption spectroscopy and soft X-ray spectroscopy), helped researchers to develop nickel-containing catalysts that show excellent activity to reduce CO_2 to CO.

Researchers from the University of Adelaide used the soft X-ray beamline to investigate the chemical properties of novel nickel-carbon nanoparticles with high catalytic activity and corrosion resistance. The results demonstrated strong electron confinement properties in the nanoparticles which explains their excellent catalytic properties.

THE IMPACT

These catalysts can be used to improve industrial processes and demonstrate a simple and low-cost method to generate hydrogen (splitting water using energy from sunlight) with an outstanding efficiency of 31%. It also opens a new promising avenue of research using similar compounds with tailored chemistry to further lead to green and sustainable sources of energy storage and production.

Research Priorities

Net zero future

ANSTO Capabilities

- Synchrotron X-ray spectroscopy
- Synchrotron X-ray diffraction

ANSTO Instruments

X-ray Absorption Spectroscopy (XAS) Beamline
Soft X-ray Spectroscopy (SXR) Beamline
Powder Diffraction (PD) Beamline

Collaborators/Client

University of Adelaide

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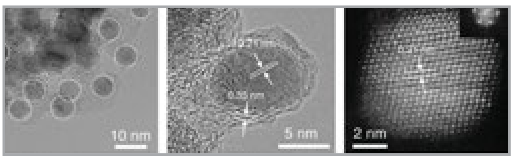

FIGURE 1:
Electron microscopy images of the nickel-carbon nanoparticles.

Carbon negative metal mining

Extracting critical metals from waste

Mining underpins the Australian economy and demand for critical metals such as nickel and cobalt is expected to increase dramatically as the world moves towards a green energy economy. The mining industry also produces waste streams that are regulatory and economic liabilities, including stockpiled mineral waste, acidic waste, and CO_2 emissions. It is necessary to meet the growing demand for critical minerals, while also sourcing and processing them in an ethical and environmentally conscious way.

THE CHALLENGE

Nickel and cobalt are typically mined from ultramafic igneous rocks, rich in magnesium and calcium that are an ideal feedstock for sequestering CO_2 via natural rock weathering. This process is accelerated when rocks are crushed and exposed with a high surface area, such as in the waste tailings from mining. With the increase of critical mineral mining and associated tailings production over the coming decades, an opportunity exists to couple critical metal production with accelerated carbon capture in these materials to support green technology.

THE SOLUTION

This team saw an opportunity to reframe mining waste (mineral wastes, acids, and CO_2) as source materials for carbon capture. By repurposing conventional technologies, the team developed a low-energy input and low-cost process to create value from waste and offset CO_2 emissions from mining. Led by Dr Jessica Hamilton, the team was able to scale up acid treatment systems from the lab to the field using experiments on the X-ray fluorescence microscopy (XFM) beamline. XFM was essential in characterising valuable trace metals in the acid-leached tailings and revealing metal mobilisation at a grain scale, allowing the team to 'see' how these metals were redistributed in the material after treatment.

THE IMPACT

This research developed an innovative process of recovering critical metals from waste using a carbon neutral and potentially carbon negative method. With this process, relatively small changes in tailings infrastructure and management can lead to a sector of the mining industry becoming carbon neutral or potentially carbon negative while generating valuable products. Additional environmental benefits could be realised through the reduced footprint and legacy of mining. This work has fed into a larger, current industry-partnered international research collaboration to further scale up this technology for a pilot study at a mine.

Research Priorities

Environment

Net zero future

ANSTO Capabilities

- Synchrotron X-ray fluorescence microscopy

ANSTO Instruments

X-ray Fluorescence Microscopy (XFM) Beamline

Collaborators/Client

University of Alberta

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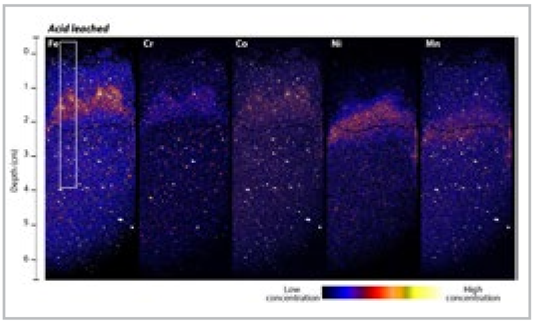

FIGURE 1:
An X-ray fluorescence microscopy image of the elemental distribution of metals in treated mining tailings.

Optimising radiation shields

Protecting satellites against harsh ionising radiation in low-earth orbit

In Earth's orbit, space-based radiation fields can disrupt electronic systems and cause mission failure. For Australian companies seeking to enter national and international space sector supply chains, the use of space-qualified components can be expensive, limiting the technology available for agile development..

THE CHALLENGE

Technological development is needed to protect satellites against harsh ionising radiation in low-earth orbit.

THE SOLUTION

Titomic will use Titomic Kinetic Fusion technology to mitigate ionising radiation, prolonging a satellite's lifespan. The cold spray additive manufacturing and coating process allows the deposition and fusion of dissimilar metals. ANSTO conducted a detailed Monte Carlo simulation modelling the interaction of ionising radiation in a range of different multi-layered shields. They subsequently tested samples of these shields at ANSTO's high-dose gamma irradiation facility (GATRI). The optimised shields will help protect satellites against the harsh ionising radiation in low-earth orbit for South Australian company Fleet Space Technologies.

THE IMPACT

The radiation shields developed for Fleet Space Technologies are expected to use the world's first fully additive manufactured (3D printed) satellites, due for launch in 2023.

Research Priorities

Net zero future

ANSTO Capabilities

- Gamma radiation
- Radiation modelling

ANSTO Instruments

Gamma Technology Research Irradiator (GATRI)

Collaborators/Client

Titomic

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Fleet Space's Alpha satellite prototype illustration (Courtesy: Titomic).

Remediating PFAS contamination

Using autoradiography techniques to image the micro-distribution of PFAS in concrete

Since the 1950s, synthetic per- and poly-fluoroalkyl substances (PFAS) have seen their widespread application in a variety of industrial and consumer products. PFAS have a unique ability to repel water and organic substances. Such applications could be seen in fire retardant equipment, non-stick kitchen equipment and appliances.

THE CHALLENGE

Due to the high mobility and persistence of many PFAS, which can accumulate in the environment, there is widespread concern regarding the risk of cancer, lower fertility rate, and children/foetal development delays among other potential health effects. Efforts are being focused on developing remediation options for contaminated media such as concrete. Understanding the micro-scale properties of PFAS within concrete will inform both modelling efforts to better understand PFAS mobility and larger-scale remediation, particularly at sites exposed to years of contamination, such as airports and industry sites.

THE SOLUTION

ANSTO performed autoradiography analysis on carbon-14 labelled, PFAS-impregnated samples of aged concrete prepared at CSIRO. This preliminary study evaluated whether autoradiography techniques can be used to map the mass/activity distribution of carbon-14 labelled PFAS compounds in the concrete. The Biosciences Biology and Preclinical Imaging team used a biomolecular imager, Typhoon 5, to analyse samples. If deemed suitable, subsequent studies will focus on assessing the mobility of the labelled PFAS in response to the application of prospective remediation options aimed at displacing adsorbed PFAS.

THE IMPACT

This pilot study demonstrated the feasibility of autoradiography techniques in imaging the micro-distribution of PFAS in concrete, despite the small amount of PFAS present in the samples. Future studies plan to analyse the clearance rate of PFAS-contaminated samples with various treatments. This work will help to better understand the mobility of PFAS and assist with the remediation of PFAS contamination in Australia.

Research Priorities

Health | Environment

ANSTO Capabilities

- Autoradiography

ANSTO Instruments

Typhoon 5 Biomolecular Imager

Collaborators/Client

CSIRO

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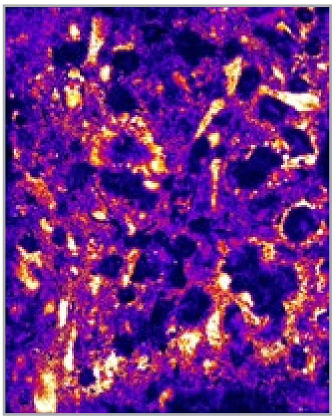

The image produced from autoradiography depicting the distribution of ^{14}C-PFAS within the concrete slab.

Testing for PFAS

Nuclear reaction analysis provides a screening approach

Per- and poly-fluoroalkyl substances (PFAS) are a group of over 9000 diverse fluorinated compounds known for their resistance to heat, stains, grease, and water due to the strong carbon-fluorine bond. However, these properties also result in long environmental lifetimes and bioaccumulation, leading to increased human exposure. Research links PFAS to various health issues, including cancer, fertility problems, and compromised immunity.

THE CHALLENGE

In response, the National PFAS Position Statement (2018) was adopted by all Australian governments, committing to phasing out PFAS in industries. In 2021, the Australian Packaging Covenant Organisation (APCO) and Planet Ark conducted a pilot study with ANSTO and Envirolab titled “PFAS in Fibre-Based Packaging” to assist businesses in identifying and eliminating such products. Detecting PFAS in these materials is challenging and costly, especially when its presence is unknown. Could ANSTO’s particle-induced gamma-ray emission (PIGE), an ion beam analysis technique, be utilised to rapidly screen for total fluorine in packaging?

THE SOLUTION

PIGE, available at the ANSTO Centre for Accelerator Science, is a form of nuclear reaction analysis used for surface analysis. By directing a MeV proton beam onto a sample, this technique can penetrate approximately 100 µm, exciting the nuclei and emitting characteristic gamma rays. PIGE is particularly effective in quantifying light elements like fluorine, which are difficult to analyse using other X-ray methods. With minimal sample preparation, the multi-sample cartridge allows efficient processing of large sample numbers. Analysis for each sample takes only minutes, providing fluorine concentration down to ~40 ppm. Knowing which surfaces contain fluorine helps identify when and where it was added. Samples with elevated fluorine concentration can be further analysed for specific PFAS compounds, as the samples remain intact. The testing cost is lower and faster than targeted PFAS techniques while potentially representing all possible PFAS substances.

THE IMPACT

The pilot study demonstrated the effectiveness of PIGE in rapidly identifying the likely presence of PFAS in various fibre-based recyclable or compostable packaging. These packaging materials have the potential to contaminate food, environmental systems, and bioaccumulation over time. To mitigate these risks, APCO is collaborating with the industry to phase out PFAS in food packaging by 2025 aligning with National goals. The study’s outcomes underscore the value of PIGE as a screening approach for PFAS.

Research Priorities

- Health
- Environment

ANSTO Capabilities

- Total fluorine analysis via ion beam analysis
- Centre for Accelerator Science

ANSTO Instruments

STAR
2MV Tandem Particle Accelerator

Collaborators/Client

APCO
Department of Agriculture, Water and the Environment
Envirolab
Planet Ark

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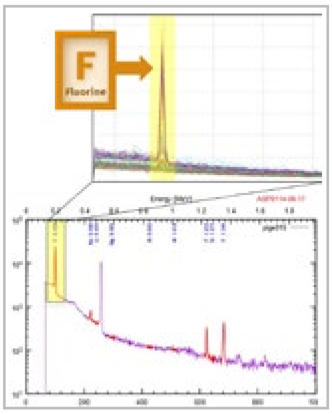

FIGURE 1:
(Bottom) Typical PIGE spectrum, (Top) Highlighted region associated with the 197keV gamma energy peak for fluorine. Multiple fluorine peaks have been overlayed in this image, the different peak heights are proportional to different fluorine concentrations.

Improving polymer manufacturing

Understanding the solubility of polymer substances in mineral oil

Polymer materials are integral for packaging, appliances, construction, and other applications. To improve the processing of polymers (i.e., by enhancing polymer softness and malleability), mineral oil is used as an additive solvent during manufacturing. However, the oil must be sufficiently soluble with the polymer. Understanding the solubility of polymers in mineral oil is critical for optimising the manufacturing of new and improved polymers.

THE CHALLENGE

Understanding the solubility of polymers in mineral oil is difficult because both substances are composed of hydrocarbon materials. The hydrogen atoms contained in both the polymer and the oil can be difficult to distinguish, making it challenging to observe interactions between the polymer and the oil. Therefore, a method of labelling the hydrogen atoms is needed to distinguish between each substance.

THE SOLUTION

The National Deuteration Facility (NDF) at ANSTO has devised a new one-pot method of labelling deuterium (the heavy isotope of hydrogen) in the mineral oil solvent on a multigram scale. Deuteration involves exchanging the hydrogen atoms of the mineral oil with deuterium (hydrogen-2) atoms. Deuteration makes the mineral oil distinguishable from the polymer during analysis using neutron scattering experiments so that the structure of the dissolved polymer can be observed. This allowed the team to then use ANSTO's small angle neutron scattering (SANS) instrument analysis to discern between polymer and oil additives and better understand the solubility interactions between the polymer and the oil.

THE IMPACT

This work was vital in supporting industry research by Japanese chemical manufacturer Mitsui Chemicals that sought to better understand the solubility of polymer substances in mineral oil. The team developed a novel and simple method using deuteration that was fundamental in facilitating neutron scattering experiments needed to improve polymer production. This work could facilitate other lines of enquiry for polymer manufacturing, healthcare, cosmetics, and other industries that require improved polymer products.

Research Priorities

Net zero future

ANSTO Capabilities

- Chemical Deuteration
- Neutron scattering

ANSTO Instruments

Quokka
Small Angle Neutron Scattering

Collaborators/Client

Mitsui Chemicals Inc

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Publications

doi.org/10.1039/D0PY00690D

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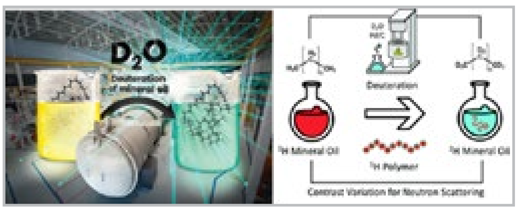


FIGURE 1:
Part of this work was published in the RSC Journal Polymer Chemistry and featured on the inner cover.

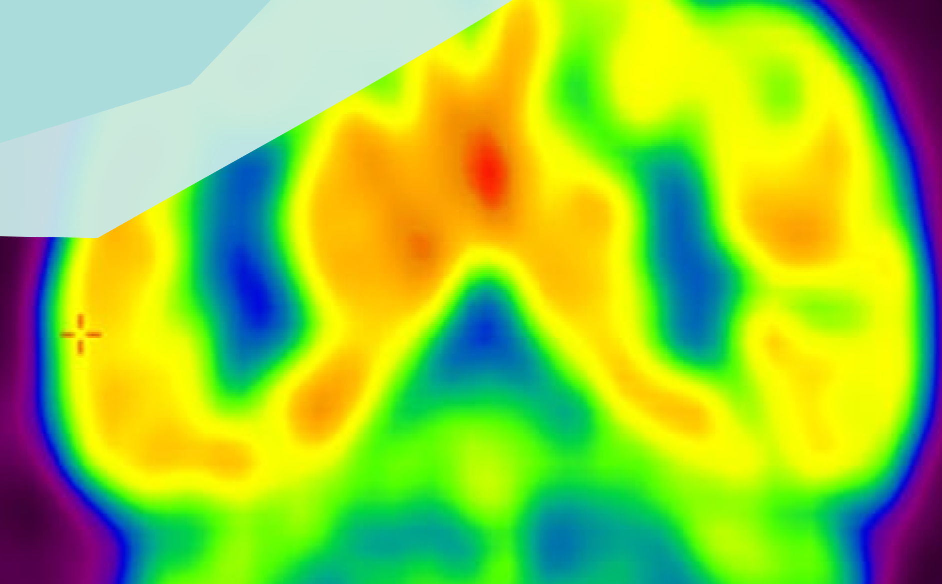
Improving health with nuclear technologies

Improving the health of Australians by using nuclear technologies in the diagnosis and treatment of current and emerging diseases is a major focus of research by ANSTO and external collaborators.

With experience in understanding the beneficial impacts of radiation, and the use of radioisotopes as radiotracers and pharmaceutical agents, ANSTO's health research has enabled progress against malignancies including breast, prostate and difficult-to-treat cancers.

ANSTO was proud to support a range of outstanding COVID-19 research by Australian scientists during the pandemic.

There are case studies of more specialised areas of investigation, including the impact of nanoplastics, understanding the impact of radiation on humans in space, improved drug delivery systems and the development of antibacterial and antiviral therapeutics.



Tackling antibiotic resistance

How peptides from green tree frogs can help to produce new antibiotics

Antibiotic resistance is an increasing health concern as what were once treatable infections are becoming untreatable. More than half a million deaths are estimated to occur globally every year due to antimicrobial resistance.

THE CHALLENGE

New antibiotic treatments are needed to combat antibiotic-resistant diseases. Antimicrobial peptides (AMPs) are one option being explored to address antibiotic resistance. AMPs attack the bacterial cell membrane and cause catastrophic damage to the bacterium. Any resistance the bacterium could have developed prior to this attack is now highly unlikely to occur. Three main challenges exist in using AMPs as a therapeutic agent:

- AMPs are broad spectrum and generally not specific;
- AMPs can attack mammalian (e.g., human) cells; and
- delivery of AMPs to the cells can be difficult.

THE SOLUTION

Critical solutions to these challenges involve understanding how AMPs interact with bacterial and mammalian cell membranes, and how AMP aggregates form within a membrane. This study used a synthetic version of an AMP known as maculatin 1.1. Derived from the skin secretions of the Australian green-eyed tree frog (Litoria genimaculata), maculatin 1.1 forms part of the frog's innate immune response to ward off infections from bacteria. Maculatin 1.1 is most effective at killing bacteria such as Staphylococcus aureus (commonly known as golden staph). To understand its structure and function, the team labelled one-half of the maculatin 1.1 with deuterium (a stable type of hydrogen). By labelling different molecules with deuterium using deuteration facilities at ANSTO, it was easier to identify them within a complex biological system using neutron scattering. The team then used neutron reflectometry on the Platypus instrument to observe how maculatin 1.1 inserted itself into various membranes. The membranes chosen were modelled from a red blood cell or a bacterial cell. These techniques allowed scientists to observe how maculatin 1.1 assembles in model cell membranes to conduct anti-microbial action.

THE IMPACT

The results provide pivotal information on how antimicrobial peptides (AMPs) could be used as a new class of antibiotics to overcome multi-drug-resistant bacterial infections. This work provides insights into how naturally occurring AMPs target bacterial membranes to kill bacterial cells. Since there are a wide variety of AMPs, this work highlights how AMPs assemble in a cell membrane. This work is essential in avoiding potential harm to human cells if AMPs are used therapeutically.

Research Priorities

Health

ANSTO Capabilities

- Deuteration
- Neutron Scattering

ANSTO Instruments

Platypus
Neutron Reflectometer

Collaborators/Client

University of Melbourne

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Publications

doi.org/10.1016/j.bbamem.2020.183204
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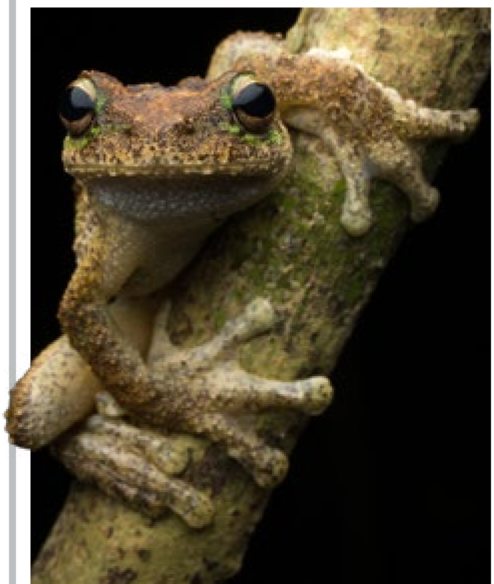

The green-eyed tree frog (*Litoria genimaculata*) whose skin secretions contain an antimicrobial peptide (AMP) known as maculatin 1.1.

Nanoplastics research

Characterising the effects of nanoplastics within the human body

There is concern about the increasing quantities of plastic waste, which undergo physical and chemical breakdown to form minute particles (e.g., microplastics and nanoplastics), entering the environment.

THE CHALLENGE

Studies on the of engineered nanoplastics used in biomedical applications have indicated they gain easy entry and mobility within the body, often side-stepping important biological barriers and defence mechanisms. The potential toxicity of nanoplastics that form in nature is poorly understood.

The toxicity of nanoparticles is directly linked to their physical and chemical properties. When nanoplastics enter the body, they are surrounded by layers of proteins, known as a "protein corona".

A major challenge in understanding the toxicity of nanoplastics lies in understanding the links between their properties and biological effects, which are known to be protein-corona dependent.

THE SOLUTION

To develop a better understanding of the biological response to nanoplastics, this work investigated a model system of polystyrene nanoplastic and human serum albumin (HSA) protein (a nanoplastic-protein corona combination). The team used a range of techniques to characterise the size, composition, and geometry of the nanoplastic-protein complex. It was found that small angle neutron scattering is the effective method to investigate the properties of the protein corona. Classical crystallography techniques, such as diffraction, prevent clear signals due to the disordered atomic arrangement of the nanoplastic-protein combination. With neutrons, however, the signals from nanoplastics can be effectively eliminated, allowing the detection of clear signals from the protein coronas. Scientists discovered that the protein (in this case HSA) actively participated in bonding with the nanoplastic, while the size of the plastic particle, charge on particle and pH play a key role in characterising the corona that forms.

THE IMPACT

This research conducted on Bilby instrument at ANSTO provided vital data that was needed to better understand nanoplastic toxicity in the human body. The work reveals new details about the formation of the protein corona on nanoplastics and describes the molecular details of protein-corona structure that is integral in understanding nanoplastic toxicity. These findings will have implications for future studies that investigate nanoparticle toxicity by providing a fundamental understanding of the interactions between nanoparticles and biomolecules.

Research Priorities

Environment

Health

ANSTO Capabilities

- Neutron Scattering

ANSTO Instruments

Bilby
Small Angle Neutron Scattering

Collaborators/Client

University of Auckland
Flinders University

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Publications

doi.org/10.1021/acs.bioconjchem.9b00015

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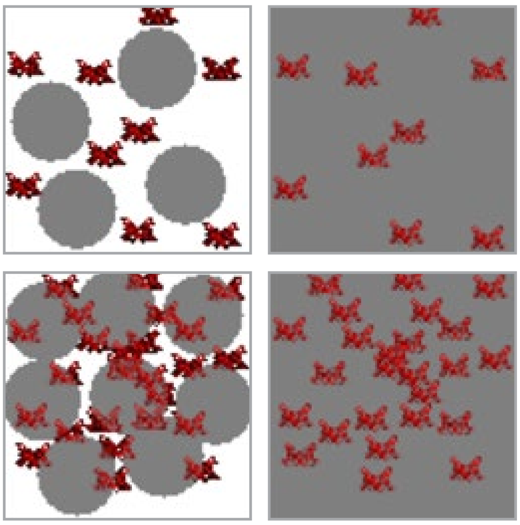

FIGURE 1:
Small angle neutron scattering on the Bilby instrument uncovered the structure of two different types of protein corona (top – loosely packed proteins; bottom – tightly packed proteins) that bonded onto polystyrene nanoplastic particles. This information revealed the properties of the corona and how they interact with different-sized nanoplastics.

Innovations in diagnosing and treating malaria

A portable diagnostic tool and progress towards better vaccines

Malaria is a major blood-borne disease spread by mosquitos around the globe. In 2019, there were approximately 230 million cases of malaria infection and around 409,000 deaths.

THE CHALLENGE

Although malaria is treatable, early diagnosis has been difficult to implement, particularly in developing countries. Researchers have also struggled to understand how malaria parasites infect our blood cells.

THE SOLUTION

To overcome obstacles in the diagnosis and treatment of malaria, different groups of ANSTO scientists have collaborated with visiting scientists from around Australia who have harnessed the high precision capabilities of three beamline instruments, IRM, MX, and SAXS, at the Australian Synchrotron, as well as small angle neutron scattering on the Quokka instrument.

Prof. Bayden Wood from Monash University employed infrared microspectroscopy (IRM) to develop a small, portable diagnostic instrument that works in any setting with a single drop of blood. This instrument can rapidly detect early-stage malarial infections.

To explore atomic-level processes of malaria infection, Prof. Wai-Hong Tham of the Walter and Eliza Hall Institute used macromolecular crystallography (MX). This technique showed how the parasite binds to blood cells at the infection site and revealed that monoclonal antibodies can inhibit this binding. With this information, scientists identified 'weak spots' that could be exploited, such as therapeutic targets, to develop a new and effective anti-malaria vaccine.

Prof. Ben Boyd from Monash University employed small angle X-ray scattering (SAXS), as well as small angle neutron scattering on the Quokka instrument to develop highly effective malaria treatments. These techniques allowed scientists to better understand the digestion and absorption of anti-malaria drugs to improve their performance. Potential applications of this work span a variety of drug classes and diseases.

THE IMPACT

This research has improved our understanding of malaria infection and disease. It has led to several innovations in diagnosing and treating malaria. Innovations include an efficient and portable diagnostic tool, and a better understanding of how to develop anti-malaria vaccines. This research is significant in the identification and prevention of illness and death in regions which are currently difficult to access.

Research Priorities

Health

ANSTO Capabilities

- Neutron Scattering
- Crystallography

ANSTO Instruments

Macromolecular Crystallography (MX) Beamlines
Infrared Microspectroscopy (IRM) Beamline
Small Angle X-ray Scattering (SAXS) Beamline
Quokka
Small Angle Neutron Scattering (SANS)

Collaborators/Client

Walter and Eliza Hall Institute
Monash University

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Publications

doi.org/10.1016/j.jconrel.2018.10.027
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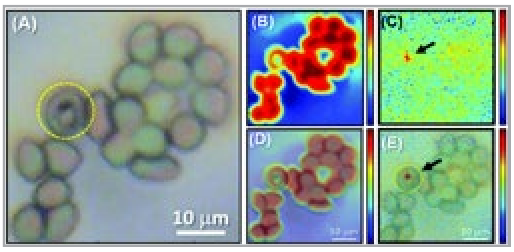

FIGURE 1:
Visible and infrared maps of red blood cells using the IRM Macro-ATR system. (A) Visible light microscopy; (B) Infrared map associated with the Amide 1 band in Haemoglobin; (C) Infrared map associated with the malarial protein Hemozoinn; (D, E) Overlay of respective visible and infrared maps.

Novel vaccines

Developing treatments against *Streptococcus pneumoniae*

Streptococcus pneumoniae is the world's most prevalent bacterial pathogen. Not only does this bacterium cause infection in the blood and middle ear, but it also causes pneumonia and meningitis. Each year it is responsible for one to two million deaths worldwide, killing more children than AIDS, malaria, and tuberculosis combined.

THE CHALLENGE

Current vaccines against *Streptococcus pneumoniae* have major shortcomings in terms of cost and coverage. They protect against just 13 of the 97 known variations, or serotypes, of *S. pneumoniae*.

THE SOLUTION

GPN Vaccines Pty Ltd was established in 2017 to develop and commercialise a new broad-spectrum vaccine against *S. pneumoniae*. When cultured and then inactivated using ANSTO's high-dose gamma irradiation facility, a whole-cell pneumococcal vaccine Gamma-PNTM is produced. This vaccine induces broad-spectrum immunity against all pneumococci, regardless of strain serotype.

THE IMPACT

Promising pre-clinical studies have demonstrated that intranasal vaccination with Gamma-PNTM protects experimental animals against lethal pneumococcal sepsis caused by *S. pneumoniae*. The project is currently undergoing phase I clinical trials.

Research Priorities

Health

ANSTO Capabilities

- Gamma irradiation

ANSTO Instruments

Gamma Technology Research Irradiator (GATRI)

Collaborators/Client

GPN Vaccines Pty Ltd
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Publications

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Electron micrograph of *S. pneumoniae* after irradiation at ANSTO (Image credit: University of Adelaide).

Supporting COVID-19 research

Understanding mechanisms of infection, the immune response, diagnosis, and treatment

In early 2020, an outbreak of the SARS-CoV-2 virus led to a global pandemic, commonly known as COVID-19. SARS-CoV-2 has proved to be a highly virulent disease that has manifested itself in several different variants that can cause severe illness. As of December 2022, there have been more than 645 million cases of COVID-19 reported worldwide and more than 6.6 million deaths.

THE CHALLENGE

An unprecedented international scientific effort is still needed to better understand the SARS-CoV-2 disease, its impacts, and treatment.

THE SOLUTION

ANSTO used an extensive suite of Australian Synchrotron beamlines to address the scientific challenges related to COVID-19. In March 2020, the COVID-19 Rapid Access Program was established and has supported more than 50 related experiments. Further research activities have been carried out through the Merit Access Program, which continued to operate in support of COVID-19 research during lockdown periods.

Understanding the mechanisms of infection and immune response

The Macromolecular Crystallography beamlines (MX1 and MX2) enabled atomic-scale structural studies of both SARS-CoV-2 viral proteins and their interaction with human proteins. This knowledge aids significantly in the development of new medicines to prevent infection and replication of the virus within the host. It also improves our understanding of the immune response and lasting impacts of the virus.

Diagnosis

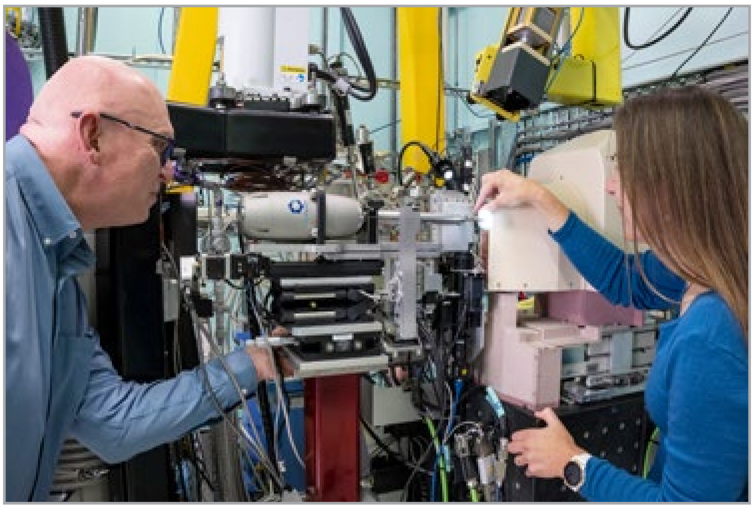
The rapid speed and the high sensitivity of Infrared Microspectroscopy (IRM) data enabled the development of a new infrared-based, rapid test for COVID-19. Soft X-ray Spectroscopy (SXR) and X-ray Absorption Spectroscopy (XAS) have helped to improve the development and manufacturing processes for magnetic nanoparticles, which are key components of the widely used polymerase chain reaction (PCR) tests.

New treatments

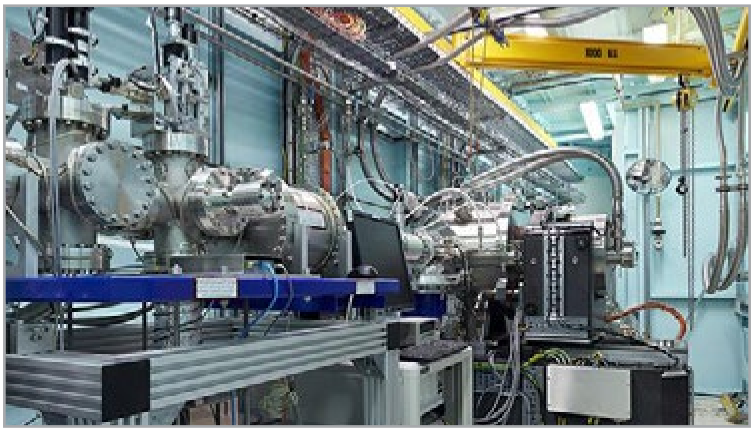
There have been several studies in the development of new drugs that act as targeted anti-viral therapies against the SARS-CoV-2 virus. Based on nanobodies derived from the alpaca, human monoclonal antibodies, and anti-viral drugs, these new therapies stemmed from those used to treat the SARS-CoV virus, commonly known as Severe Acute Respiratory Syndrome or SARS.

THE IMPACT

The extensive collaborative effort of this work has dramatically aided in the fight against COVID-19. The capabilities of the Australian Synchrotron instruments implemented have led to important developments in diagnosis, understanding mechanisms of infection and the immune response, and new treatments for COVID-19. The development of an infrared-based COVID-19 test has laid the foundations for scientists to produce a small, portable infrared spectrometer for rapid point-of-care detection in saliva.



Instrument scientists Dr Alan Roboldi-Tunnicliffe and Dr Rachel Williamson at the Micromolecular crystallography beamline.



The powerful synchrotron beam is delivered into the beamline to elucidate crystal structures.

The unique immune system of the llama was studied in COVID-19 research.

Research Priorities

Health

ANSTO Capabilities

- X-Ray Spectroscopy
- Crystallography

ANSTO Instruments

Macromolecular Crystallography (MX) Beamlines
X-ray Absorption Spectroscopy (XAS) Beamline
Soft X-ray Spectroscopy (SXR) Beamline
Infrared Microspectroscopy (IRM) Beamline

Collaborators/Client

Monash University
University of Melbourne
La Trobe University
Walter and Eliza Hall Institute for Medical Research
Charles Sturt University
University of Queensland
QIMR Berghofer Medical Research Institute
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doi: 10.1016/j.isci.2020.101258
doi: 10.15252/embj.2020106275
doi: 10.1002/anie.202104453
doi: 10.1016/j.isci.2021.102096
doi: 10.1073/pnas.2101918118
doi: 10.1016/j.immuni.2021.04.006
doi: 10.3390/cells10102646
doi: 10.1021/acsomega.1c07186

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Working towards a better diagnostic and therapeutic options for neuroblastoma

Using imaging to understand role of key transporter

Neuroblastoma is the third most common type of childhood cancer after leukaemia and brain tumours. Originates in one of the adrenal glands, it can develop in nerve tissue in the neck, chest, abdomen, or pelvis. It is a complex cancer that can present in various forms. Aggressive neuroblastomas are challenging to treat with an estimated survival rate of around 40%. Additionally, current therapy methods (typically using Cisplatin) used to treat the disease are extremely aggressive, toxic and can cause side effects to the young patients.

THE CHALLENGE

In previous work with our collaborators in Children's Cancer Institute Australia (CCIA) and University of New South Wales (UNSW), we have established an important link between Copper Transport (Ctr1) found in the neuroblastoma cancer cells and the mechanism of cancer cell death. Interestingly, cell lines that are resistant to the current therapy methods using Cisplatin are found to have lower expression of Copper Transporter 1. Such findings mean that should we are able to detect a lower level of Copper Transporter 1 in the neuroblastoma patients, we can avoid using the often harmful mainstream treatment and select other suitable treatments for the patients. In doing so, treatment strategies can be formulated earlier, leading to better patient outcomes.

THE SOLUTION

The Vivarium and Biosciences house a suite of integrated capabilities to develop, establish and maintain expertise for investigation into biological pathways for disease and illness using radiation, with the aim of improving the lives for all Australians.

To examine the distribution of Copper Transporter 1, the project used a suitable animal model developed to mimic neuroblastoma patients and see whether there are any differences in the availability of Copper Transporter 1 between the drug-resistant versus normal neuroblastoma cell line.

ANSTO's state of the art Positron Emission Tomography (PET) and Computed Tomography (CT) scanning were used to non-invasively assess the distribution of Copper Transporter 1 and see whether cancer treatment works in our model.

THE IMPACT

These experiments have provided important data towards a new diagnostic method that can serve as an important addition in treating the disease, producing better outcomes, better patients' quality of life and survival.

Research Priorities

Health

ANSTO Instruments

Inveon PET/CT
In Vivo Imaging Platform

Animal House
Vivarium

Collaborators/Client

University of New South Wales
Children's Cancer Institute Australia (CCIA)

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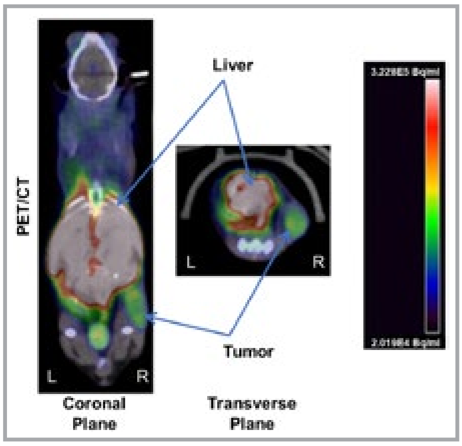

FIGURE 1:
PET/CT scanning using copper-64 in mice showing tumour uptake and organ distribution.

Novel prostate cancer therapy

Efficient and scalable delivery of lutetium-177

Prostate cancer is the second most common cancer diagnosed in Australian men and the third most common cause of cancer death. If prostate cancer spreads to other regions of the body, known as metastatic castration-resistant prostate cancer or mCRPC, the average patient survival rate is 9 to 13 months.

THE CHALLENGE

In recent years, metastatic prostate cancer research has seen promising results with the use of a prostate-specific biomolecule (PSMA-I&T) that can be attached to the radionuclide lutetium-177 (^{177}Lu) as a targeted therapy for diagnoses and treatment. Although the nuclear medicine, [^{177}Lu]Lu-PSMA-I&T, had been established as a targeted therapy for metastatic prostate cancer, there were no known large-scale centralised manufacturing sites available to produce and deliver a quality product with sufficient radiochemical purity to remote locations.

THE SOLUTION

This work developed a set of products that could be used to manufacture the nuclear medicine, [^{177}Lu]Lu-PSMA-I&T, at scale on-site where it is needed most. A key to this solution was using a portable radiosynthesiser, a device that medical professionals can use to prepare nuclear medicine. The team created a product formula that would maintain the desired radiochemical purity on delivery to hospitals around Australia.

THE IMPACT

This research produced a stable product formulation for the nuclear medicine, [^{177}Lu]Lu-PSMA-I&T, extending its shelf life to four days, making it a suitable and scalable method to treat metastatic prostate cancer. Since gaining Australian regulatory approval from the TGA in March 2022, this lutetium-177 treatment is now routinely available to patients.

Research Priorities

Health

ANSTO Capabilities

- Radiopharmaceutical Development

ANSTO Instruments

Trasis Mini-AllInOne radiosynthesiser

Collaborators/Client

Advanced Molecular Therapies Pty Ltd

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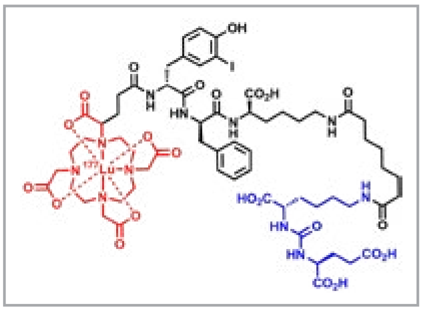

FIGURE 1:
Chemical structure of [^{177}Lu]Lu-PSMA-I&T.

New treatment for urogenital and pancreatic cancers

Effective radiolabelling of [^{67}Ga]Miltuximab for clinical use

Treatment of metastatic or recurrent urogenital and pancreatic cancers remains a challenge and new approaches are required.

THE CHALLENGE

Glypican-1 (GPC-1) is a protein that becomes elevated in cases of prostate, pancreatic, and bladder cancer. Miltuximab (MIL-38) is an antibody directed against GPC-1 but the ability to radiolabel it effectively and safely for clinical use had not previously been demonstrated.

THE SOLUTION

This study demonstrated that MIL-38 could be successfully radiolabelled with gallium-67 while retaining the form and function of the antibody to target the GPC-1 protein. The product, [^{67}Ga]MILGa, was designated the first molecular imaging agent targeting GPC-1. To translate [^{67}Ga]MILGa from the laboratory into the clinic, the team developed radiochemical methods, robust radiolabelling conditions, purification, formulation and quality control criteria, and testing to meet stringent quality standards.

THE IMPACT

The [^{67}Ga]MILGa agent produced by ANSTO enabled the successful completion of a first-in-human clinical trial. The clinical trial met all primary trial endpoints with no adverse events found in any of the patients. This outcome led to a successful Cooperative Research Centres Projects grant application with ANSTO, providing $3 million to continue the development of radiotheranostics targeting GPC-1. The success of the project has demonstrated ANSTO's clinical translation capability. The capability will attract companies in the pharmaceutical and medical devices sector seeking to advance the technology readiness level of potential cancer treatments.

Research Priorities

Health

ANSTO Capabilities

- Radiotracer Research and Development
- Radiotracer supply

Collaborators/Client

Minomic International Pty Ltd
Glytherix Ltd
Auspep Ltd
Macquarie Medical Imaging, Macquarie University Hospital

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The [^{67}Ga]Miltuximab product in its shielding transport container.

Nanoparticle toxicology

Improving standardised testing procedures of engineered nanomaterials

Determining the toxicity of naturally occurring and manufactured nanomaterials that we consume through our food and that we are exposed to in the environment is far more complex than first anticipated. We see nanomaterials in diverse applications such as food colouring agents and active ingredients in sunscreens, where they add value to products. Manufactured nanomaterials are developed to exploit nanoscale features, such as using zinc and titanium nanoparticles to make clear sunscreens, as opposed to using 'bulk' zinc particulate emulsions in opaque sunscreens. Nanoparticle properties vary considerably, which can lead to differing impacts on human health, reaching parts of organs and cells that bulk forms can't access.

THE CHALLENGE

Currently, accepted chemical testing procedures are not sensitive enough to measure and assess the internal exposure of many nanomaterials ingested by mouth. Standardised testing is required for regulators to be able to: assess the safety (human health & environment) of new and existing engineered nanomaterials; increase consumer confidence in products containing engineered nanomaterials; and provide research and development certainty for industry, developing products that enhance our daily lives.

THE SOLUTION

ANSTO is an associate partner of the EU Horizon 2020-funded Nanoharmony project, which is developing a set of scientifically reliable and 'ready for regulation' test methods and best practice documentation, based on current scientific knowledge. ANSTO holds key landmark infrastructure and expertise for radiotracer-based measurements of orally ingested nanomaterials, such as the colouring agent E171, with high sensitivity and precision using animal models.

THE IMPACT

Data from this research will lead to improvements in the standardised testing procedures of engineered nanomaterials, harmonising the needs of regulators with industry. This work positions ANSTO at the forefront in answering key questions such as the potential toxicity of E171 and other nanoparticles in human health, which are difficult to investigate as their size is well beyond the limits of standard chemical detection techniques.

Research Priorities

Health

ANSTO Capabilities

- Scanning electron Microscopy (SEM)
- X-ray Diffraction
- Dynamic Light Scattering (DLS)
- Gamma-ray spectroscopy
- Neutron activation analysis
- Radiotracer biodistribution, Imaging
- Vivarium - Animal models and agistment
- Radioisotope dispensing and formulation
- Elemental analysis

Collaborators/Client

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UKHSA, UK
NRCWE, Denmark
Nanometrology, NMIA

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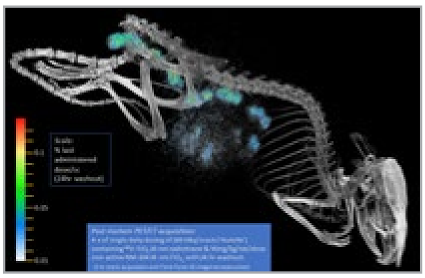

FIGURE 1:
Postmortem PET/CT image of diet ingested E171 radioactive nanoparticles (formulated into food) in an adult female rat. Internal exposure is primarily located with the gastrointestinal track, as has been indicated from prior literature.

Reducing costs of ^{18}F-radiochemistry

Increasing yield and decreasing production time and costs

Radiopharmaceuticals containing fluorine-18 (^{18}F) are used extensively to diagnose and treat diseases such as prostate cancer, breast cancer, Alzheimer's disease, and epilepsy. A key step in producing these nuclear medicines is incorporating fluorine-18 into a 'biological vector' or drug, a process known as radiolabelling. The efficiency of this process not only affects the cost of these medicines but can completely prevent some new diagnostic candidates from ever advancing to human clinical trials.

THE CHALLENGE

The critical challenge is to reduce the costs of fluorine-18 radiopharmaceuticals by developing higher radiolabelling yields and more efficient methods of fluorine-18 incorporation into biological vectors. Greater innovation will lead to more patients undergoing lifesaving positron emission tomography (PET) scans.

THE SOLUTION

The team discovered two entirely new methods of incorporating fluorine-18 into biological vectors or drugs. Rhenium metal-promoted fluorination reactions allow fluorine-18 to be incorporated into drugs at higher yields, via faster reaction times and under milder reaction conditions. The full scope of radiolabelling reactions was fully evaluated at ANSTO. The chemical structure classes including 1,10-phenanthroline and 2,2'-bipyridine are now available to researchers for evaluation as new radiopharmaceuticals. It was previously not possible to radiolabel these structures with the efficiency and flexibility that this research demonstrated.

^{18}F-ethenesulfonyl fluoride ([^{18}F]ESF)is an innovative nuclear medicine tool developed at ANSTO that allows very rapid, efficient, and high-yielding radiolabelling reactions with [^{18}F]fluoride. [^{18}F]ESF acts as a source of [^{18}F] fluoride and in many ways is superior to using pure [^{18}F]fluoride. It is extremely easy to produce at a central cyclotron site and can be packed and shipped as a "mini-generator" with a ready-to-use radiofluoride solution. The reagent can be used in any satellite radiopharmacy laboratory, such as in Nuclear Medicine departments, using simplified equipment to obtain specific radiopharmaceutical doses needed at the imaging site.

THE IMPACT

This work pioneered methods that can increase the yield of fluorine-18 radiopharmaceuticals, and reduce the costs and time involved in medicine production. Innovations include a seamless transition from early-stage development to production scale, significantly reducing initial costs and dose exposure for our scientists and students, while still featuring native automation and process reliability. The work has obvious benefits to hospitals and governments, providing new innovative methods that allow more patients to receive life-saving PET scans at a lower cost.

Research Priorities

Health

ANSTO Capabilities

- Synthetic Chemistry
- Camperdown Cyclotron and Radiochemistry Facility*

ANSTO Instruments

IBA Cyclone 18 Twin cyclotron*
**no longer operational*

Collaborators/Client

Monash University
Curtin University

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The radioactive isotope fluorine-18, which emits positrons and can be used to make many radiopharmaceuticals including a radioactive form of glucose that is readily taken up by cancer cells and other cells. Using nuclear imaging (PET scans) it can be used to detect tumours, map brain function, and detect other illnesses.

Human radiobiology in space

Understanding the impacts of ionising radiation and its effects on human health

In the coming years, the Australian space industry is expected to grow exponentially. Interest in space has escalated due to increasing demand for space tourism and the preparations of manned missions to Mars. The health and safety of astronauts and space tourists during space travel depends on strategies to protect them from radiation exposure.

THE CHALLENGE

A crucial factor in studying space radiation on living biological systems is to replicate standard atmospheric pressure. Until recently, we have only been able to study the impact of radiation on materials under vacuum, which is not suitable for living organisms.

THE SOLUTION

The ANSTO team developed a unique facility, where biological material can be irradiated at standard atmospheric pressure, allowing experiments to replicate conditions more closely to those inside a space vehicle. The first test experiments confirmed that the setup functioned well. The team detected DNA double-strand breaks in human cells after irradiation with the in-air proton microbeam.

THE IMPACT

This work delivered innovative research capabilities for future space industry activities by characterising the impacts of low-energy ions on living matter. ANSTO developed capabilities to investigate and characterise biological samples under extreme conditions such as those found in space. Understanding the impacts of ionising radiation and its effects on human health will help to develop strategies which protect humans in space and benefit medical applications on Earth.

Research Priorities

Health

ANSTO Capabilities

- Radiobiology
- X-Ray Irradiation (XRAD)

ANSTO Instruments

ANTARES
10MV Tandem Particle Accelerator

Collaborators/Client

French Space Agency (CNES)
Australian Space Agency (ASA)
Inserm U1296 Radiation: Defense, Health, Environment

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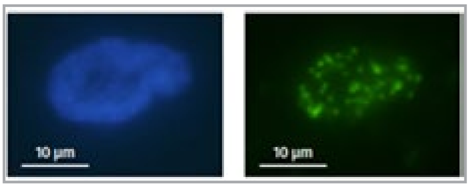

(Bottom) DNA breaks observed after Proton irradiation (green) in the nucleus of human cells (blue).
(Top) ANTARES 10MV Accelerator in-air external irradiation chamber.

Impact of low-dose radiation

Insights for neural disease, radiotherapy, and space travel

Life on Earth has previously adapted to significantly higher levels of radiation. Noticeable physiological adaptation is seen at the earliest stages of evolution in single-celled organisms. One such biological manifestation of the evolutionary-adaptive process is the regulatory pathways of cell survival and cell death as determined by mitochondria, endobiotically incorporated single-cell organisms that had evolved earlier.

THE CHALLENGE

Humans are constantly exposed to radiation through natural sources including cosmic and terrestrial radiation or via medical procedures such as X-rays and CT scans. Understanding the impact and mechanisms of ionising radiation is crucial for protecting public health, the environment, and optimising the treatment of diseases. By focusing on the brain's responses to low-dose radiation, we can gain insight into the critical pathways linked to its impact on health and neuroinflammatory diseases, whilst also building tools and knowledge that are critical for the development of novel radiotherapies.

THE SOLUTION

Developed at ANSTO, a knockout mouse model of the evolutionary highly conserved mitochondrial translocator protein (TSPO) enabled the conclusive testing of ANSTO-patented TSPO-binding compounds with potential applications, such as theranostics. The model is also very suitable for low-dose radiation studies as mitochondria are particularly radiosensitive organelles. The expression of TSPO is an early cell stress biomarker and occurs well before overt tissue pathology can be detected. It offers a unique opportunity to study the role of TSPO as one of the most abundant mitochondrial proteins and regulators of responses to cell stress.

THE IMPACT

Understanding the impact of low-dose radiation on normal physiological adaptive-protective responses is important to understanding hazards and risks. This work provides insights into how low-dose radiation may be used to mitigate neural diseases such as Alzheimer's and Parkinson's disease and will have applications in space radiobiology and space medicine. In addition, the TSPO knockout animal model is used for the evaluation of theranostic compounds in neuroinflammation and cancers.

This work has been noted by policymakers, most recently in the context of subclinical brain injury and the search for better biological biomarkers for subtle disease or long-term stress responses in post-exposure scenarios (physical, chemical, and radiation injuries). The Royal Commission on Defence and Veteran Suicide sought early input from ANSTO by advisors assisting the commission.

Research Priorities

Health

ANSTO Capabilities

- Radiobiology
- Bioimaging, X-Ray (XRAD) and gamma irradiation
- Vivarium

Collaborators/Client

University of New South Wales
University of Wollongong
University of Adelaide
University of Sydney
INSERM, France
Ludwig-Maximilians
University of Munich, Germany
Université Paris Sud,
Université Paris-Saclay, France

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Publications

doi:10.1038/s41593-022-01013-9
doi:10.3390/ijms24032474
doi:10.3390/cells10092381
doi.10.3389/fcell.2021.715444
doi:10.3390/cells9020512
doi:10.3390/ijms19092707
doi:10.1080/15384101.2017.1281477
doi:10.1016/j.redox.2016.08.002

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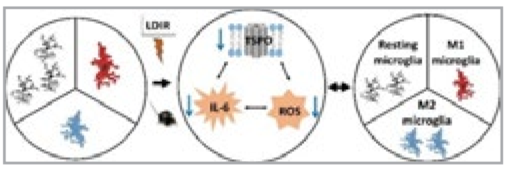

FIGURE 1:
Low-dose ionising radiation alters the microglial functional states by modifying the levels of cytokines and reactive oxygen species (ROS).

Deuteration for biological research

Understanding cellular functions and mechanisms of disease and infection

Understanding the complex structure of the cell membrane and its components that regulate cellular functions is critically important in understanding the mechanisms of infection and causes of disease.

THE CHALLENGE

It is difficult to discern between some cell membrane components at the nanoscale using X-ray or neutron scattering techniques alone.

THE SOLUTION

ANSTO has developed unique capabilities to provide specifically deuterated cell membrane components including lipids, sterols, and proteins and is the world leader in the provision of these components to research and industry. Deuteration, in which hydrogen (H-1) atoms are replaced by deuterium (H-2) atoms, is essential for neutron techniques to differentiate between cellular components and highlight those of interest.

THE IMPACT

ANSTO's National Deuteration Facility team collaborated on novel international research studies which:

- investigated the fundamental understanding of how the SARS-CoV-2 (COVID-19) spike protein interacts with cell membranes to enable viral infection and the role of calcium and cholesterol in the infection stage. The research provided greater understanding of infection mechanism with valuable insights for the future development of vaccines and more effective therapeutics.
- provided novel insight into the removal and deposition of lipids into artery walls and factors of importance for the build-up and reversibility of atherosclerotic plaque, and
- developed a novel method for the fast screening of membrane protein structures which mediate multiple cellular processes, including transport mechanisms of various molecules into and out of the cell. ANSTO's deuteration facility is the only place in the world that can produce the deuterated molecules (detergents) necessary to enable solution phase small-angle neutron scattering (SANS) structure studies of membrane proteins, which has led to a partnership with the Institut Laue-Langevin (ILL), France.

Research Priorities

Health

ANSTO Capabilities

- Biological deuteration
- Chemical deuteration

Collaborators/Client

Institut Laue-Langevin (ILL)
Paul Scherrer Institut (PSI)
Institut de Biologie Structurale (IBS)
University of Cambridge
Malmö University
University of Copenhagen
Aarhus University

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Publications

doi.org/10.1038/s41598-021-93996-x
doi.org/10.1021/jacs.1c09856
dx.doi.org/10.1016/j.bbalip.2020.158769
dx.doi.org/10.3389/fchem.2021.630152
dx.doi.org/10.1111/febs.14345
doi.org/10.1107/S2052252518012186

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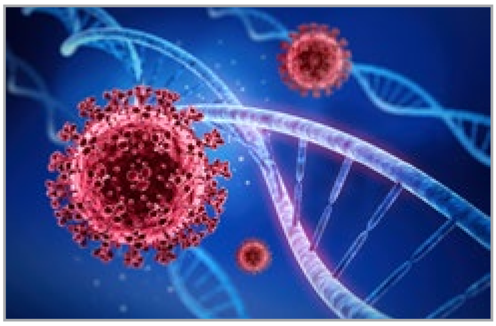


SARS-Co-V-2.

Neutron capture enhanced particle therapy (NCEPT)

Effective targeted radiotherapy with fewer side effects, shorter treatment times, and lower costs

Addressing the key challenges in improving cancer therapy's safety and effectiveness through charged particle therapy has become a key focus of health research. Radiation oncologists face the arduous task of pinpointing small or hidden cancer lesions during treatment planning. Compared to traditional photon therapy, radiotherapy using high-energy to ensure the successful eradication of all primary cancer cells, administering an adequate dose to the target margins is a critical step that needs extra focus. Particles show promise in tackling hard-to-reach tumours. This method is more accurate, limiting damage to surrounding healthy tissue. However, it works best when cancer is located in a specific, well-defined area, and is less effective or not useful at all if the cancer has spread (metastasised) or dispersed (diffuse).

THE CHALLENGE

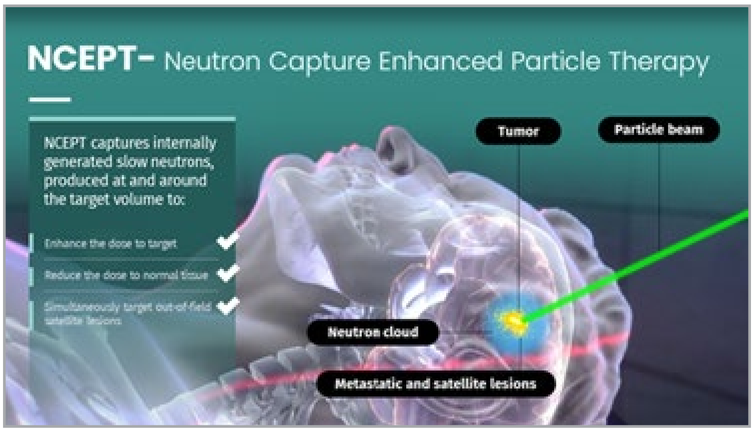
Even though charged particle therapy is more accurate and provides a lower entrance dose compared to traditional photon therapy, it can still harm healthy tissue and requires careful planning. Furthermore, the inelastic collisions of charged particles and cancer cells result in nuclear fragments like lighter ions and neutrons. These can lead to further radiation damage to the surrounding tissue. To ensure the successful eradication of all primary cancer cells, administering an adequate dose to the target margins is a critical step that needs extra focus.

THE SOLUTION

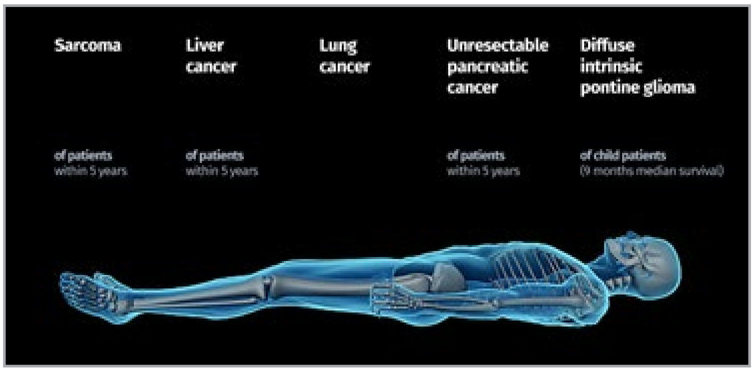
ANSTO researchers pioneered a transformative targeted radiotherapy technique called neutron capture enhanced particle therapy (NCEPT), an enhanced charged particle therapy used to treat cancers of poor prognosis. The therapy is delivered by a proton or carbon ion beam combined with an injected tumour-targeting neutron capture agent (NCA). NCEPT can deliver a double blow to cancers, delivering a radiation dose directly to tumour cells even if they are outside the primary target area. This technique can either boost the tumour dose or allow the dose to be reduced, mitigating the impact on healthy tissue. NCEPT provides promising results in vitro and in vivo for cancer cell survival and tumour growth inhibition.

THE IMPACT

NCEPT provides direct benefits to patients, particularly paediatric patients, through more effective, targeted radiotherapy with fewer debilitating side effects, shorter treatment times, and lower costs per patient to the public health system. This research positions ANSTO as a key player in the development of new diagnostic, therapeutic, and theranostic agents for NCEPT and related therapies—leveraging ANSTO's existing portfolio of radioisotopes and strengthening strategic research partnerships with its domestic and international counterparts.



Physics of NCEPT - As ions travel through the patient, some collide with tissue and create a variety of nuclear fragmentation products, including neutrons, which disperse in the body and thermalise. Target-specific agents deliver ^{10}B or ^{157}Gd payloads to cancer cells where thermal neutrons are captured resulting in emission of short-range (5-9 µm for ^{10}B, 10-20 nm for ^{157}Gd), high-LET particles. While the particle beam treats the bulk of the tumour, the neutrons released are captured anywhere that NCAs are present - inside and outside the primary treatment volume - that would have otherwise remained unirradiated.



Disease specific translation.

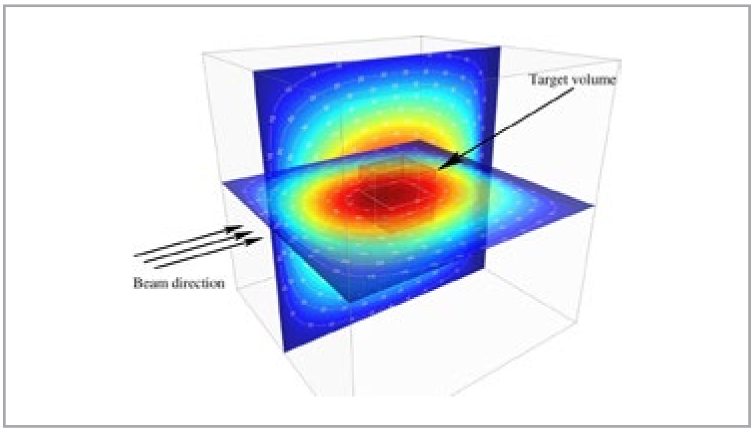


FIGURE 1:
Discovery and proof of concept simulation.

Research Priorities

Health

ANSTO Capabilities

- Geant4 Monte Carlo simulation
- Radiobiology
- Neutron irradiation
- Gamma irradiation
- Vivarium
- High Performance Computing (IDS)
- Tesla
- X-ray fluorescence microscopy

ANSTO Instruments

Dingo
Neutron Imaging
Gamma Technology Research Irradiator (GATRI)
Inductively Coupled Plasma Mass Spectrometer (ICP-MS)

Collaborators/Client

Quantum Science and Technology, Japan
Sumitomo Heavy Industries, Ltd
IFJ-PAN, Poland
Loma Linda, USA
RaySearch, Sweden
University of Sydney
University of Wollongong
University of Technology Sydney

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Publications

doi.org/10.1038/s41598-018-34643-w

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Radioisotope measurement

Improved treatment outcomes and patient safety

Quantitative imaging is a powerful tool that can provide data for oncological staging, treatment planning, monitoring of disease progression, and assessment of the efficacy of new radiopharmaceuticals during clinical trials.

THE CHALLENGE

There is often the requirement to directly compare CT images acquired over time, on different scanner models using different image reconstruction and analysis methods, across different locations, etc. The only way to generate coherent data is to ensure that all radioactivity measurements related to the imaging procedure are directly traceable to international activity standards.

THE SOLUTION

ANSTO, as the Australian designated institute with the authorisation to maintain primary and secondary radioactivity standards, provides calibration services to nuclear medicine practices and industry. To this end, it has developed primary standards for the radioisotopes most widely used for imaging: technetium-99m (the major radionuclide used for SPECT scans, comprising 82% of all nuclear medicine procedures); fluorine-18, the major PET scan isotope, used in 10% of procedures); copper-64 (PET theranostic) and germanium-68/gallium-68 (a long-lived surrogate for calibration for the PET radioisotope Ga-68).

THE IMPACT

ANSTO's radionuclide metrology services have led to improved accuracy and precision in the administration of radiopharmaceuticals, facilitating the realization of quantitative data from CT scans leading to improved patient outcomes. Approximately 100 certificates of traceability and 100 client reports were issued as part of calibration services for imaging radionuclides in 2020.

Research Priorities

Health

ANSTO Capabilities

- Primary standardisation by 4πβ-γ coincidence counting,
- Secondary Standard Ionisation Chamber calibrated for ^{99m}Tc, ^{18}F, ^{64}Cu and $^{68}Ge/^{68}Ga$

Collaborators/Client

ANSTO Health
Cyclotek
Australian nuclear medicine departments

ANSTO Contributors

Radionuclide Metrology

Publications

doi.org/10.1016/j.apradiso.2017.10.005
doi.org/10.1016/j.apradiso.2019.108935
doi.org/10.1016/j.apradiso.2017.10.052
doi.org/10.1088/0026-1394/60/1A/06013

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Using the Liquid Scintillation System at ANSTO.

Developing new therapeutic materials

Encapsulating peptides in their functional form for better food and pharmaceuticals

Biological cell membranes are complex systems consisting of proteins, lipids, and carbohydrates. Membrane proteins are important drug targets. Understanding their structure enables rational drug design. There has previously been limited understanding on how membrane composition influences protein activity. Membrane composition has a significant effect on how cells adapt to viral infections, bactericides, and antibiotics. Therefore, the development of new therapeutics relies on a detailed understanding of membrane composition.

THE CHALLENGE

The emergence of multi-drug-resistant bacteria and new viral infections, such as COVID-19, necessitates the development of novel antibacterial and antiviral therapeutics. Peptides are excellent candidates that have shown much lower antimicrobial resistance than traditional antibiotics. In 2016, there were more than 50 therapeutic peptides marketed worldwide, with 70 in clinical trials, and more than 200 in preclinical development. Several factors limit peptides as a clinical option, these include their inability to pass the intestinal barrier requiring intravenous injection; low stability; low solubility in water; tendency to form aggregates; and adsorption to surfaces requiring advanced delivery methods. To overcome these major challenges and create new effective peptide-based oral therapeutics by encapsulating peptides in new lipid nanomaterials, researchers needed to develop novel approaches.

THE SOLUTION

The team sought a method to study the location and conformation of membrane proteins in lipid self-assembly materials. Previously, studies focused on the nanostructure of the lipid materials, but it was not possible to isolate and observe the behaviour of the protein. Scientists observed the behaviour of the protein using chemical deuteration of monoolein and small-angle neutron scattering on the Bilby instrument. A fully deuterated lipid matrix can be contrast-matched in heavy water (D_2O) allowing observation of the protein location and conformation within the material. This method can also be used to investigate the protein structures, determining their function within composite materials.

THE IMPACT

This work found that the physicochemical properties, including lateral bilayer pressure, of the membrane in nanoparticles are essential to encapsulate peptides in their functional form. Developing new functional materials can increase Australia's competitiveness in the (functional) food and pharmaceutical industries. The combination of deuteration and neutron scattering made possible at ANSTO was integral in understanding peptide structures for this work.

Research Priorities

Health

ANSTO Capabilities

- Neutron Scattering
- Biological deuteration

ANSTO Instruments

Bilby
Small Angle Neutron Scattering

Collaborators/Client

Monash University
RMIT University
The Walter and Eliza Hall Institute
ETH Zurich

ANSTO Contributors

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Publications

doi.org/10.1021/acs.jpclett.6b01173
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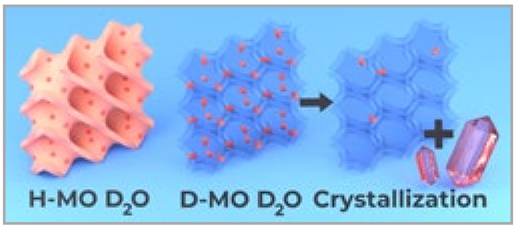

FIGURE 1:
Illustration of protein crystallisation.

Enhancing drug delivery systems

Engineering drug nanocrystals in polymeric shells – Elongated nanocapsules

Non-targeted, high-dose and high-frequency cancer drugs are often used for their therapeutic effects. However, these anti-cancer drugs are not only toxic to diseased cells but also toxic to healthy cells—causing serious side effects such as hair loss and fatigue. For these reasons, cell-targeted cancer therapy has become a major research focus in recent years.

THE CHALLENGE

Nanoparticles have been used to improve the delivery efficiency of anti-cancer drugs because of their compatibility with biological matter, versatility, and their ease of functionalisation for cell targeting. Researchers have hypothesised that elongated nanocapsules can be produced to aid in the targeted delivery of high-payload, long-circulating anti-cancer drugs. However, it has previously been impossible to visualise the existence of formed nanocapsules directly using even the most advanced electron microscopy. Therefore, high-powered analytical techniques were needed to determine the characteristics and functionalisation of newly engineered elongated nanocapsules.

THE SOLUTION

The team used the BILBY instrument at the Australian Centre for Neutron Scattering and deuteration to determine the structural features of newly engineered high-drug-payload nanocapsules. These techniques were integral to the structural analysis of an elongated liposomal nanocapsule template and the exploration of the formed elongated polymeric nanocapsules. ANSTO's National Deuteration Facility made it possible to label specific hydrogen-containing features in the substances, which the team used to 'visualise' different parts of the samples independently using neutron scattering.

THE IMPACT

This work proved the practicability of a loading method to form drug nanocrystals inside elongated nanocapsules, providing strong evidence that complements previous research using microscopy techniques and X-ray scattering. The combination of the high drug payload (in the form of nanocrystals) and the non-spherical feature of liposome nanocapsules provides a promising approach for a much more efficient drug delivery system that has the potential to lower the risks of unwanted side effects in patients.

Research Priorities

Health

ANSTO Capabilities

- Deuteration
- Neutron scattering
- Synchrotron X-ray scattering

ANSTO Instruments

Bilby
Small Angle Neutron Scattering

Quokka
Small Angle Neutron Scattering

Kookaburra
Ultra Small Angle Neutron Scattering

(SAXS) Beamline
Small Angle X-ray Scattering

(WAXS) Beamline
Wide Angle X-ray Scattering

Collaborators/Client

Monash University

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Publications

doi.org/10.1016/j.colsurfb.2019.110362

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FIGURE 1:
Samples prepared for the Bilby experiment.

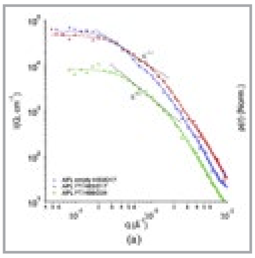

FIGURE 2:
Data collected for the project.

Safe ventilation practices for infants

Preventing unnecessary brain injuries in preterm babies

Every year millions of babies are born 'preterm', delivered before 37 weeks of gestation. Globally, prematurity is the leading cause of death in children under five years of age.

THE CHALLENGE

Mechanical ventilation is often used to prevent lung collapse in premature infants; however, the side effects of this treatment are not well known.

THE SOLUTION

Researchers revealed that the high pressures used in the ventilation of preterm infants can result in brain injuries. The team used the Imaging and Medical Beamline at the Australian Synchrotron to obtain clear and detailed images that showed how blood vessels change with lung pressure. Higher pressures caused enlargement of the blood vessels in the brain, which can slow blood flow and potentially cause brain injuries.

THE IMPACT

This research has provided key information to hospitals to prevent brain injuries in preterm infants. Hospitals were alerted to ensure that ventilator pressures and volumes are kept as low as possible. This research also instigated the study of how an infant's sleep position can impact blood flow and the potential for brain damage. The Australian Synchrotron imaging methods that were developed during this research have already been applied in a range of lung, brain, and cardiovascular studies.

Research Priorities

Health

ANSTO Capabilities

- Synchrotron X-ray imaging

ANSTO Instruments

Imaging and Medical Beamline (IMBL)

Collaborators/Client

Monash University
Hudson Institute of Medical Research
Monash Newborn

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Publications

doi.org/10.1177/0271678X211045848

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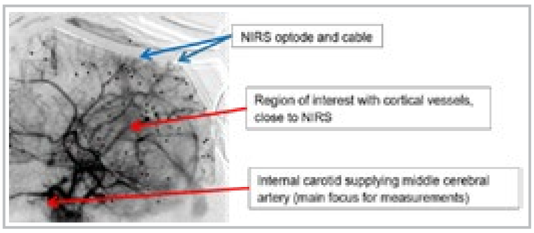

FIGURE 1:
Imaging performed at the Australian Synchrotron showing the inside of micro-blood vessels that allowed researchers to understand the impacts of ventilation pressures on infants.

Advancing neural implant surgery

Stentrode™: Implanting a safe and stable neural device without open-brain surgery

Many Australians are affected by neurological conditions caused by illnesses, such as motor neuron disease or injuries to the brain or spinal cord. This can leave them without normal motor function and includes symptoms such as paralysis and slurred speech. Neural implants can be used to help patients control the technology directly from the brain.

THE CHALLENGE

In the past, brain surgery has been required to implant neural interfaces within the brain. However, such surgery is risky and could be detrimental to the patient's well-being. New, less-invasive implant methods are needed to reduce the current risks associated with neural device implant surgery.

THE SOLUTION

A research collaboration based around the Vascular Bionics Laboratory at the University of Melbourne designed the Stentrode™, a device which can record high-fidelity brain activity following vascular implantation using a minimally invasive procedure – without the need for open-brain surgery. Stentrode™ is comprised of an endovascular electrode array which lies over the cortex, and so can avoid having to disrupt the blood-brain barrier. The device was tested on animals, and non-destructively imaged on the Medical and Imaging Beamline at the Australian Synchrotron to determine how the Stentrode™ was incorporated into the blood vessel walls. The studies showed that the device remained stable for six months in animals and did not obstruct the blood vessels.

THE IMPACT

The Stentrode™ has now been successfully implanted in human trial participants with motor neuron disease (MND), enabling them to control a computer directly through the neural device without having to go through risky brain surgery. In the future, this technology could be used to aid in a range of neurological disorders and has the potential to help patients with spinal cord injuries walk again.

Research Priorities

Health

ANSTO Capabilities

- Synchrotron X-ray imaging

ANSTO Instruments

Imaging and Medical Beamline (IMBL)

Collaborators/Client

University of Melbourne

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Publications

doi.org/10.1109/TBME.2016.2552226

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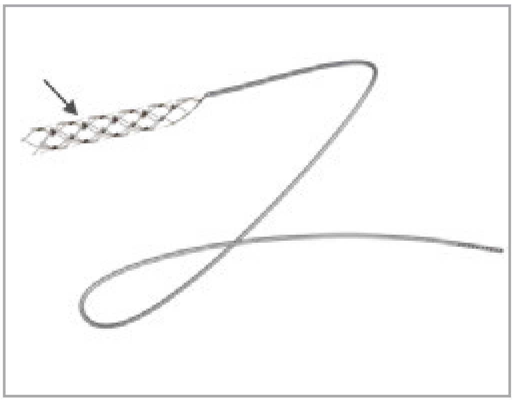

FIGURE 1:
Image of the Stentrode™ in its expanded form, showing the electrodes (arrow) which are 8 x 750 micrometres (µm) in size.

Treating osteoporosis

Comparing relative effects of different drug molecules on bone regrowth

Osteoporosis is a severe bone disease that has been estimated to affect approximately 23% of women and 6% of men over the age of 50 in Australia. It can cause a 40% higher chance of bone fractures and drastically lower quality of life.

THE CHALLENGE

A pharmacological agent used to treat osteoporosis, parathyroid hormone (PTH), may stimulate bone formation differently from natural bone growth. In normal bone growth, a collagen-containing matrix (osteoid) hardens over time as mineral crystals accumulate. Research is required to determine whether new bone produced following PTH replacement therapy is the same composition and strength as normal bone.

THE SOLUTION

Researchers from St. Vincent's Institute of Medical Research conducted infrared microspectroscopy (IRM) to study the overall structure, matrix, and mineral composition of bones after treatment with several therapeutic drugs including PTH. The team showed that PTH led to the production of bone with a very similar, if not identical, composition to that produced under normal growth. The partnership with ANSTO enabled medical researchers to collect diagnostic IRM data that was previously difficult to acquire without the expertise and innovation of the Synchrotron's research team.

THE IMPACT

This work provided information pivotal to improving future therapeutic outcomes for osteoporosis sufferers. The team enabled complex pharmaceutical research including a comparison of the relative effects of different drug molecules on bone regrowth. The ability to study bone in detail using Australian Synchrotron beamlines has allowed studies to extend to other areas of osteoporosis research and bone disease therapies.

Research Priorities

Health

ANSTO Capabilities

- Synchrotron Infrared microspectroscopy

ANSTO Instruments

Infrared Microspectroscopy (IRM) Beamline

Collaborators/Client

St. Vincent's Institute of Medical Research

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Publications

doi.org/10.1038/s41586-018-0240-x
doi.org/10.1016/j.bone.2016.09.022
doi.org/10.1007/s00223-018-0455-8
doi.org/10.1038/s41467-019-11373-9
dx.doi.org/10.1016/j.ijpp.2020.07.003
dx.doi.org/10.1038/s41598-021-83264-3

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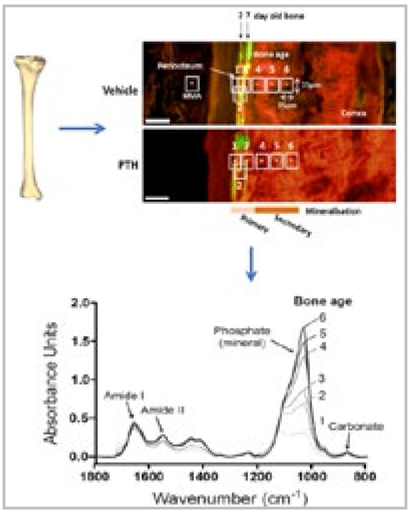
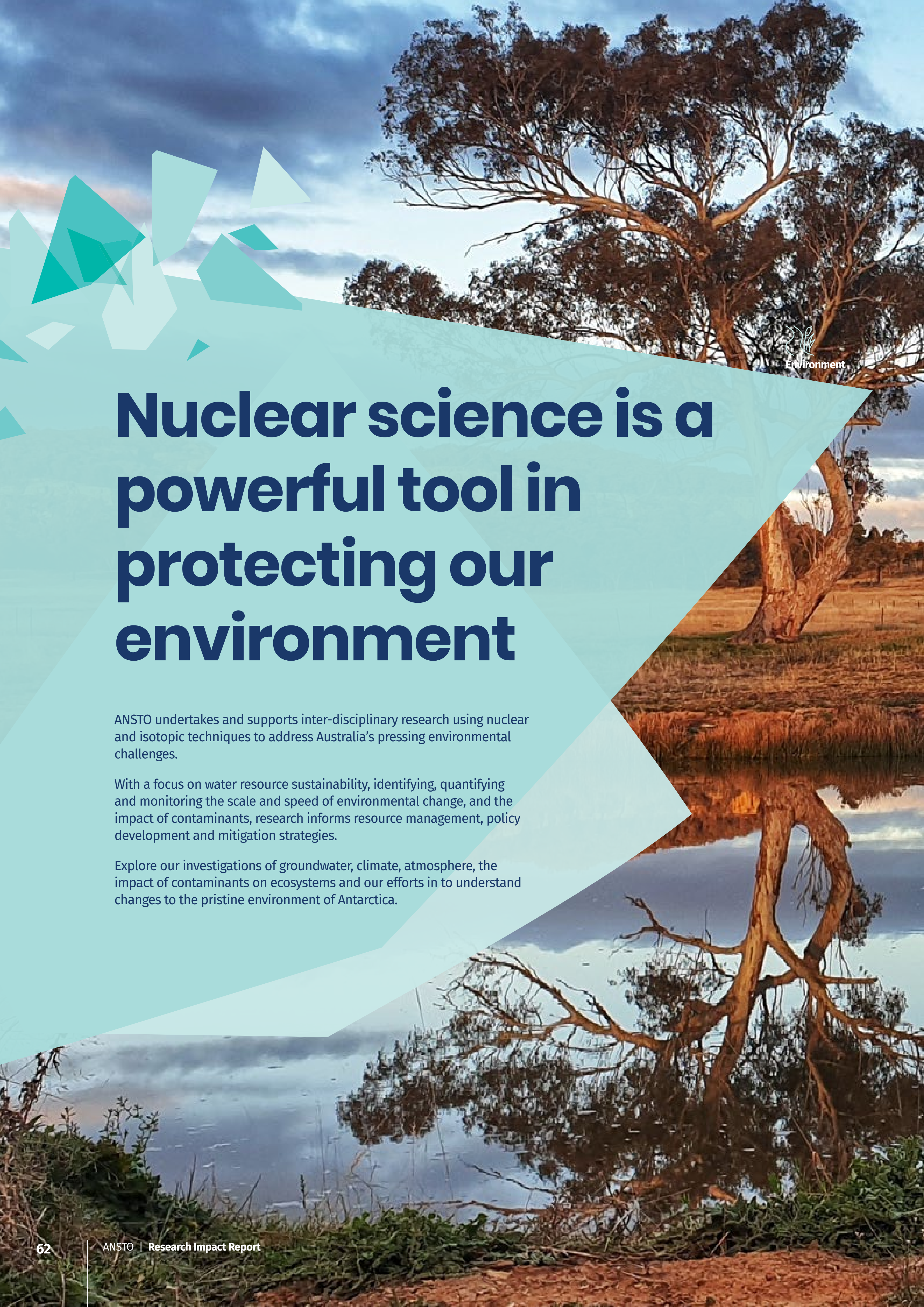


FIGURE 1:
Synchrotron FTIR micro-spectroscopic measurement of regions on thin tibial sections. Fluorescence micrographs showing the six 15 × 15 µm square regions from which spectra were collected on tibial samples from vehicle and parathyroid hormone (PTH) treated bone. Scale bar = 20 µm.



Nuclear science is a powerful tool in protecting our environment

ANSTO undertakes and supports inter-disciplinary research using nuclear and isotopic techniques to address Australia's pressing environmental challenges.

With a focus on water resource sustainability, identifying, quantifying and monitoring the scale and speed of environmental change, and the impact of contaminants, research informs resource management, policy development and mitigation strategies.

Explore our investigations of groundwater, climate, atmosphere, the impact of contaminants on ecosystems and our efforts in to understand changes to the pristine environment of Antarctica.

Bushfire hazard reduction

Reconstructing Australia's fire history using cave stalagmites

Over the last few decades, there has been an increasing trend in extreme fire weather and a longer fire season. Many parts of the world have experienced unprecedented catastrophic wildfires and bushfires. In Australia between October 2019 and February 2020, bushfires burned nearly 17 million hectares of land.

THE CHALLENGE

Our understanding of past fire regimes is limited. Environmental proxy archives can be used to improve our understanding of historical fire behaviour. These archives can reveal the climatic conditions leading to fires and human-climate-fire relationships. However, there has been a data shortage on past fire events.

THE SOLUTION

Cave stalagmites provide a previously unexplored opportunity to examine the frequency and intensity of past fires. This project aimed to determine fire and climate records stretching back hundreds of years through the investigation of limestone cave stalagmites.

Metals leached from ash following bushfire events are incorporated into cave stalagmites. Researchers obtained high-resolution measurements of trace metals using X-ray fluorescence microscopy (XFM) at the Australian Synchrotron and LA-ICP-MS techniques. The annual growth layers of the cave stalagmites could then be counted, and growth layers containing ash-derived metals dated to construct a timeline of past bushfires.

THE IMPACT

This work produced the world's first dataset on past fire events recorded in cave stalagmites. Data revealed the pre- and post-colonial burning regimes for Yanchep National Park in Western Australia.

The techniques developed by this research can be applied to caves in fire-prone regions elsewhere in the world. This will enable other researchers to investigate how past fire regimes have varied with climate, land-use change, early human migration, and colonisation.

This research informed changes to the NSW Department of Planning and Environment policy on hazard reduction burns on karst areas in National Parks. Additional studies and techniques are now in progress to reconstruct the degree of severity of historical bushfires and wildfires.

Research Priorities

Environment

ANSTO Capabilities

- Isotopic analysis with Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)
- Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES)

ANSTO Instruments

X-ray Fluorescence Microscopy (XFM) Beamline
Infrared Microspectroscopy (IRM) Beamline
Inductively Coupled Plasma Mass Spectrometer

Collaborators/Client

University of New South Wales
Australian Research Council

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Publications

doi.org/10.1016/j.gca.2022.03.020
doi.org/10.1029/2022RG000790
eos.org/editors-vox/using-cave-formations-to-investigate-ancient-wildfires

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A fire burns the Borenore landscape. Cave stalagmites can help us to uncover the record of past fire events and the climatic conditions leading to them (Image credit: Andrew Baker, left; and Liza McDonough, right).

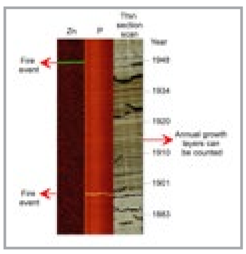

FIGURE 1: Elements (e.g., P, Pb, Zn, Cu, Al, and Fe) leach from ash after fires and become incorporated into stalagmite calcite, which can be dated using carbon-14 methods and counting annual growth layers.

Sustainable urban planning

Radon-based assessments of urban air quality and urban climate

Urban populations are ageing, making them more vulnerable to health risks. Some risk factors, such as poor air quality and heat stress, increase as city size and population density increase. To develop healthier and more sustainable urban centres, it is essential to first understand the processes that drive urban air pollution and climate.

THE CHALLENGE

An evidence-based approach to sustainable city management relies on methods capable of characterising 'controllable' influences, such as urban design and energy consumption, and 'uncontrollable' influences, such as the stability of the atmosphere, on urban risk factors. Atmospheric stability, also known as the mixing state, is an 'uncontrollable' influence on risk factors to public health that controls the atmosphere's ability to trap or disperse harmful emissions and excess heat in urban centres.

Atmospheric mixing varies depending on the time of day, season, and weather. Conventional ground-based meteorological observations can be unreliable, however, especially during very long-lived still weather conditions called persistent inversions, which can lead to very high pollution levels. Alternative techniques are needed to better understand the mixing state of the atmosphere and address public health risks in complex urban environments.

THE SOLUTION

The naturally occurring radioactive gas radon (radon-222) is emitted from all land surfaces and is a convenient and unambiguous tracer of atmospheric mixing and transport under conditions when conventional techniques fail to characterise the atmospheric mixing state. Radon-based stability measurements have been applied on large spatial and vertical scales. A single near-surface radon measurement location can be used to help interpret results from an entire 3D network of climate and air quality measurements throughout an urban region. ANSTO has achieved this with its world-leading dual-flow-loop two-filter atmospheric radon-222 monitors, and various sensitive and portable radon detectors.

THE IMPACT

Atmospheric radon observations are a valuable and increasingly popular, means of evaluating and improving the performance of regional urban climate and pollution models. Radon-based stability measurements are more effective than conventional meteorological approaches in identifying conditions which lead to high risks of poor air quality or dangerous heat exposure. Radon data will allow policymakers to assess current risks, review target limits, develop and assess mitigation measures, and evaluate urban scale models for better town planning. This will play a crucial role in sustainable urban planning globally in the coming decades.

Research Priorities

Environment

ANSTO Capabilities

- Radon analytical facilities

ANSTO Instruments

Dual flow loop, two-filter atmospheric radon-222 monitors
(1500 L radon detectors)
(200 L radon detectors)

Collaborators/Client

NSW Dept. of Planning & Environment
CSIRO
University of Wollongong
University of Melbourne
University of Basel, Switzerland
University of Łodz, Poland
Jožef Stefan Institute, Slovenia
National Physical Laboratory, United Kingdom
"Horia Hulubei"
National Institute for Physics and Nuclear Engineering, Romania

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Publications

doi.org/10.3390/atmos10010025
doi.org/10.1029/2018JD029507
dx.doi.org/10.1016/j.scitotenv.2023.162126
dx.doi.org/10.3402/tellusb.v68.30967
doi.org/10.1016/j.jenvrad.2016.01.010

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Baseline climate data

ANSTO radon measurements identify the cleanest air on the planet

The Earth's climate and air quality are changing due to changes that are occurring in the composition of the planet's atmosphere. These changes include increases in natural and synthetic greenhouse gases, ozone-depleting substances such as chlorofluorocarbons or CFCs and fine particles that affect cloud formation.

THE CHALLENGE

Our ability to measure recent climatic impacts, forecast future impacts, and evaluate emission mitigation strategies relies upon accurate monitoring of the slowly changing global background atmosphere. Background atmosphere is referred to as the atmospheric 'baseline' because it is unaffected by local pollution sources and represents the world's most pristine air. Accurate measurements of this baseline depend on high precision and strategically placed monitoring equipment.

THE SOLUTION

At the Kennaook/Cape Grim Baseline Air Pollution Station (KCG-BAPS) in Northwest Tasmania, the Bureau of Meteorology together with CSIRO and ANSTO measure the composition of some of the world's most pristine 'baseline' air.

To distinguish pure 'baseline' air coming across the Southern Ocean from the air that has had more recent contact with terrestrial sources from Australia, the trace gas radon (^{222}Rn) is measured by ANSTO scientists at KCG-BAPS. Radon is a naturally occurring radioactive gas with a short half-life of 3.8 days which prevents it from accumulating in the atmosphere. Since radon is emitted almost exclusively from the land surface, it is an ideal tracer for identifying air masses that contain even the smallest traces of recent anthropogenic pollution.

An ANSTO-built radon detector at KCG-BAPS is recognised by the World Meteorological Organisation as the world's best radon detector for 'baseline' atmospheric composition studies. It is capable of reliably and accurately measuring extremely low radon concentrations equivalent to 5 atoms per litre of air (below 10 mBq m^{-3}).

THE IMPACT

Identification and characterisation of 'baseline' air is the primary task of more than 20 World Meteorological Organisation-Global Atmosphere Watch (WMO-GAW) stations at remote and high-altitude locations around the world. KCG-BAPS is one of three 'premier' WMO-GAW stations. ANSTO's unique technology for highly sensitive measurements of atmospheric radioactivity has established an international benchmark and reputation for precision and quality at key WMO-GAW sites. ANSTO-built radon detectors are also deployed at WMO-GAW stations in Hawaii, South Africa, Antarctica, the Swiss Alps and South Korea.

Long-term monitoring at baseline stations provides vital atmospheric information to the scientific community. This knowledge informs contributions to international conventions, protocols, and collaborative reporting on climate change.

Research Priorities

Environment

ANSTO Capabilities

- Radon monitoring

ANSTO Instruments

ANSTO Radon detector: HURD3
Cape Grim (Kennaook)

Collaborators/Client

Australian Bureau of Meteorology
CSIRO

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Publications

doi.org/10.1016/j.atmosenv.2017.12.010
doi.org/10.3390/rs15020461
doi.org/10.1016/j.envpol.2018.08.043
doi.org/10.5194/acp-21-1861-2021

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Kennaook / Cape Grim Baseline Air Pollution Station (top); and HURD3 - ANSTO's flagship radon detector (bottom).

Understanding climate through coral records

Reconstructing past sea surface temperatures to plan for future extreme weather events

Because of climate change, the impact of extreme weather is becoming an increasing threat. To better predict and plan for future extreme weather events, we first need an understanding of past climate events, their frequency, and their magnitude.

THE CHALLENGE

Corals are excellent environmental archives of past climates. To distinguish the small variation seen in corals over time and reconstruct past sea surface temperatures, high-precision analyses are required.

THE SOLUTION

The team at ANSTO developed a set of unique methods to determine element ratios in corals with high precision. By pairing stable oxygen isotopes ($\delta^{18}O$) and strontium/calcium (Sr/Ca) element ratios, ANSTO researchers with collaborators from the University of Wollongong established good proxies for past seawater surface temperature and El Niño events.

THE IMPACT

High-precision isotope and element analyses of corals conducted at ANSTO have led to better records of past sea surface temperatures. Records of past climate extreme frequency and magnitudes enable better modelling to predict and plan for future extreme weather events that may impact Australia, Southeast Asia, and the Americas. Over the years, ANSTO has developed a good reputation in the study of corals and expanded its expertise to other archives of past environments; a record of past hydrology and fire history has recently been investigated from cave deposits.

Research Priorities

Environment

ANSTO Capabilities

- Inductively Coupled Plasma-Atomic Emission Spectrometry

ANSTO Instruments

Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES)

Collaborators/Client

University of Wollongong
University of Melbourne
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Publications

doi.org/10.1038/ngeo1936
doi.org/10.1002/2014PA002683
doi.org/10.1038/s41467-020-18083-7
doi.org/10.5194/cp-18-2321-2022

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The underwater drilling of modern coral (Porites) to reconstruct the history of sea surface temperature. Picture from Jessica Jean Gaudry Honours 2012 Bachelor of Environmental Science thesis "El Niño-Southern Oscillation during the past 50 years: Reconstructions from a western Pacific coral", University of Wollongong.

Mitigating climate change

The role of coastal wetlands in carbon capture

According to an Inter-governmental Panel on Climate Change (IPCC) report, sea level rise is projected to accelerate over the 21st Century. More extensive and frequent flooding is expected. Very low-lying areas including coastal wetlands, such as mangroves, tidal marshes, and seagrass, are likely to be permanently inundated. These wetlands capture and store the largest volumes of atmospheric carbon dioxide (CO_2) of all natural systems and could play a key role in mitigating the effects of greenhouse gas emissions.

THE CHALLENGE

Understanding how coastal wetlands respond to rising sea levels is essential to mitigating the impacts of sea level rise and climate change. Researchers conducted an initial examination of 300 salt marshes across six continents that record 6,000 years of history. Results indicated that salt marshes on coastlines which experienced sea level rise captured more carbon than those where the sea level was relatively stable. On coastlines where the sea level is rising, organic carbon is more efficiently buried and stored as the wetlands grow to accommodate the increasing water level. As well as removing CO_2 from the atmosphere, the organic carbon that accumulates in salt marshes builds the elevation of the wetland. Researchers aimed to test if this process could potentially offset the degree of coastal inundation that may occur with sea-level rise.

THE SOLUTION

The team tested this hypothesis by investigating a sediment core from a salt marsh at Lake Macquarie in New South Wales. The sediment was deposited in the lake during the removal of supports from an underground mine in the 1980s. Due to the lack of underground support, the shoreline subsided by a metre in a matter of months. Researchers analysed sediment samples using ANSTO's radiocarbon dating, lead-210 dating, X-ray fluorescence scanning (ITRAX), and stable isotope facilities to accurately determine the timing of subsidence. They measured the carbon concentrations before and after subsidence occurred as a proxy for rapid sea level rise. Results implied that rapid relative sea-level rise leads to a four-fold increase of organic material in the sediment, much of it as carbon.

THE IMPACT

This work provides a powerful incentive for wetland conservation and restoration in Australia and across the globe. Preservation of coastal wetlands is critical if they are to play a role in sequestering carbon and mitigating climate change.

Research Priorities

Environment

ANSTO Capabilities

- Radiocarbon dating with Accelerator Mass Spectrometry
- Lead-210 dating with alpha spectrometry and gamma spectrometry
- Micro-X-Ray Fluorescence

ANSTO Instruments

X-Ray Fluorescence Core Scanner ITRAX
ANTARES
10MV Tandem Particle Accelerator

Collaborators/Client

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Macquarie University
Deakin University

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Publications

doi.org/10.3389/fmars.2022.807588
doi.org/10.1038/s41586-019-0951-7
doi.org/10.1016/j.scitotenv.2019.03.345

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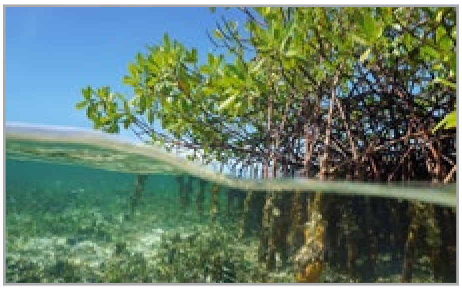

Mangroves capture CO_2.

Managing water resources

Mapping rainfall to address Australia's water crisis

Australia is amid a water crisis. Increasingly, there are shortages of fresh clean water for drinking, agriculture, industry, and our natural environment. Climate change, droughts, and floods are accelerating this water shortage. Water supplies may be drawn from groundwater, dams, and rivers, but ultimately, they all derive from rainfall.

THE CHALLENGE

Australia's challenge is to sustainably manage its water. Studies are needed to investigate what happens to water between the time it falls as rain to when it comes out of the tap. What is not well constrained is the age of our groundwater and how, where, and when groundwater recharges.

Hydrogen and oxygen isotopes are excellent tracers of water in our environment. The ratio of heavy water ($^{2}H/^{18}O$) to light water ($^{1}H/^{16}O$) allows researchers to fingerprint where in time and space the water was derived, which processes have affected it, and what climate and weather conditions existed at the time. Hydrogen-3 (^{3}H or tritium) in rainfall can be traced through the groundwater to acquire age data. For these reasons, the various water isotopes are excellent tracers of water cycling on land and in the atmosphere, past water and climate, food provenance, ecological dynamics, and forensics.

To enable these applications, work is needed to characterise the signature of the water at its source – rainfall.

THE SOLUTION

The IAEA/WMO Global Network of Isotopes in Precipitation (GNIP) started operating in 1962, collecting monthly rainfall samples at up to 15 sites around Australia. ANSTO analyses these samples at its low-level tritium and stable isotope laboratories to contribute to Australian and global science. ANSTO scientists have been developing models and maps, or 'isoscapes', to predict how the rainfall isotope signature varies across space and time in Australia.

THE IMPACT

The ANSTO GNIP data and isoscapes are used extensively by researchers, government, scientists, and industry across Australia and the world. The data is being used to understand the age of our groundwater and how, where, and when it recharges; compare present-day climate and weather patterns with past climate data to reconstruct a timeline of dry and wet periods over centuries to millennia; measure the effect of evaporation on our dams and rivers; and improve global circulation and land surface models used in climate projections. Rainfall isotope maps are also being combined with maps of soil and plant isotopes and elements to identify the source or provenance of foods and agricultural products. This work safeguards Australia's agriculture industry and biosecurity.

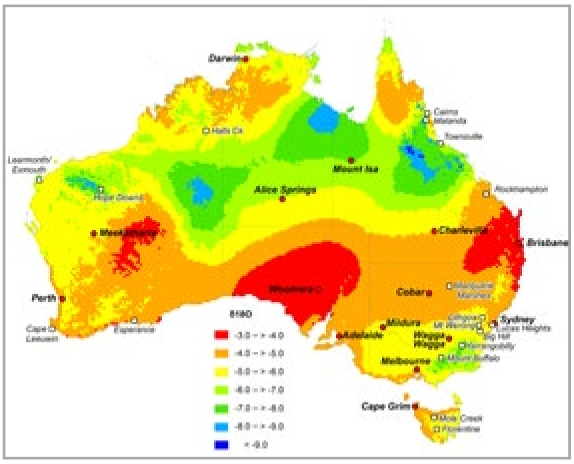

FIGURE 1:
Australian rainfall isoscape (left) used to show how groundwater recharge in NE Australia differs between the coast and the semi-arid interior. (right) D-excess is a measure of evaporation. On the coast (black line) groundwater and rainfall match, but inland (red dashed line) the effect of evaporation on groundwater increases toward the arid interior. ANSTO research has shown that large scale flooding dominates recharge in much of inland Australia (From Hollins et al, 2018).

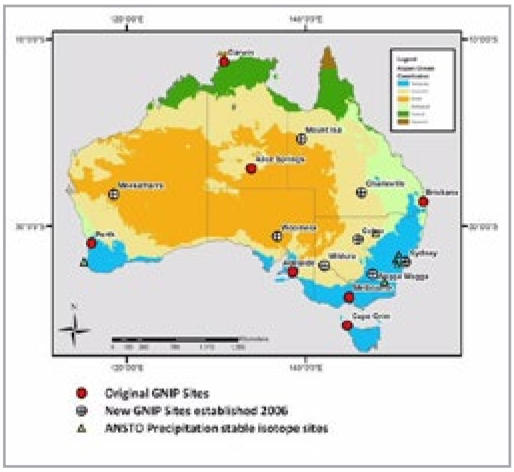

FIGURE 2:
GNIP Sites

Rainfall in Victoria

Research Priorities

Environment

ANSTO Capabilities

- ANSTO Low-Level Tritium measurements
- ANSTO Environmental Isotope Laboratory

ANSTO Instruments

Liquid Scintillation Counter with electrolytic enrichment
Cavity Ring Down Spectrometer

Collaborators/Client

International Atomic Energy Agency (IAEA)
Australian Bureau of Meteorology
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Publications

dx.doi.org/10.1016/j.scitotenv.2018.07.082
dx.doi.org/10.1016/j.jhydrol.2014.03.031
dx.doi.org/10.1016/j.jhydrol.2012.07.029

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Reducing the impacts of burning coal

Identifying technologies that reduce mercury emissions to protect local communities

When power stations burn coal, mercury is released into the atmosphere and falls back onto the Earth's surface. If a high level of mercury enters lakes or rivers, it can be transferred to fish and other organisms, which may ultimately be consumed by humans. Exposure to unsafe levels of mercury can damage the nervous system, brain, and other organs.

THE CHALLENGE

In New South Wales (NSW), coal power stations are required to use 'bag filters', a technology that traps mercury and other fine particles before they enter the atmosphere. In Victoria, coal-fired power stations operate without some of the mandated controls used to reduce air pollution in NSW and other developed countries. To better understand the efficacy of using bag filters, researchers needed to compare mercury levels around coal-fired power stations in NSW and Victoria before and after the implementation of this technology.

THE SOLUTION

The team collected sediment cores from lakes close to coal-fired power stations located in the Latrobe Valley, Victoria and the Hunter Valley, NSW. By analysing the mercury levels in the sediment core samples with high-precision micro-X-ray fluorescence (µ-XRF) at ANSTO, researchers gained a historical record of mercury back to 1940. ANSTO dating facilities played an important role in analysing the age of the sediment layers by using lead-210 dating. Results showed how much naturally occurring mercury there was before and after coal-fired power stations were built. The adoption of bag filters in the Hunter Valley, NSW corresponded with a decline in mercury emissions from the 1990s. In contrast, mercury emissions in Victoria, where they do not use bag filters, have continued to increase near Hazelwood power station since it opened in 1971.

THE IMPACT

This study provides authorities with clear evidence that technologies such as bag filters can reduce mercury emissions from coal-fired power stations and protect local communities. Communities can use this research to seek regulations that will minimise this pollution and the health impacts of burning coal.

Research Priorities

Environment

ANSTO Capabilities

- Lead-210 dating with Alpha spectrometry & Gamma spectrometry
- Micro-X-ray Fluorescence

ANSTO Instruments

X-Ray Fluorescence Core Scanner (ITRAX)

Collaborators/Client

Australian National University
Monash University

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Publications

doi.org/10.1016/j.envpol.2021.117596
doi.org/10.1525/elementa.440
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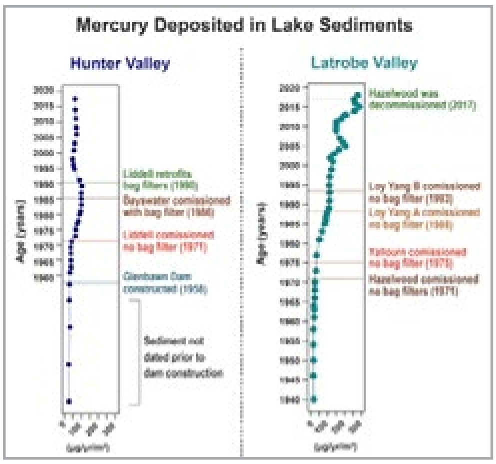

FIGURE 1:
Mercury deposited in sediments of Lake Glenbawn (left) in the Hunter Valley and Traralgon Railway Reservoir (right) in the Latrobe Valley.

Accurately reconstructing environmental history

Benefits to environment, society, and economy

Climate change and human activities have impacted our environmental landscape. To protect the environmental landscape and adopt sustainable management policies, it is essential to study past environmental changes. This approach will bring environmental, social, and economic benefits.

THE CHALLENGE

Sediment cores preserve evidence of past environmental change through time. To analyse environmental proxies used to reconstruct the environmental history at a sample site, accurate dating and trace element analyses are needed.

THE SOLUTION

ANSTO operates unique capabilities, enabling researchers to perform analyses on sediment cores to study environmental history. Trace metals are used as proxies for pollution history, which can be analysed at ANSTO using the micro-X-ray fluorescence (μ-XRF) core scanner (ITRAX), inductively coupled plasma-atomic emission spectroscopy (ICP-AES), and inductively coupled plasma-mass spectrometry (ICP-MS).

To reconstruct the timing and duration of past environmental processes from sediment cores, accurate dating techniques are essential. ANSTO operates unique facilities for dating, that allowed this research to be conducted.

THE IMPACT

The project findings have resulted in improvements to both the environment and human health. This work supports lobbying efforts for changes in environmental regulation to reduce the emission of mercury and other contaminants from mining activities and coal-fired power stations; and provides knowledge that can be used to implement effective fire management policies. This work demonstrates that vegetation changes since the European invasion are leading to more catastrophic fires. In addition to climate change, this results in the increased likelihood of frequent and more severe fires that need informed management strategies. This work also leads to the protection of local communities and ecosystems from buried contamination through more informed local councils' management decisions; and the knowledge that coastal wetlands are important resources, which will store carbon during sea level rise and hence, must be protected.

Platform used to extract lake sediments in Tasmania. Image: Michela Mariani

Research Priorities

Environment

ANSTO Capabilities

- Radiocarbon dating with Accelerator Mass Spectrometry
- Lead-210 dating with Alpha spectrometry & Gamma spectrometry
- Micro-X-Ray Fluorescence

ANSTO Instruments

X-Ray Fluorescence Core Scanner ITRAX

Collaborators/Client

Australian National University
Deakin University
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University of Melbourne
Monash University
University of New South Wales
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Publications

doi.org/10.1016/j.quascirev.2021.106824
doi.org/10.1016/j.envpol.2021.117596
doi.org/10.3389/fmars.2022.807588
doi.org/10.1016/j.scitotenv.2021.149542
doi.org/10.1007/s12237-021-00919-0
doi.org/10.1177/2053019620968133
doi.org/10.1016/j.envpol.2020.114695
doi.org/10.1016/j.scitotenv.2020.137398
doi.org/10.1016/j.scitotenv.2018.11.241

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Modelling climate change

Determining groundwater sources of atmospheric CO_2

Climate change from the accumulation of greenhouse gases in the atmosphere is expected to significantly impact ecosystems, human health, water, and food availability. A noteworthy source of the greenhouse gas carbon dioxide (CO_2) is the breakdown of dissolved organic carbon (DOC).

THE CHALLENGE

Groundwater is a source of DOC. However, groundwater is still largely excluded from carbon budget estimates and climate models because the concentrations, storage times, and transformations to CO_2 of DOC in groundwater are poorly understood. This is partly due to the low concentrations of DOC typically present in groundwater, which can be very difficult to measure.

THE SOLUTION

The team at ANSTO used a host of high-precision analytical techniques in the Centre for Accelerator Science to measure radiocarbon (carbon-14) in samples smaller than 100 micrograms. This allowed the team to determine the age of the DOC in groundwater from lower quantities of water, making it possible to collect and measure samples from a variety of aquifer types, depths, and ages. The team determined that dark, low-oxygen groundwater environments trap DOC that would otherwise be converted into CO_2 by microbes in sunlit, oxygen-rich surface conditions, such as in rivers and oceans. Once brought to the surface, the DOC can be rapidly broken down into greenhouse gases.

THE IMPACT

This work, which is vital for climate modelling, successfully examined and characterised DOC that had been preserved underground for up to 25,000 years. If extracted from bores for human water use, or transferred to oceans during natural groundwater transport processes, it is estimated that groundwater DOC brought to the surface is equivalent to annual amounts of DOC transferred from the Congo River into the ocean. As this old groundwater may be a significant source of atmospheric CO_2, this research provides important implications for global carbon budget estimates which inform climate models, and, ultimately, policymakers.

Research Priorities

Environment

ANSTO Capabilities

- Liquid Scintillation Analysis
- Accelerator mass spectrometry (Radiocarbon dating)

ANSTO Instruments

ANTARES
10MV Tandem Particle Accelerator

STAR
2MV Tandem Particle Accelerator

VEGA
1MV Tandem Particle Accelerator

Collaborators/Client

Australian Research Council
Southern Cross University
University of New South Wales
National High Magnetic Field Laboratory, Florida, USA
Stable Isotope Facility, University of California, Davis USA

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doi.org/10.1038/s41467-022-29711-9

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Groundwater sampling bore holes at Wellington, NSW, one of the sampling field sites.

Monitoring legacy nuclear testing sites

Protecting people and the environment at Montebello Islands, Western Australia

The first nuclear test in Australia was detonated in 1952 aboard a surplus British ship, the HMS Plym, anchored in the Montebello Islands, Western Australia. The blast vapourised much of the ship and released radionuclides into the surrounding archipelago. Today, the islands host a marine park that provides recreation for visitors and a habitat for a diverse range of biota.

THE CHALLENGE

The site managers on Montebello need to know if any remaining radionuclides might impact sea turtles that nest on the Island's beaches or endangered mammals that use the island as a refuge. One of the main challenges has been providing accurate, up-to-date information about the location and levels of radionuclides present on the Island so that public visitation can be safely managed.

THE SOLUTION

ANSTO was invited to assess Montebello Island by park managers - the WA Department of Biodiversity, Conservation, and Attractions (DBCA), due to ANSTO's special expertise and equipment for precise radionuclide measurement. Samples, including biopsies from the fins of adult sea turtles, and from old, hatched turtle eggs, beach sands, island soils, and the bones of mammals that had died of natural causes, were collected and analysed. ANSTO can precisely measure small amounts of radionuclides including plutonium using a highly sensitive accelerator mass spectrometry at the Centre for Accelerator Science, and liquid scintillation and gamma spectrometry to measure caesium-137 and strontium-90, which are the major isotopes of concern.

THE IMPACT

ANSTO's research provided Montebello Park managers with the appropriate knowledge to safely manage recreation and conserve wildlife on the Island. This work confirmed most areas are safe for public camping and recreation, with levels that are similar to background measurements, and that local fish are safe to eat. Researchers highlighted some unsafe areas and advised on appropriate health and safety measures. This work demonstrated that for most animals, such as sea turtles, the health risk is low. However, ANSTO continues to work with DBCA biologists to measure radionuclides taken up by certain species to determine and explore additional safety and management actions and is collaborating with geneticists to evaluate potential impacts on affected species. Overall, this ANSTO project has vastly improved the safety of the public, researchers, and wildlife in the Montebello Islands.

Research Priorities

Environment

ANSTO Capabilities

- Liquid scintillation analysis
- Alpha Spectroscopy
- Gamma-ray Spectroscopy
- Accelerator Mass Spectrometry
- Vivarium Facilities

ANSTO Instruments

VEGA
1MV Tandem Particle Accelerator

Collaborators/Client

WA Department of Biodiversity, Conservation, and Attractions (DBCA)

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)

Edith Cowan University

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The Montebello Islands marine reserve is a popular tourist destination, providing a home to a diverse range of marine and island species.

Protecting people and the environment

Managing radioactive contamination at Australia's legacy nuclear sites

Australia has a number of nuclear legacy sites including the Little Forest Legacy Site in New South Wales, Montebello Islands off the coast of Western Australia, and Emu Field and Maralinga in South Australia.

From 1952-1963, Britain conducted nuclear tests and research at three sites – the Montebello Islands, Emu Field and Maralinga. These tests dispersed radioactive material into the environment. From 1960-1968, the Australian government buried low-level nuclear waste in shallow unlined trenches at the Little Forest Legacy Site, which was considered international best practice at the time.

THE CHALLENGE

The intergenerational legacy of nuclear testing and related waste in Australia must be characterised and quantified, while any spread of contaminants into the environment must be mitigated.

THE SOLUTION

To understand the persistence and environmental pathways of radioactive contamination as well as any radiation impacts on local wildlife and human visitors, ANSTO researchers conducted ground surveys and radiological characterisation at the legacy nuclear test sites at Maralinga and the Montebello Islands, and radioactive waste disposal at the Little Forest Legacy Site. The team characterised the chemical, physical, and radiological properties of materials dispersed or disposed of at the sites and surrounding environmental systems and the migration pathways of contaminants including the use of hydrological models.

THE IMPACT

This project directly facilitates better management of radioactively contaminated sites by Australian governments and industry. The radiological characterisation techniques developed establish a national sovereign capability that supports ANSTO's research objectives, radiological monitoring, and emergency preparedness and response, and supports Australia's nuclear security and safety. Data, modelling outcomes, and specific advice are made available to land resource managers to protect human health and the environment in areas with radioactive contamination. These capabilities feed into the national and international radiological assessment of Australian mining and nuclear test sites. More broadly, the work contributes to evaluating the environmental impacts of the Fukushima Daiichi Nuclear Accident, as well as the emerging needs for Australia's National Radioactive Waste Management Facility and the AUKUS nuclear submarine program.

Montebello Island.

Sampling at legacy nuclear site.

Sampling at legacy nuclear site.

Research Priorities

Environment

ANSTO Capabilities

- Accelerator Mass Spectrometry (AMS)
- Alpha Spectrometry
- Gamma-ray Spectrometry
- Inductively coupled plasma atomic emission spectroscopy (ICP-AES)
- Inductively coupled plasma-mass spectrometry (ICP-MS)
- Light Microscopy
- Liquid Scintillation Analysis
- Photo-stimulated Luminescence
- Autoradiography
- Scanning Electron Microscopy (SEM)
- Synchrotron Beamlines

ANSTO Instruments

X-ray fluorescence microscopy (XFM) beamline
VEGA
1MV Tandem Particle Accelerator

Collaborators/Client

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)
BHP
Edith Cowan University
Flinders University
Heathgate Resources
Maralinga stakeholders
JRHC Enterprises
Monash University
National Energy Resources Australia
University of Adelaide
University of Melbourne
University of Newcastle
University of New South Wales
University of Wollongong
Western Australian Government
International Atomic Energy Agency (IAEA)
ALMERA
LeTrench
ENVIRONET
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Publications

doi.org/10.1021/acs.est.6b01864
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Nitrogen in agricultural landscapes

Mapping regional nitrogen dynamics

Farmers require fertilisers to produce crops. A balance is needed between optimised crop production and potential off-farm dispersion of nutrients, such as nitrogen compounds, into the surrounding environment.

THE CHALLENGE

Most studies have investigated nitrogen sources in isolation, either in rivers, groundwater, or the atmosphere. The challenge is to assess the nitrogen cycle in all three environments, across different regions.

THE SOLUTION

The team at ANSTO and UNSW collaborators developed longitudinal studies, sampling rivers, groundwater, and air from the Central Highlands near Emerald, Queensland, the Lower Namoi River near Narrabri, and the Lower Murrumbidgee River near Darlington Point, New South Wales. They conducted a two-year study on the rivers and air with a one-time groundwater survey for each region.

The team collected and analysed samples for a range of environmental tracers including major ions dissolved in water, natural stable isotopes, radioactive and radiogenic isotopes, and ultra-trace level chemicals e.g., rare earth elements (REE). Tritium (hydrogen-3) revealed modern (<70 years) groundwater distribution and its connection to rainfall sources in rivers. Radiocarbon (^{14}C) informed on longer residence times "age" of groundwater. Chlorine-36 provided ages of nearly 1 million years for some Great Artesian Basin groundwaters near Narrabri and traced sources of salinity as well as irrigation water movements in the Emerald region. Ultra-trace level REE provided a novel approach to determine anthropogenic REE inputs into rivers that may be linked to certain fertilisers or industrial/urban sources of pollution.

Most stable and all radioactive isotopes were analysed at ANSTO with some N_2O stable isotopes analysed by UNSW collaborators and other international laboratories.

THE IMPACT

The combination of tracers and time-series has provided the most complete environmental tracer studies in the targeted regions. This work provides key stakeholders with a better understanding of regional nitrogen dynamics in their waterways, groundwater, and air and establishes a baseline for them to trace and mitigate future impacts. Data revealed that most nitrogen compounds in rivers are transported during high-flow events, not during drought. Furthermore, the monitoring of soil moisture conditions and the timing of irrigation and fertilisation could minimise N2O emissions. This work is also helping to resolve other local water issues such as increased salinity downstream of some rivers.

Research Priorities

Environment

ANSTO Capabilities

- Inductively coupled plasma atomic emission spectroscopy (ICP-AES)
- Inductively coupled plasma-mass spectrometry (ICP-MS)
- Liquid scintillation analysis
- Accelerator mass spectrometry (radiocarbon dating)

ANSTO Instruments

VEGA
1MV Tandem Particle Accelerator

SIRIUS
6MV Tandem Particle Accelerator

Collaborators/Client

University of New South Wales
Cotton Research and Development Corporation

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Publications

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Left: Groundwater pumping in the Lower Murrumbidgee (NSW); Centre: Surface water sampling of the Namoi River near Narrabri (NSW); Right: Degassing groundwater for isotopic analysis of N_2O near Emerald (QLD).

Understanding climate patterns

Links between intensifying westerly winds, drought and bushfires

Presently, the Southern Ocean acts as a 'carbon sink', reducing the amount of carbon dioxide (CO_2) accumulating in the atmosphere. The Southern Hemisphere westerly winds, or 'westerlies' play an important role in controlling how much CO_2 is absorbed by the Southern Ocean, and transporting moisture southward, towards Antarctica, which is linked to droughts and bushfires in parts of southern Australia, New Zealand, South Africa and South America.

THE CHALLENGE

In recent decades, the westerlies have been intensifying and shifting south due to climate change and ozone depletion. Yet it is unclear how this shift will influence the capacity of the Southern Ocean to act as a 'carbon sink' and affect the incidence of droughts and bushfires.

Research was needed to investigate how wind strength has changed in the past to understand these recent trends.

THE SOLUTION

The team collected sediment cores from lakes on sub-Antarctic islands, located in the Southern Ocean. Their climates, ecosystems and environments are determined by the strength of the westerlies. Stronger winds are associated with the build-up of more sea salt and windblown grains in the lakes. Over time, the lake sediments accumulate layers, which preserve 'snapshots' of sediment composition through time. The team analysed these samples, including the amount of windblown grains using ANSTO's micro-X-ray fluorescence core scanner. To accurately date the age of the layers, they used high-precision carbon-14 and lead-210 dating techniques. They investigated fossil diatoms (tiny algae) because different species indicate different amounts of sea salts in the lakes. These data allowed them to reconstruct the past climate, lake ecosystems, and the surrounding environment.

THE IMPACT

This work confirmed that over at least the past 12,000 years, higher wind intensity directly corresponds with increasing atmospheric CO_2 as measured from ice cores. Findings suggest that further increases in wind strength may reduce the Southern Ocean's capacity to act as a 'carbon sink', lessening its ability to slow the rate of climate change. As the winds continue to migrate southwards in association with climate change, these trends are likely to continue. These data are invaluable to climate models and informing policymakers.

Research Priorities

Environment

ANSTO Capabilities

- Radiocarbon dating with Accelerator Mass Spectrometry
- Ion Beam Analysis (IBA)
- Micro-X-ray Fluorescence
- Lead-210 dating with Alpha Spectrometry

ANSTO Instruments

ITRAX
X-ray Fluorescence Core Scanner

VEGA
1MV Tandem Particle Accelerator

Collaborators/Client

Australian Antarctic Division
British Antarctic Survey
Institute for Marine and Antarctic Studies, University of Tasmania
Monash University
Queensland University of Technology
University of Aberystwyth
University of Bern
University of Ghent
University of Wollongong

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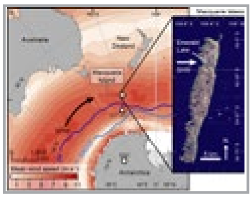

FIGURE 1: (Left) Location of study sites.
FIGURE 2: (Centre) Dr Krystyna Saunders collecting sediment cores on sub-Antarctic Campbell Island.
FIGURE 3: (Right) Images of a sediment core using ANSTO's high-resolution micro-x-ray fluorescence core scanner.

Antarctic research

Impacts of climate change on Antarctic vegetation

The Antarctic region is a critically important part of Earth's climatic system. The climate and biogeophysical properties of Antarctica are closely coupled to the global environment. In recent decades, Antarctica has been experiencing regionally distinct climatic shifts that are rapid and severe. Across much of the Southern Hemisphere, wind patterns and wind intensity have changed due to ozone depletion and increasing levels of greenhouse gases. In addition, ultraviolet-B (UV-B) radiation has increased over and around Antarctica.

THE CHALLENGE

There is a relatively short and patchy record of coastal climate in Antarctica, leaving very little known about how vegetation is changing around most of the Antarctic continent. A lack of both weather stations and ecosystem monitoring systems contributes to this knowledge gap; investigation using other climate proxies is therefore required.

THE SOLUTION

The team used mosses, the dominant terrestrial plants in Antarctica, in their research as a biological proxy for climate change in ice-free areas where meteorological records are sparse. Although tiny, typically less than 5 cm tall, mosses can persist for up to 500 years. Researchers used radiocarbon dating and stable carbon isotopes ($\delta^{13}C$) analysis at ANSTO to determine accurate moss growth rates, and explore the influence of climate change (e.g., wind, temperature) on moss growth and water availability over time.

THE IMPACT

This research, as part of the ARC Special Research Initiative project entitled "Securing Antarctica's environmental future (SAEF)", provided the first evidence that anthropogenic climatic changes are causing the drying of East Antarctic ecosystems. Further work on Antarctic mosses is in progress to improve our knowledge on widespread patterns of climate change across Antarctica. This research contributes to the global research effort to build accurate models of coastal climate change over the past century, and how it has affected vegetation on the edge of the Antarctic continent. This is of great value for better understanding of the impact of Antarctic climate change at regional and global scales.

Research Priorities

Environment

ANSTO Capabilities

- Accelerator Mass Spectrometry (AMS)
- Radiocarbon dating
- Stable carbon isotope analysis

ANSTO Instruments

VEGA
1MV Tandem Particle Accelerator

Elementar VarioMICRO EA/IsoPrime IRMS

Collaborators/Client

University of Wollongong
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FIGURE 1: (Left) Much like tree rings, moss shoots preserve a record of past climate, and how wet or dry it was while they were growing.
FIGURE 2: (Right) Prof Sharon Robinson and Dr Melinda Waterman in the laboratory at the University of Wollongong. Melinda is holding a core of moss shoots from East Antarctica. Image credit: Paul Jones.

Advanced imaging: ptychography

Accurately quantifying carbon in deep-sea limestones to understand the carbon cycle

X-ray fluorescence microscopy (XFM) is the most sensitive non-destructive method used to map the spatial distribution of elements, particularly metals, in a broad range of samples, from biological specimens to meteorites and artworks.

THE CHALLENGE

The spatial resolution of XFM images is limited to the micrometre size of the X-ray beam, and the distribution of key elemental components may be difficult to interpret without additional information. Consequently, it is vital to establish the context of the XFM images within the morphology of the specimen.

THE SOLUTION

Ptychography is a new scanning X-ray diffraction microscopy method that uses a focused coherent X-ray beam to probe a thin sample, producing a series of diffraction patterns. Algorithms are used to reconstruct images with spatial resolution below 100 nm from the diffraction patterns. Ptychography data can be obtained at the same time as XFM data, providing correlated ultrastructure images showing contextual morphology for the elemental composition images (Figure 1).

THE IMPACT

Correlated XFM and ptychography were used to provide the first estimates of the amount of carbon captured in microscopic seams of deep-sea limestone (Figure 2). Ptychography images revealed that the rock contained densely spaced micro-dissolution seams, only tens of nanometres in size, which are not visible with conventional imaging techniques. The XFM data indicated that about 10 per cent of the total carbon in the limestone was contained within the seams. Accurately quantifying the carbon captured in deep-sea limestones is fundamental to understanding the long-term carbon cycle.

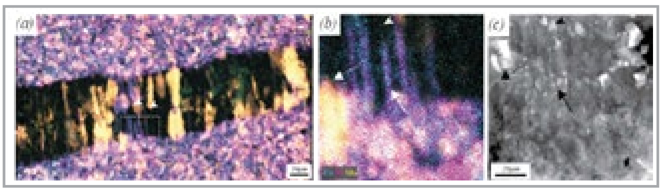

FIGURE 1:
A large-area correlated XFM-ptychography image of a small vein in a freestanding thin section of shale. (a) An XFM image of the entire 800 × 440 μm^2 scan area is shown in cyan, magenta and yellow for Cu, Fe and Mn, respectively; (b) An enlargement of the region of interest (ROI) of the 100 × 100 μm^2 area indicated by the dashed square in panel (a). (c) A ptychographic phase-contrast reconstruction in the same ROI, revealing high-resolution high-contrast structural information. The scale bars represents 50 µm in (a), 20 µm in (c), and the pixel size in (c) is 25 nm.

Research Priorities

Environment

ANSTO Capabilities

- Synchrotron X-ray fluorescence microscopy

ANSTO Instruments

X-ray Fluorescence Microscopy (XFM) Beamline

Collaborators/Client

Queensland University of Technology
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Publications

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doi.org/10.1038/s43247-021-00257-w

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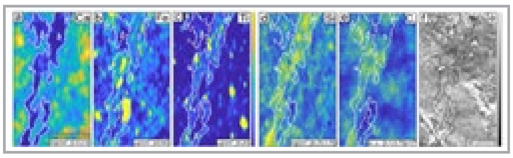

FIGURE 2:
Nano-scale chemical and structural maps of an individual micro-dissolution seam. (a) XFM calcium map of a micro-dissolution seam and its immediate surroundings in deep-sea limestone. Seam boundaries obtained with automated segmentation are marked with white lines. Other XFM elemental maps in the same area are (b) iron, (c) titanium, (d) silicon, and (e) Compton scattering. Iron, titanium, and silicon are enriched within the seam, while the Compton scattering intensity demonstrates a density increase within the seam. (f) shows a nano-scale ptychographic map of the complex X-ray wavefield phase exiting the sample, which is closely linked to the electron density. The micro-dissolution seam does not display a marked structural difference in comparison to the micritic matrix.

Impacts of drought

Establishing how native Australian trees adapt and cope with drought

Australia is experiencing longer and more frequent droughts due to climate change. Drought is now occurring in regions that historically have not experienced these conditions.

THE CHALLENGE

One reason trees die during droughts is due to a catastrophic failure of the system that moves water from the soil to the leaves. This system depends on maintaining a delicate pressure balance, which can rupture if under stress. To gain insight into the vulnerability of native Australian trees during droughts and heatwaves, it is necessary to understand how these systems adapt and cope under these conditions.

THE SOLUTION

In this study, researchers investigated a pine tree stem using the Imaging and Medical beamline at the Australian Synchrotron. The beamline is equipped with accurate high payload handling equipment that allows manipulation of larger and heavier objects, such as potted saplings. Researchers imaged the pine stem in three dimensions with X-ray computed tomography (CT) to visualise water-filled and blocked (embolized) regions. This information was combined with computational models to predict the thresholds that, when crossed, can cause tree death, and how trees can recover after drought.

THE IMPACT

This study increased our understanding of plant response to drought, specifically by revealing how water transport systems can be damaged. Researchers can use this information to devise strategies that can lessen the effect of tree mortality on the ecosystem during times of drought and heat stress.

Research Priorities

Environment

ANSTO Capabilities

- Synchrotron X-ray CT

ANSTO Instruments

Imaging and Medical Beamline (IMBL)

Collaborators/Client

University of Western Sydney
University of Tasmania
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Publications

doi.org/10.1111/pce.14265
doi.org/10.1093/aob/mcac053
doi.org/10.1038/s41586-018-0240-x

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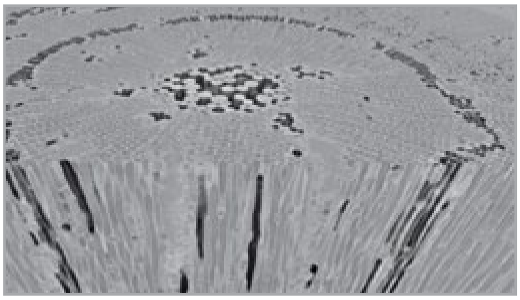

FIGURE 1: A 3-D X-ray computed tomography (CT) image of a thirsty tree stem. Water-filled tracheids (long, tapered cells) are grey, whereas the black tracheids are empty. This image allowed scientists to visualise the way trees transport water, and ultimately how trees may cope with drought and heat stress.

Identifying waste management strategies

Understanding the causes of contaminant mobilisation at a legacy waste site

Little Forest Legacy Site (LFLS) was used for the disposal of low-level laboratory wastes for a discrete period from 1960 to 1968. Waste was placed into shallow unlined trenches, following the industry standard of the time. Subsequent exposure to environmental processes including groundwater circulation has resulted in waste decomposition at LFLS, producing complex mixtures containing organic compounds, minerals, and radionuclides such as plutonium, that could be harmful if leached into the environment.

THE CHALLENGE

The persistence of water-soluble organic compounds such as tributyl phosphate (TBP) which could bond with radionuclides means that harmful radioactive compounds could more easily migrate into the groundwaters of the LFLS. The primary challenge was to develop robust methods that could specifically target and locate these organic compounds.

THE SOLUTION

An initial investigation qualitatively identified if any organic compounds were present since waste disposal had occurred at the LFLS approximately 50 years ago. The team analysed the specific compound TBP through solid-phase extraction, which is a technique designed to retain organic compounds from an aqueous phase onto a solid surface. The team used tandem gas chromatographic-mass spectrometry to quantify the results, which could be compared to a comprehensive internal library of data.

THE IMPACT

This work facilitated mapping of the location and concentration of organic compounds, including TBP, that are linked to radionuclide migration and transport at the Little Forest Legacy Site. This information is vital in identifying waste management strategies that effectively constrain harmful waste products from legacy disposal methods.

Research Priorities

Environment

ANSTO Capabilities

- Organic Compound Identification and Quantification – National Deuteration Facility

ANSTO Instruments

Gas Chromatographic Mass Spectrometry

Collaborators/Client

University of New South Wales
Agilent Technologies

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dx.doi.org/10.1016/j.jenvrad.2017.05.015

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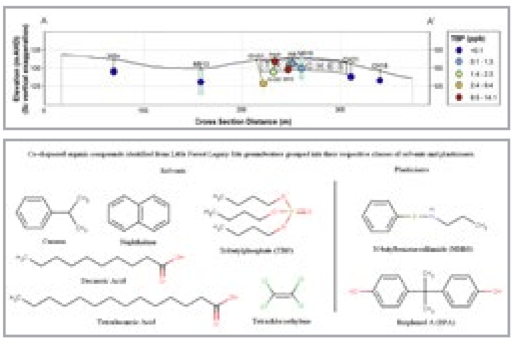

FIGURE 1: Organic compounds from LFLS Groundwaters, schematic of LFLS and cross section of LFLS.

Guiding environmentally sustainable investments

Monitoring pollutants for better air quality and industry practices

An enduring issue related to mining and industrial activities is the numerous impacts they can have on the environment, such as habitat destruction, biodiversity loss, and reductions in air and water quality. Fine particulate matter (less than 2.5 microns) has been widely attributed to undesirable health outcomes such as cancer, heart disease, stroke, and low birth weights.

THE CHALLENGE

The Lower Hunter region of New South Wales (NSW) is an area with both industrial activities and regional households. Monitoring the environmental burdens that industries can place in these regions is of key importance to environmental agencies, government agencies, residents, and the industries themselves. The NSW Government's Department of Planning and Environment (DPE) commissioned both ANSTO and CSIRO to provide a detailed study into the air quality of the NSW Hunter region.

THE SOLUTION

Air was sampled twice a week for 12 months using an ANSTO aerosol sampler at the industrial hub in Stockton, NSW. The team collected pollutants on stretch PTFE filters, which they then analysed for elemental concentrations using ion beam analysis (IBA) on the particle accelerator, STAR. They combined IBA results with ion chromatography analysis at CSIRO to help determine the source of the pollutants. The preliminary 12-month study from DPE, CSIRO, and ANSTO, incorporating statistical analysis and wind modelling, identified that a major source of fine particle pollution was industrial nitrate, originating from a dominantly northwest direction from Kooragang Island. These studies determined that industrial nitrate contributed an average of 19% of the mass at Stockton, with as much as a 40% contribution in the wintertime.

THE IMPACT

Due to this work, regulatory bodies took rapid action to identify and notify the nitrate manufacturer responsible on Kooragang Island. The company made commitments to minimise its impact on the region, firstly by engaging ANSTO's Centre for Accelerator Science individually to carry out a follow up study for a further 3 years to 2018, and then by investing $39 million into a prill tower upgrade. This outcome was the direct result of ANSTO's collaboration with DPE and CSIRO to help monitor, regulate, inform policy, research air pollution, and influence industry. ANSTO's Centre for Accelerator Science continues to monitor at the Stockton, NSW location as part of an ongoing collaboration with DPE.

Research Priorities

Environment

ANSTO Capabilities

- Fine particle pollution monitoring via Ion Beam Analysis

ANSTO Instruments

STAR
2MV Tandem Particle Accelerator

Collaborators/Client

NSW Government
Department of Planning and Environment
CSIRO

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Publications

doi.org/10.3390/atmos11010004

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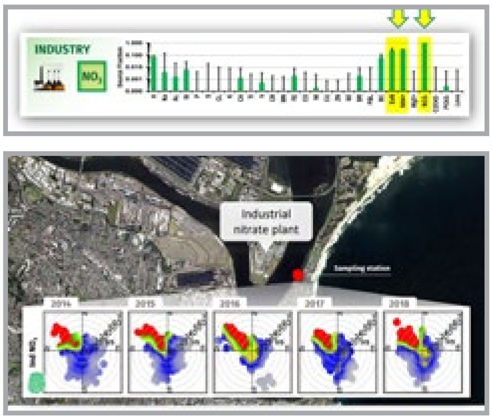
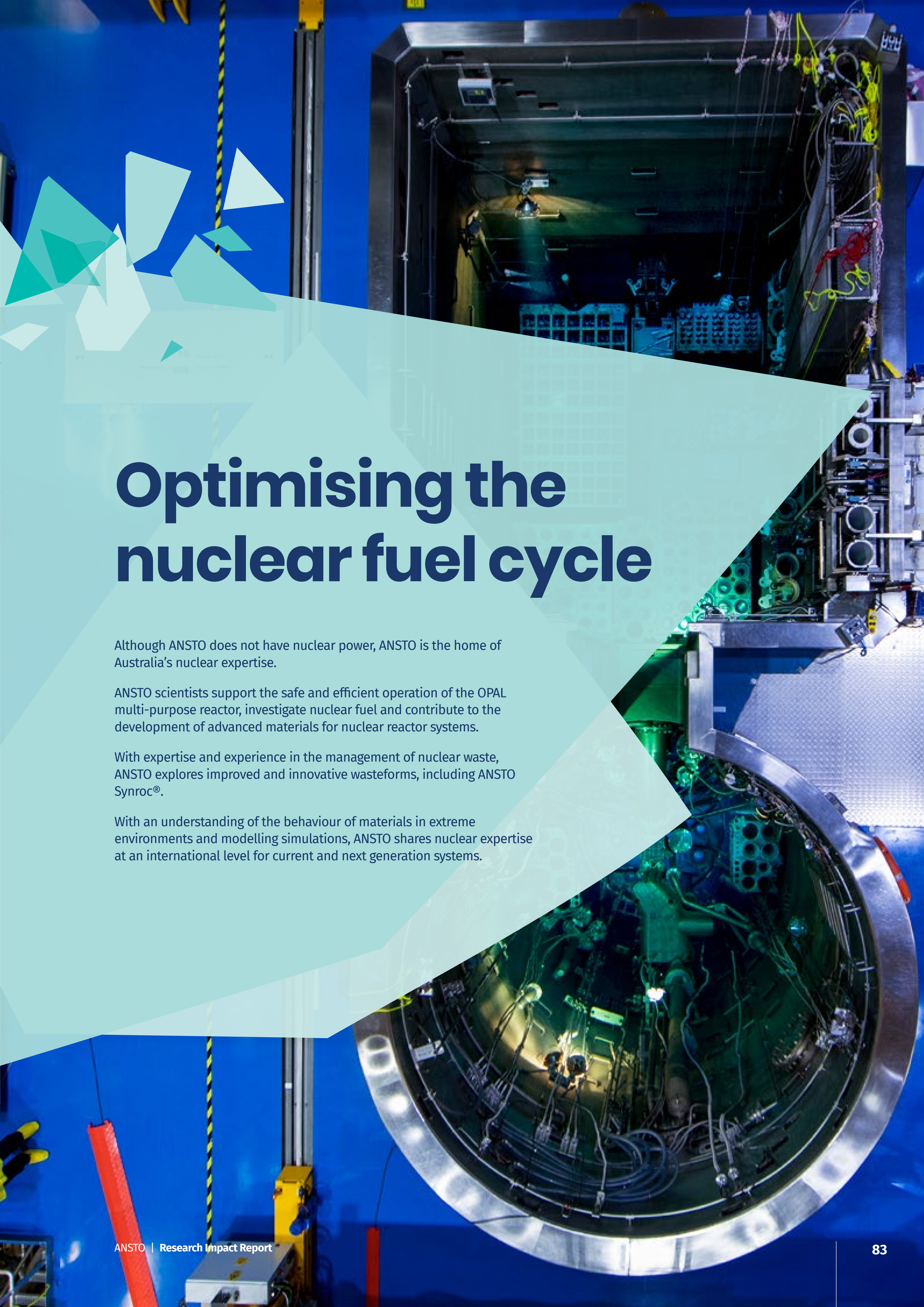


FIGURE 1:
(top) Column plot showing the species associated with the identified ammonium nitrate source fingerprint and, (bottom) annual pollution roses of the ammonium nitrate contributions (colour scale) versus wind direction and speed showing the prevailing north-west direction of the industrial nitrate fingerprint.



Optimising the nuclear fuel cycle

Although ANSTO does not have nuclear power, ANSTO is the home of Australia's nuclear expertise.

ANSTO scientists support the safe and efficient operation of the OPAL multi-purpose reactor, investigate nuclear fuel and contribute to the development of advanced materials for nuclear reactor systems.

With expertise and experience in the management of nuclear waste, ANSTO explores improved and innovative wasteforms, including ANSTO Synroc®.

With an understanding of the behaviour of materials in extreme environments and modelling simulations, ANSTO shares nuclear expertise at an international level for current and next generation systems.

ANSTO's Synroc® Waste Treatment plant

Safe and sustainable treatment of nuclear medicine waste

Molybdenum-99, produced in the OPAL multi-purpose reactor, is the precursor to technetium-99m, the most commonly used nuclear imaging radiopharmaceutical. Every week, about 30 litres of alkaline intermediate-level liquid radioactive waste (ILLW) is produced as a by-product of molybdenum-99 manufacturing at ANSTO. The ILLW radioactive waste will eventually be treated using ANSTO's Synroc® Waste Treatment Plant (SWTP) technology to produce a disposal-ready solid waste form safely contained in a stainless-steel canister.

THE CHALLENGE

As the waste form will not undergo any destructive testing, quality assurance is a requirement for acceptance into Australia's future nuclear waste repository. To assure that the final product meets performance requirements, an accurate determination of both the chemical and radiological properties of the intermediate-level liquid waste was necessary before ANSTO Synroc® processing.

Characterising nuclear waste has been undertaken at ANSTO for decades through our highly experienced Waste Management Services Group. However, characterising higher-activity nuclear waste as an input material into a highly regulated Synroc® waste processing facility requires a new systematic approach.

THE SOLUTION

Initially, the team developed analytical chemistry methods which they validated using a non-radioactive synthetic model of the ILLW. The team also developed methods for radiological characterisation of the liquid waste, which allowed verification and validation of the decayed waste and its source term (time radioactive). Following a safety assessment through sampling and testing of the actual ILLW, the team characterised its chemistry. These analytical methods were also implemented in waste management service laboratories to allow operational control over the process quality.

THE IMPACT

This work developed and implemented a complete characterisation program for the ILLW waste produced during molybdenum-99 production. These methods will help to monitor the properties of ILLW as it is continuously generated and are vital for ANSTO's Synroc® Waste Treatment Plant quality assurance program. This will guarantee that the waste form meets the required specifications for disposal. In line with ANSTO's sustainability vision, the developed capabilities are being utilised with other waste treatment programs including alternate and previous molybdenum-99 manufacturing waste products.

Research Priorities

Environment

ANSTO Capabilities

- ANSTO Synroc® Waste Treatment Technology

Collaborators/Client

The SyMo Project
ANSTO Nuclear Medicine
ANSTO Synroc® Waste Treatment Facility
ANSTO's Waste Management Services

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Dr Anton Peristyy undertaking method development testing on non-radioactive, synthetic waste material in the ANSTO Synroc Quality Control Laboratory.

Innovative nuclear waste solutions

Managing problematic radioactive waste with ANSTO's Synroc® Technology

Solutions for the treatment and disposal of nuclear waste, both legacy materials as well as waste arising from the deployment of innovative reactors and fuel cycles, is a global issue. Intermediate-level waste (ILW) and high-level waste (HLW) arises from spent fuel and reprocessing activities such as the production of molybdenum-99 for nuclear medicine. Concerns about nuclear waste are a barrier to community acceptance of nuclear facilities.

THE CHALLENGE

Regulators now require consideration of waste disposal pathways as part of the approvals process for all nuclear facilities. This is particularly challenging as the chemical composition of principal and probable waste from future technologies is modified as designs continue to evolve. Viable solutions to convert nuclear waste into a solid, stable, and reduced form for permanent and efficient disposal have never been more important.

THE SOLUTION

ANSTO's Synroc® group is recognised globally for developing a leading technology in waste treatment solutions for problematic nuclear wastes. Synroc® processing technology employs hot-isostatic processing (HIP) to produce a range of consolidated and volume-reduced waste forms, ceramic, glass, and glass-ceramic, which can be tailored to the chemical, physical, and radiological properties of the waste. The different waste forms are used to lock up different radioactive waste materials. ANSTO Synroc® is currently engaged with different international partners in four high-profile collaborative waste treatment programs for actinide immobilisation; volatile radioiodine immobilisation; molten salt immobilisation; and advanced fuel cycle waste immobilisation. These strategic research engagements use all aspects of Synroc®'s waste form design and development, and nuclear engineering capability.

THE IMPACT

This project establishes Australia as a leader in the treatment of problematic nuclear wastes including plutonium, radioiodine, and molten salts. Synroc® technology is part of the global, 'new nuclear build paradigm', including the future Gen IV reactor technologies. It is regarded by the international community, including the IAEA, as a key emerging technology addressing the full lifecycle treatment of nuclear waste. It also provides Australia with capability in next-generation nuclear technology. Synroc® enhances ANSTO's reputation as an international leader in the safe and sustainable treatment of nuclear waste and provides a nuclear-skilled workforce that can contribute to the Australian government's sovereign capability and national priorities. The work also presents commercial opportunities for ANSTO as nuclear nations seek to treat their nuclear waste.

Research Priorities

Environment

ANSTO Capabilities

- ANSTO Synroc® Waste Treatment Synroc® Demonstration Plant

Collaborators/Client

International Government Agencies
Technology development companies with waste responsibilities
National Laboratories
Research Centres
Universities

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An example of a HIP (hot-isostatic processing) canister designed for waste containing actinides (e.g., plutonium). A significant reduction in size can be seen post HIP, which allows for more efficient storage solutions.

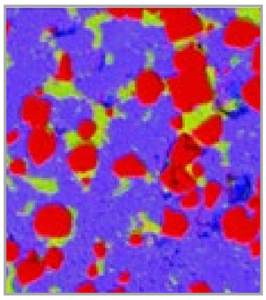

FIGURE 1:
An electron microscope image showing the incorporation of iodine into targeted materials of the waste form.

Selective elemental separation for nuclear waste

Reducing the volume and lifetime of hazardous nuclear waste

A big challenge in the nuclear industry is the public perception of nuclear wastes, due to the longevity and radiotoxicity of these wastes. One possible strategy to address these concerns is the separation and re-use of the long-lived, radiotoxic actinide elements: uranium (U), plutonium (Pu), americium (Am), curium (Cm), and neptunium (Np), remaining in spent nuclear fuel. An established commercial process exists for the recycling of more than 95% (U and Pu) of used nuclear fuel, but the remaining waste, containing the minor actinides Am, Cm, and Np, still retains its radiotoxicity for tens of thousands of years.

THE CHALLENGE

Designing materials for actinide separations already presents challenges. The removal of Am, Cm, and Np from used nuclear fuel is the next big challenge. Stability in the presence of acid and radiation is essential for these materials to function during the harsh conditions of radioactive waste treatment. Selective separation of minor actinides is also particularly difficult due to their chemical similarity to lanthanide fission products that are also present in used nuclear fuel. For example, neodymium is chemically similar to americium.

THE SOLUTION

The ANSTO team is developing solid adsorbent materials for the selective separation of actinides from radioactive wastes, in particular minor actinides. Typically, hybrid materials are developed that combine the chemical stability of an inorganic framework, such as titania or zirconia, with the selectivity provided by organic binding molecules. Zirconium and titanium phosphonate materials have proven highly effective for actinide separations. This work produced the first solid phase adsorbent material, a zirconium bistriazolylpyridine phosphonate, to demonstrate selective removal of the minor actinide, Am, from a solution containing excess lanthanides.

THE IMPACT

This work developed hybrid materials such as zirconium phosphonates that have the potential to be directly converted into durable ceramic materials. These ceramics could then be added to fuel elements to "burn" the captured actinide element in reactors. This could close the loop of the nuclear fuel cycle leading to more complete use of the energy potential in the actinide elements, while also reducing the volume and lifetime of hazardous waste requiring disposal. Work is ongoing to further improve the selectivity, efficiency, and stability of these materials to make them more practical for deployment and applicable to solving challenges in nuclear medicine, mining, and environmental remediation.

Research Priorities

Environment

ANSTO Capabilities

- Chemical Deuteration
- Electron Microscopy
- Nuclear Magnetic Resonance Spectroscopy (400 MHz)
- Synchrotron spectroscopy

ANSTO Instruments

X-ray Absorption Spectroscopy (XAS) Beamline

Collaborators/Client

UNSW
Sydney University
CEA, France
CNEA, Argentina

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Publications

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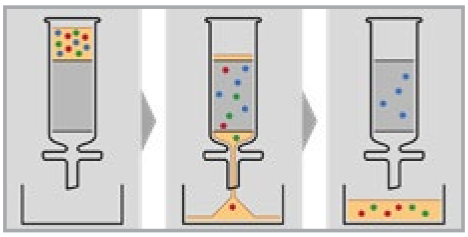

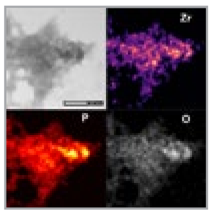

FIGURE 1: (Top) Schematic showing how solid phase materials could be deployed in a column to selectively separate a targeted element (blue) from a complex mixture of elements.

FIGURE 2: (Right) Scanning electron microscopy and energy dispersive x-ray (SEM/EDX) images the showing distribution of elements.

Development of advanced glass-ceramic wasteforms

Approach to immobilise actinides

Radioactive wastes are generated from the current nuclear fuel cycle. In particular, intermediate- and high-level wastes (ILWs and HLWs) are primarily arising from the fission of uranium fuels in nuclear reactors as either spent nuclear fuels (SNFs) or separated wastes from the reprocessing of SNFs. In addition, significant amounts of ILWs and HLWs were also generated from nuclear medicine industry.

THE CHALLENGE

ILWs and HLWs often contain actinide elements with long half-lives and are commonly complicated by the presence of significant amounts of processing chemicals. Hence, proper conditioning and treatments are essential to convert them into more stable solid forms suitable for successive waste management, e.g., transportation, interim storage and final geological disposal.

THE SOLUTION

As the emerging advanced waste forms for immobilising actinide-rich radioactive wastes, glass-ceramic composite materials based on some durable ceramic phases are being developed. They have obvious advantages over the conventional borosilicate glasses and multi- or single-phase ceramics as they essentially combine the chemical and processing flexibilities of glasses to accommodate processing impurities and excellent chemical durability of ceramic phases to host actinides.

Some new advances have been made at ANSTO on scientific and technological aspects including new glass-ceramic systems; improved understanding of ceramic phase evolution in glass; actinide validation studies and simplified processing techniques.

THE IMPACT

Development of suitable waste forms for immobilising various actinide-rich radioactive wastes arising from the nuclear fuel cycle.

Optimisation of hot isostatic pressing (HIPing) as a final waste form consolidation step to ensure that all waste forms meet the performance criteria.

ANSTO is the international leader offering technical solutions for waste management across the nuclear fuel cycle focusing on ILWs and HLWs.

ANSTO is able to assist the Australian government in ensuring its sovereign capability in all aspect of the back end of the nuclear fuel cycle.

Research Priorities

Environment

ANSTO Instruments

Materials Fabrication
Active fabrication (MFB)
Nuclear Fuel Cycle, Nuclear Materials Development and Characterisation

Material Characterization
Active characterization (SEM, XRD, TG-DSC)
Nuclear Materials Development and Characterisation

Structures and spectroscopies
MX1, MX2, PD, XAS beamlines
Australian Synchrotron

Collaborators/Client

Julich Institute, Germany
University of Huddersfield, UK

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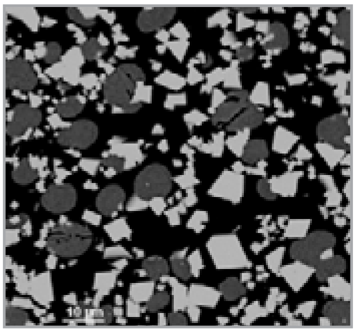

A backscattered SEM image of a uranium pyrochlore glass-ceramic containing pyrochlore crystals (bright), CaF2 (round grey) and residual glass (dark background).

Reprocessing nuclear fuel

Solutions for managing spent nuclear fuel using uranium oxide hydrates

Spent nuclear fuel (SNF) can be managed by reprocessing or direct disposal. Reprocessing the actinides from SNF introduces additional chemicals and complicates the composition of the waste. For countries that have not established reprocessing, direct disposal of SNF in a geological repository becomes attractive.

THE CHALLENGE

Spent nuclear fuel will encounter humid and oxidative environments under geological conditions. Subsequently, the alterations of SNF, such as the formation of uranium oxide hydrates, need to be well studied and understood to predict the long-term behaviour of SNF in underground repositories.

Current lapses in finding new uranium oxide hydrate (UOH) minerals, especially in the form of good-quality single crystals, stem from further alterations along the paragenetic sequence (equilibrium sequence of mineral phases) and other geochemical factors at specific uranium deposits. As such, investigating synthetic UOH phases can help to fill existing knowledge gaps and pave the way for the exploration of further structural diversity, properties, and other potential applications.

THE SOLUTION

As a perfect natural analogue for SNF alterations, natural weathering of the mineral uraninite resulted in the formation of a stable uranyl ion $[(UO2)^{2+}]$ through the process of oxidation, changing tetravalent U^{4+} to hexavalent U^{6+}, forming various uranyl minerals. UOH minerals are among the initial weathering products and play a key role in controlling the formation of other uranyl minerals in nature.

Apart from the typical layered structures commonly found in UOH minerals, various uranyl oxide hydrate frameworks (UOHFs) are being identified among synthetic UOH phases. The latest developments include 3D transition metals and the incorporation of lanthanides, the evolution of uranyl oxide hydroxide layers through interlayer charge, UOH structure diversity and the intrinsic energy for the formation of diversified structure types.

THE IMPACT

The project provides a unique opportunity to train ANSTO early career researchers including PhD students on actinide crystal chemistry and synchrotron small molecule crystallography.

ANSTO is the international leader in delivering advanced knowledge of SNF alterations and assists the Australian government in ensuring its sovereign capability in the back end of the nuclear fuel cycle.

Research Priorities

Environment

ANSTO Capabilities

- Synthesis and characterization of uranium-doped nuclear materials
- Structural and spectroscopic methods
- Synchrotron X-ray crystallography and spectroscopy

ANSTO Instruments

Scanning Electron Microscopy
Lab and synchrotron X-ray powder diffractions
Synchrotron macromolecular crystallography (MX) beamline
X-ray absorption spectroscopy (XAS) beamline
Diffuse reflectance spectroscopy

Collaborators/Client

University of Sydney
National Museum, Czech Republic

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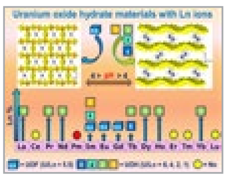

FIGURE 1:
A summary of synthetic UOH materials with Ln^{3+} ions.

Materials for next-generation energy systems

Development and deployment of low-emission molten-salt-based energy systems

Molten-salt-based energy-generation and energy-storage systems promise to provide the world with safe, low-emission, efficient, reliable, and economical energy. These systems employ molten salt as an energy-transfer medium and energy-storage medium or both in the case of hybrid generation-storage systems. The high boiling point and low vapour pressure of molten salt provide inherent safety, allowing molten-salt-based systems to operate at atmospheric pressure, eliminating any possibility of explosion-like accidents.

THE CHALLENGE

The widespread deployment of molten-salt-based energy systems is predominantly hindered by a lack of suitable structural alloys, which are required to withstand a combination of extreme in-service operating conditions, including high temperature and molten salt corrosion, in addition to radiation damage in the case of nuclear-based energy-generation systems.

THE SOLUTION

ANSTO developed a testing apparatus which can characterise materials in the molten salt environment for an extended period. It provides data on the molten salt corrosion resistance and degradation of various structural alloys in molten salt at temperatures up to 850°C. The team used ANSTO's high-temperature material testing laboratories and ion irradiation facilities to test the effect of high-temperature, molten salt corrosion, and radiation environments on the microstructure of candidate materials. The interplay between an alloy's microstructure, chemical composition, and in-service operating conditions was studied, shedding new light on the behaviour of molten salt corrosion and the performance of new alloys under development.

THE IMPACT

This significant contribution directly advances the development and implementation of low-emission energy generation systems, including molten salt reactors and concentrated solar thermal power plants. The insights gained from ANSTO's research provide valuable knowledge for the design, optimization, and long-term reliability of these energy systems, enhancing their durability, safety, and operational efficiency. With its commitment to scientific advancement and collaboration with industry partners and experts, ANSTO continues to drive progress towards a cleaner and more sustainable energy future.

Research Priorities

Net zero future

ANSTO Capabilities

- Electron Back-Scatter Diffraction
- Energy Dispersive Spectroscopy
- Scanning Electron Microscopy
- High temperature creep testing rigs
- Molten salt corrosion testing rig

Collaborators/Client

University of New South Wales
Shanghai Institute of Applied Physics
COMTES FHT

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doi.org/10.1016/j.corsci.2020.108915
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Doi.org/10.1016/j.corsci.2019.108306
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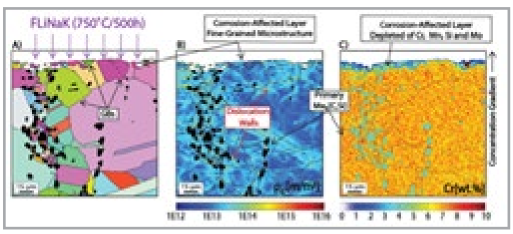

FIGURE 1: Electron Back-Scatter Diffraction and Energy Dispersive Spectroscopy maps of the near-surface corrosion-affected region of a NiMoCr alloy after exposure to FLiNaK molten salt at 750 °C for 500 h.

Nuclear operational life and safety

Understanding and improving radiation damage of structural alloys

The operational life and safety of nuclear reactors can be significantly reduced when structural components experience radiation damage. Effective measures are needed to improve the radiation damage tolerance of structural materials used in advanced nuclear systems.

THE CHALLENGE

Different radiation-induced defects and defect clusters may exhibit similar nanoscale structures, making them challenging to correctly identify. It is crucial to reveal the origins of radiation-induced defects and fully understand defect formation and growth mechanisms. However, neutron irradiation studies of materials for fission and fusion reactors are limited by the lack of test reactors, long irradiation times, and high operating costs.

THE SOLUTION

ANSTO plays a significant part in Australia's ability to both generate and characterise radiation and the irradiation of objects. In addition to neutron irradiation services in the OPAL reactor, ANSTO's Centre for Accelerator Science offers ion beam irradiation as a technique which can emulate standard microstructural changes with higher dose rates and shorter irradiation time than in materials irradiated within nuclear reactors. Irradiated samples of metallic materials for current and advanced nuclear reactors are investigated using advanced analytical transmission electron microscopy (TEM) in combination with TEM image simulations and molecular dynamic (MD) simulations.

THE IMPACT

This study revealed the atomic origins of radiation-induced structural defects and led to a fundamental understanding of the formation and growth mechanisms of these defects, which is essential to safely operating nuclear reactors. ANSTO's ability to characterise radiation impacts is informing the design of future nuclear technologies, positioning Australia at the forefront of materials research for Generation IV reactors. This work greatly increases the academic reputation of ANSTO and Australia in the nuclear industry.

Research Priorities

Environment

ANSTO Capabilities

- Transmission Electron Microscopy
- Ion irradiation
- Neutron irradiation
- Computing Facilities
  High Performance Computing Clusters

ANSTO Instruments

STAR
2MV tandem accelerator
OPAL multipurpose reactor

Collaborators/Client

Argonne National Laboratory

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doi.org/10.1016/j.actamat.2020.06.009
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doi.org/10.1016/j.addma.2019.06.017
doi.org/10.1016/j.nimb.2019.06.026
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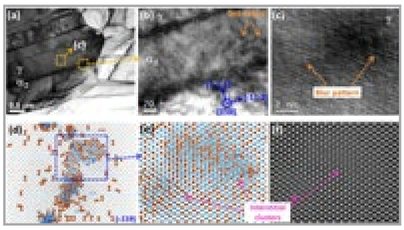

FIGURE 1:
Radiation-induced dot defects by (a)-(c) TEM, (d) and (e) MD simulation, and (f) TEM image simulation.

Self-healing ceramics for safer nuclear fuel cladding

Technology will enhance safety of industry

Most are aware of the disaster that occurred in Fukushima. The explosion that occurred was due to the sudden release of hydrogen from the zircalloy cladding that surrounds nuclear fuel to prevent it from interacting with water.

THE CHALLENGE

Can we coat the cladding too prevent it from taking up hydrogen and releasing it if temperatures get to high and can we design that cladding so that it repairs itself if damaged.

THE SOLUTION

ANSTO has been working with the JAEA and the Nagaoka University of technology for over two decades. ANSTO has now teamed up with a consortium in Japan to develop ceramics that will heal themselves even in the harsh environments of a nuclear reactor which include damage due to radiation and extreme temperatures. ANSTO has an extensive background in radiation damage characterisation of ceramics and metals. This will enable the team to determine if radiation damage enhances the self-healing properties due to migration of the doped elements in the ceramic matrix.

The technology developed will not only be applied to ensure the nuclear industry can operate with a higher degree of safety but can also be applied to current Australian industry and evolving energy storage systems such a stored solar energy via molten salts.

The existing and emerging relationships will ensure Australia's continued collaboration in science and technology with Japan and highlight the role Australia can play in Japan's industry in the future.

This project has and will build upon ANSTO's ability to characterise radiation in materials and materials degradation due to exposure in extreme environments.

THE IMPACT

ANSTO has demonstrated its world leading capability, skills and technology in Asia and will be further strengthening its ties with Japan in nuclear technology and advanced manufacturing.

Most recently we held a special session at the 5th International Symposium on Hybrid Materials and Processing (HyMaP 2021) August 4th~6th with invited talks by consortium team members.

Research Priorities

Environment

ANSTO Capabilities

- Ion beam irradiation
- Post irradiation characterisation EBSD, SEM, TEM, and micromechanical testing
- Synchrotron X-ray scattering
- Neutron diffraction

ANSTO Instruments

Powder Diffraction (PD) beamline
Echidna
High resolution powder diffractometer

Collaborators/Client

University of Wollongong

Nagaoka University of Technology

National Institute of Technology, Fukushima College

National Institute of Technology, Nagaoka College

JAEA, CLADS, Fukushima

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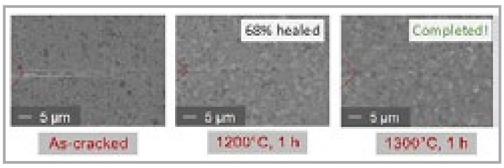

FIGURE 1: Al_2O_3 doped with Ni nano particles before, during and after the self healing process.

Leading nuclear fuel innnovation

Filling the knowledge gap in uranium chemistry using landmark infrastructure at ANSTO

Uranium oxides form the keystone of the current nuclear fuel cycle where knowledge of their performance, particularly under extreme pressure and temperature conditions, is imperative to their safe usage and final disposal. The interaction and subsequent chemical phase formation between uranium oxide fuel matrices and fission daughters during nuclear fission remains one of the most challenging processes for the nuclear industry.

THE CHALLENGE

For an appropriate safety assessment of the disposal of spent nuclear fuels, a systematic approach is required to understand the solid-state chemistry of structural phases that may form. Due to challenges encountered in studying radioactive materials, most studies of uranium-containing compounds have been conducted at room temperature in air. This environment is not ideal as it is not representative of the conditions inside a nuclear reactor or a geological repository.

THE SOLUTION

ANSTO has access to a suite of unique instruments housed at the Australian Centre for Neutron Scattering and the Australian Synchrotron, which not only provide high-resolution and precision measurements but also allow in situ experiments under extreme sample environments, such as high temperature, high pressure and controlled gas atmosphere. The ANSTO team synthesised various mixed metal ternary uranium oxides and systematically examined their structural behaviours in situ using both neutron and synchrotron X-ray diffraction and spectroscopic methods. By combining experimental results with ab initio theoretical calculations, this research explored and elucidated the condensed matter chemistry of uranium in these oxides and unravelled some remarkable properties. For example, the team discovered that only two uranium-containing oxides can undergo a reversible symmetry lowering and disorder-to-order transformation with increasing temperature (α-$SrUO_4$ and isostructural $CaUO_4$). Another fascinating property revealed in a recent high-pressure study of $SrUO_4$ is the vast difference in the apparent bulk modulus, which gives the compound an intrinsic hardness comparable to that of a diamond.

THE IMPACT

This systematic investigation has demonstrated the chemical and structural complexity of the simple mono-uranates and filled the knowledge gap in uranium chemistry. This work has also helped to train the next generation of nuclear scientists. The discovery of the remarkable structural flexibility and associated unique properties reflects the power of contemporary advanced instruments available at ANSTO and will lead the way to further nuclear materials research.

Research Priorities

Environment

ANSTO Capabilities

- Synthesis and characterization of uranium-doped nuclear materials
- Structural and spectroscopic methods
- Neutron scattering
- Synchrotron X-ray scattering

ANSTO Instruments

Echidna
High-Resolution Powder Diffractometer

Wombat
High-Intensity Powder Diffractometer

Powder Diffraction (PD) Beamline
X-ray Absorption Spectroscopy (XAS) Beamline
X-ray Fluorescence Microscopy (XFM) Beamline

Collaborators/Client

University of Sydney
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doi.org/10.1021/acs.inorgchem.0c03077
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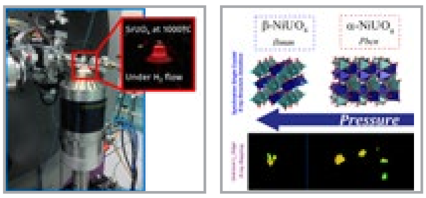

FIGURE 1:
High temperature in situ experiment on PD (left); high pressure synthesis, structural & spectroscopic studies of $NiUO_4$ (right).

Assessing nuclear reactor alloys

Simulating the effect of operating conditions on the performance of materials

During long-term service at elevated temperatures, structural alloys used in high-temperature energy-generation applications undergo microstructural changes. These changes can significantly reduce the lifetime of a component in service conditions, jeopardising the safety as well as the costs of replacement to the system.

THE CHALLENGE

To predict the remaining lifetime of a component in service conditions, it is important to understand the effects of microstructural changes on the mechanical behaviour in structural alloys. Such knowledge is particularly relevant to the assessment of candidate alloys for new energy-generation systems, including Generation IV nuclear reactors.

THE SOLUTION

The team performed a microstructural analysis of materials containing nanoscale precipitation under static-aging and creep-fatigue conditions. To quantify the precipitate size, distribution, and volume fraction, ANSTO scientists used small-angle neutron scattering on the Quokka and Bilby instruments in combination with electron microscopy. This allowed for a quick and robust bulk quantification of the precipitates across the microstructure. By combining experimental results and thermodynamic modelling, the team could observe the evolution of precipitates and develop valid models to predict their effect on yield strength based on precipitation and strengthening theories for solid solutions. This study highlighted the robust capability of advanced neutron scattering techniques to investigate suitable structural alloys for high-temperature applications in nuclear reactors.

THE IMPACT

This work is key in simulating the effect of operating conditions on the performance of materials, allowing the assessment of alloys during the lifetime of a reactor system. The demonstrated methodology could also be applied to other metallic systems.

Research Priorities

Environment

ANSTO Capabilities

- CThermodynamic modelling (Thermo-Calc®)
- Neutron scattering

ANSTO Instruments

Bilby
Small Angle Neutron Scattering

Quokka
Small Angle Neutron Scattering

Collaborators/Client

Idaho National Laboratory

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Small Angle Neutron Scattering (SANS) instruments Quokka (left) and Bilby (right) at ANSTO used to quantify the nanoscale precipitation in structural alloys.

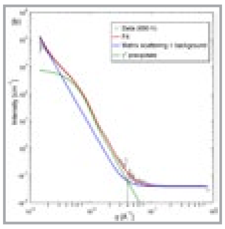

FIGURE 1:
Model fitting of SANS data to extract the precipitate characteristics (size, distribution, and volume fraction).

Fitness-for-service assessment

Remaining life evaluation of in-service components

All engineering components in an operating in-service environment undergo material degradation including fatigue, creep, creep-fatigue, stress-corrosion cracking, etc. This degradation can cause permanent damage, unplanned shutdowns, and accidents by compromising the structural integrity of in-service components.

THE CHALLENGE

To maintain the safe and reliable operation of engineering systems, operators must implement fitness-for-service and remaining life assessments. These can determine the safety and structural integrity of a component or a whole system, helping to prevent catastrophic failures. Fitness-for-service and remaining life assessment capabilities are required to determine the structural integrity of an in-service component based on the current state of damage and its projected remaining life.

THE SOLUTION

Projected remaining life and in-service margins support the continued operation of equipment under operating conditions and environmental compatibility. An example of remaining life assessments of engineering components assumes idealised defects or flaws using straightforward and conservative calculations. However, a more sophisticated assessment of metallurgical conditions and analyses of stresses was completed to indicate more precisely whether the engineering components are fit for their intended service life or whether defects or in-service degradation compromise their integrity. Advanced modelling techniques that allow flaws to grow “naturally” in complex stress fields was also undertaken to provide more accurate approximations of flaw shape and predictions of remaining life.

THE IMPACT

Fitness-for-service provides a rational basis for defining flaw acceptance limits and allows engineers to distinguish between acceptable and unacceptable flaws and damage based on industry-recognised and engineering best-practice. Remaining life assessment, using state-of-the-art modelling techniques, provides more precise evaluations for stakeholders to make critical decisions regarding the life extension of structural components or to determine if an asset can continue operating safely in current service conditions.

Research Priorities

Secure nation

ANSTO Capabilities

- Fitness-for-Service Assessment
- Remaining Life Evaluation

Collaborators/Client

Idaho National Laboratory
Argonne National Laboratory

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Publications

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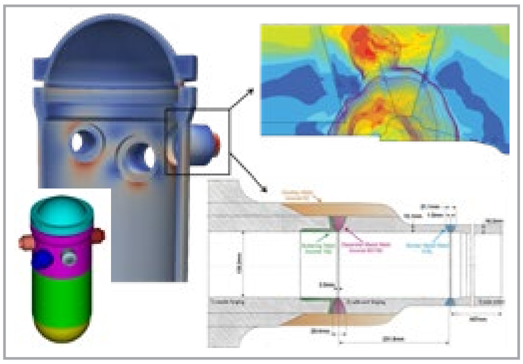

FIGURE 1:
Example of fitness-for-service evaluation for reactor pressure vessel.

Advancing materials modelling

Modelling of behaviour and degradation of nuclear materials in operating conditions

Engineering components operating in high-temperature systems undergo significant fatigue, creep, and creep-fatigue damage during their lifetime. If left unchecked, the accumulated material damage can lead to catastrophic failures causing decreased life of the system and compromised safety as well as economic viability.

THE CHALLENGE

The ability to predict the behaviour and degradation of materials operating at high temperatures is important for engineers who design and maintain high-temperature systems. This has led to the development of various empirical material models derived from the available experimental datasets. However, these material models do not necessarily account for the underlying high-temperature deformation and damage mechanisms. As a result, the current empirical material models are not that accurate and usually lead to overly conservative predictions, thus limiting the economic viability of the overall engineering system.

THE SOLUTION

ANSTO, with its international partners, is working on the development of advanced semi-empirical and multi-scale microstructure-informed material models that can predict high-temperature mechanical behaviour and degradation of structural materials with increased accuracy. The physics-based nature of these advanced models can also shed light on the underlying deformation and degradation mechanisms that may lead to material failure in service conditions. Due to the increased complexity of physics-based models, ANSTO is establishing its high-end computational capabilities while developing more efficient data-driven models based on an artificial intelligence framework.

THE IMPACT

The advanced semi-empirical and microstructure-informed material models can accurately capture the behaviour of materials operating in high-temperature conditions to ensure the safe and reliable operation of relevant engineering systems. These advanced material models may replace some expensive and time-consuming testing, thus accelerating the development and deployment of novel low-emission energy-generation systems which require reliable performance of materials at high temperatures.

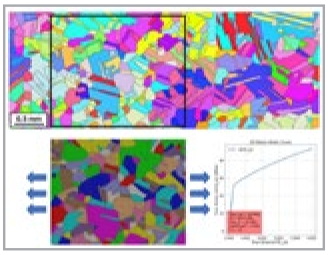

FIGURE 1:
Multiscale microstructure-informed model of nickel-based alloy.

Research Priorities

Secure nation

ANSTO Capabilities

- High-Performance Computing Clusters
- Engineering high-temperature material testing
- Microscopy
- Neutron scattering
- Synchrotron X-ray diffraction

ANSTO Instruments

SEM/EBSD Microscopy
Echidna
High resolution powder diffractometer

Bilby
Small angle neutron scattering

Kowari
strain scanner,
Powder Diffraction(PD) Beamline

Collaborators/Client

Idaho National Laboratory, USA
Argonne National Laboratory, USA
University of New South Wales
Électricité de France, UK
Defence Science and Technology Group

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Publications

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doi.org/10.1016/j.ijpvp.2020.104150
doi.org/10.1016/j.ijpvp.2019.103974
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Characterising radiation as part of decommissioning of HIFAR nuclear reactor

ANSTO designed and developed radiation imaging technology

THE CHALLENGE

The High Flux Australian Reactor (HIFAR) was a 10 MW DIDO class reactor used primarily for neutron scattering experiments and radioisotope production. HIFAR commenced operations in 1958 and after almost 50 years of safe and productive service, ceased operations in 2007 and is now being decommissioned by ANSTO.

The safe, efficient and cost-effective dismantling of the HIFAR reactor requires an accurate characterisation of radionuclide activity, including the mapping of any radiation and its dose rate.

The ability to quickly and cost effectively locate, identify, and quantify gamma emitting radionuclides using gamma imaging in very high dose environments was a superior way to reduce uncertainty that is associated with the established sampling methods and dose modelling.

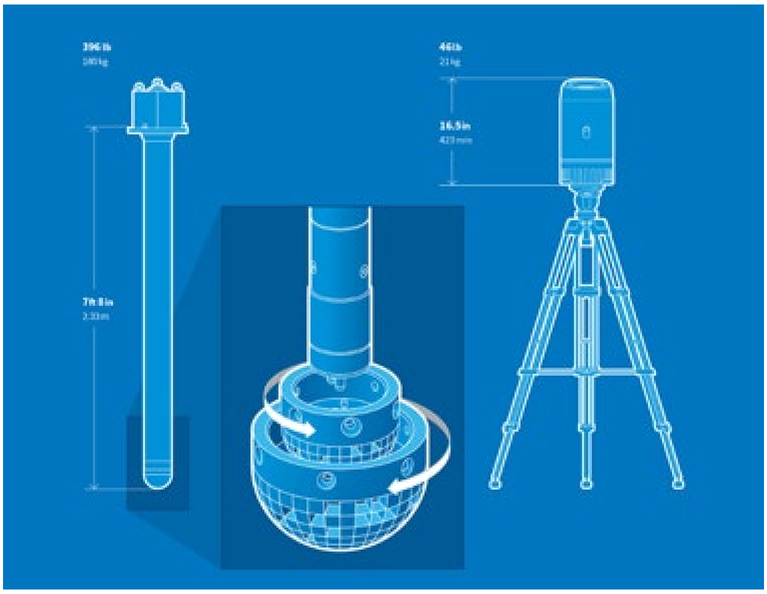
THE SOLUTION

CORIS360® enables people working radioactive environments to make better operational decisions by providing radiation identification and imaging quickly and accurately.

Because it can be deployed remotely, workers are kept safe from exposure to potentially harmful radiation in high dose environments. CORIS360® uses compressed sensing technology to accurately localise sources of radiation. This advanced technology allows spectroscopic images to be taken with far fewer samples than conventional imaging techniques.

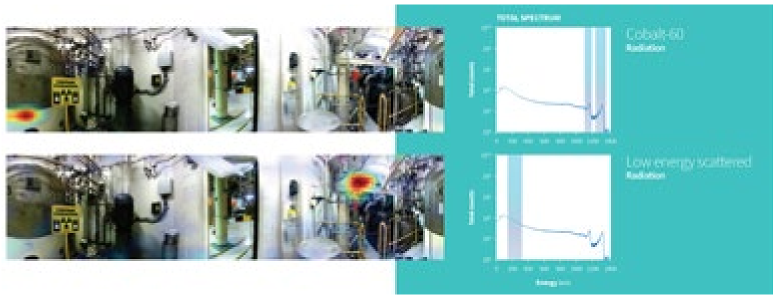
There is a significant reduction in the time to acquire images, while maintaining high image quality. The technology can be flexibly deployed in a range of dose rate environments. Compressed sensing achieves this by exploiting sparsity within an image. When an image contains less information, relatively few samples are needed to reconstruct the image.

The compressed sensing technology used in CORIS360® imaging systems, uses only a single, non-position sensitive detector and enables images to be acquired in far fewer samples compared to conventional imaging techniques. Two products were developed and deployed; one was designed for imaging inside the HIFAR reactor vessel and the other to image environments with low to medium dose rates in the facility.



CORIS360® IMAGING SYSTEM

This portable system was deployed in various locations around the HIFAR facility, including the D_2O plant room where the dose rate at the detector was measured to be 7.5 µSv/h.



Overlaying a 360° × 90° radiation image onto a panoramic optical image of the scene, makes interpretation much easier. The spectroscopic detector at the heart of the imager enables the accurate visualisation and identification of sources across a broad energy range.

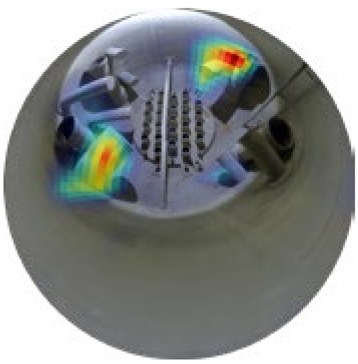
CORIS360® enables the accurate visualisation and identification of isotope specific, and scattered, sources of radiation across a broad energy range to gain a greater understanding of work environments to keep workers safe. The technology provides better data for improved operational decision making in radioactive environments

Gamma images from different energy regions of the gamma spectrum were generated from a single acquisition. This allowed both ^{60}Co and low energy scatter hot spots to be localised. Whilst the location of the ^{60}Co was known the presence and dose contribution from the scattered radiation in an overhead pipe provided new and valuable information which increased the operational understanding of the radiation environment.

REACTOR IMAGING SYSTEM

This customised device successfully identified and located ^{60}Co as the dominant radionuclide present inside the HIFAR reactor vessel. A series of quantitative images, capturing the dose rates, were collected from four different locations where the technology was deployed.

At the first location, the technology determined that two primary hot spots had dose levels of 1.8 Sv/h and 2.5 Sv/h. Three additional hot spots with lower dose rates were found, giving a total ^{60}Co dose rate of 6 Sv/h. The source of the hot spots matched stainless steel components that were identified in the HIFAR historical records.



The imaging results were able to quantitatively determine the level of radioactivity of the identified components, with measured ^{60}Co activities ranging between 2.0 TBq and 17.2 TBq. The new characterisation data provided invaluable insights to construct a broader reactor dose model. It will be used to inform decommissioning planning and be integral to the future safe and cost effective decommissioning of the HIFAR reactor.

Research Priorities

Secure nation

ANSTO Capabilities

- Detection and imaging
- Secondary Standards Dosimetry Laboratory (SSDL)
- Gamma Irradiation Suite (GIS)

Collaborators/Client

ANSTO

ANSTO Contributors

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Publications

doi.org/10.1088/1748-0221/15/04/P04014

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Establishing reactor structural integrity

The prediction of safety and remaining life on OPAL reactor structures

The OPAL multi-purpose research reactor produces high-intensity neutrons for scientific research, silicon irradiation, and to produce high-quality nuclear medicines. However, the reactor structure itself is also subject to constant bombardment by these neutrons over its lifetime, affecting the structural integrity within predicted design parameters.

THE CHALLENGE

Although the structural properties of the OPAL reactor change within known design parameters, structural assurance and expert monitoring require continued inspection and assessment to ensure the safe long-term operation of OPAL. In particular, when in-service inspections carried out remotely reveal discontinuities that require further assessment, specialist metallurgical, radiation damage, and fracture mechanics analysis must be implemented.

THE SOLUTION

With over 60 years of industry experience, ANSTO staff provide subject matter expertise in metallurgy, reactor in-service inspection, weld, and corrosion inspection, as well as fatigue and fracture mechanics analysis and testing. At ANSTO, fatigue analysis is performed through the extended finite element method (XFEM). Structural integrity assessment can be provided even for the most complex cases, such as the OPAL reactor riser component. This structure can be assessed for a hypothetical weld root crack under dynamic loading. Fatigue and fracture mechanics analysis is performed to the leading Structural Codes, which includes finite element modelling for complex crack geometries and applied stresses.

THE IMPACT

In the carefully regulated nuclear environment, we meet and exceed the expectations of the nuclear regulator. The impact of structural integrity assessment is much broader than often perceived in terms of failure mitigation, cost savings in lost revenue and loss of plant utility and reputation. This work enables the prediction of remaining life on OPAL structures and demonstration that OPAL continues to operate within safe operating margins, critically important for both human and environmental safety.

Research Priorities

Environment

ANSTO Capabilities

- Structural Integrity Assurance
- Metallurgical/Weld Inspection
- Finite element modelling
- Fracture mechanics
- Fitness-for-Service Code compliance

Collaborators/Client

Coclear
Onesteel

ANSTO Contributors

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Publications

doi.org/10.1071/AJ20024
doi.org/10.1071/EN22048
doi.org/10.1016/j.jhazmat.2022.129348
doi.org/10.1016/j.jenvrad.2022.107093
doi.org/10.1016/j.jenvrad.2021.106774
doi.org/10.1080/10643389.2021.1917949
doi.org/10.1016/j.jenvrad.2022.106979

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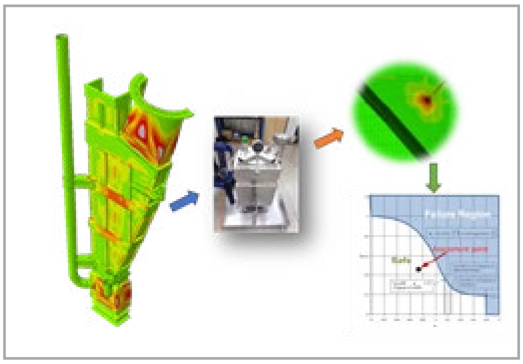

FIGURE 1:
OPAL Riser elastic-plastic finite element stress modelling, fatigue mock-up testing, fracture mechanics modeling and failure assessment to the R6 Fracture Mechanics Code.

OPAL materials surveillance program

Ongoing safety and integrity assurance for OPAL reactor

The OPAL multi-purpose reactor is the most important national nuclear facility operated by ANSTO. OPAL's structure is subject to neutron irradiation and its material properties change over time.

THE CHALLENGE

Along with routine maintenance, there is a specific requirement to assess the effect of neutron irradiation on the materials that make up the core components of the reactor.

THE SOLUTION

The OPAL Materials Surveillance Program, conducted within the Nuclear Materials Development and Characterisation group, has the important goal of providing support-based research, root cause, and structural integrity analysis for stewardship of the OPAL reactor. To achieve this objective, the group provides and maintains the hot cell facility and skills for Post Irradiation Examination (PIE) in special radioactively shielded hot cells. The group periodically removes samples from the reactor and tests them to assure structural integrity and uses international best practice methods for the analysis modelling and fracture mechanics of nuclear components to predict the remaining life of reactor components.

THE IMPACT

The OPAL Materials Surveillance Program provides ongoing safety and integrity assurance for OPAL, to forecast, maintain, and assure the safe operation of the OPAL reactor core components for its 40-year design life and potentially beyond. The program has enabled the life extension of the cold neutron source moderator and performed fatigue analysis and damage estimation of the Control Rod Guide Box pins. This work has also led to the development of irradiation damage acceptance criteria for cold neutron source vacuum containment.

Research Priorities

Environment

ANSTO Capabilities

- Post Irradiation Examination (PIE)
- Active Mechanical Testing
- Structural Integrity Assessment
- Fracture Mechanics (Radiation Damage)

Collaborators/Client

ARPANSA

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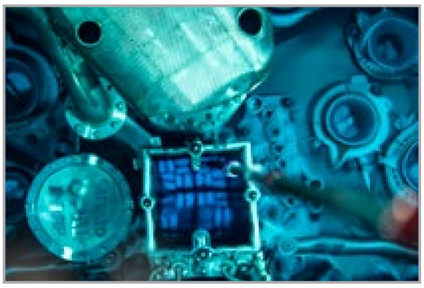

OPAL reactor.

Using nuclear techniques to support Aboriginal cultural heritage

Australia is a land that is home to the oldest continuous culture on the planet and First Nations peoples were the first scientists, engineers and traders. Recognising, valuing, protecting and managing our diverse and rich heritage is a national priority.

ANSTO's unique and complementary capabilities and expertise are playing a central role in supporting cultural heritage research in Australia.

Nuclear techniques, through their non-invasive character, coupled with their wide applicability, have become indispensable tools for planning, conservation, intervention, and for unravelling the untold story of ancient civilisations.

Internationally, ANSTO collaborates with some of the world's leading research institutes and universities on cultural heritage.

Exploring the past

Ultra-sensitive radiocarbon dating analysis

Radiocarbon dating is a powerful tool for researchers exploring the past. Useful across a wide variety of scientific fields, radiocarbon dating can help to determine the age of organic matter in the order of tens of thousands of years. Radiocarbon also permits tracing the movement of carbon within the carbon cycle and how this is affected by climate change.

THE CHALLENGE

In some cases, only minute amounts of carbon can be extracted from bulk samples. To analyse very small amounts of carbon, ultra-sensitive instruments and techniques are required.

THE SOLUTION

ANSTO's Centre for Accelerator Science (CAS) provides accelerator mass spectrometry to support ultra-sensitive analyses that enables reliable measurement of radiocarbon in just a few micrograms of carbon. CAS is the only facility in Australia able to deliver this level of sensitivity and one of only a few globally.

THE IMPACT

Dating the oldest known aboriginal rock art
A collaboration led by the University of Melbourne in cooperation with Traditional Owners in the Kimberley used microscopic amounts of charcoal in fossilised mud wasp nests to determine dates for the oldest Aboriginal rock art in this region. Radiocarbon dating demonstrated that one painting was between 17,500 and 17,100 years old and that the style had continued to ~13,000 years ago.

World Heritage Listing for Budj Bim Cultural Landscape
Radiocarbon dating, in collaboration with Monash University and the Gunditj Mirring Traditional Owners Aboriginal Corporation placed the age of the aquaculture system in the Budj Bim Cultural Landscape at 6,600 years old, amongst the oldest known fish trap systems in the world. This data helped secure its place on UNESCO World Heritage Listing in 2019.

Revealing the significance of human fossil methane contribution
A team from the University of Rochester, CSIRO, and ANSTO funded by the US National Science Foundation found that methane emissions from human fossil sources have been underestimated by 25-40%. A history of the amount of methane in the atmosphere was reconstructed from 1750 to 2013 using air and ice cores from Antarctica and Greenland with radiocarbon measurements used to determine the origin of the methane.

Budj Bim Cultural landscape.

Research Priorities

- Environment
- Indigenous knowledge

ANSTO Capabilities

- Radiocarbon dating via Accelerator Mass Spectrometry, including custom sample preparation laboratories
- Centre for Accelerator Science

ANSTO Instruments

ANTARES
10 MV Tandem Particle Accelerator

VEGA
1 MV Particle Accelerator

Collaborators/Client

The University of Melbourne
Rock Art Australia
University of Rochester
CSIRO

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Publications

doi.org/10.1126/sciadv.aay3922
doi.org/10.1038/s41562-020-01041-0
doi.org/10.1016/j.jas.2011.09.007
doi.org/10.1038/s41586-020-1991-8
doi.org/10.1126/science.aax0504
doi.org/10.1038/nature23316

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Bushfire management

Valuable knowledge from Indigenous land and fire management practices

Climate change is exacerbating bushfire risk in Australia. The landscape is becoming hotter, drier, and more prone to high wind on extremely hot and dry summer days. The increased frequency of bushfires results in less recovery time for the bush, impacting ecosystems and threatening the survival of many plants and animals struggling to adapt to habitat loss.

THE CHALLENGE

There is growing recognition of the value of Indigenous land and fire management practices to mitigate the effects of bushfires. It has been argued that by returning to an Indigenous-style fire regime, landscape fuel loads will be kept low and will ultimately reduce the frequency and intensity of bushfires. It is important to investigate whether Indigenous cultural burning can be used as an effective way of mitigating catastrophic, climate-driven bushfires in southeast Australian forests.

THE SOLUTION

The team studied how fuel loads, fuel type, fire frequency, and fire intensity have changed over the past 500 years, spanning the period of Indigenous land management to British occupation. By analysing sediment cores collected from the study sites, the team reconstructed the bushfire history in southeast Australian forests using ANSTO's radiocarbon and lead-210 dating facilities.

The study of pollens and other organic matter from sediment samples showed a loss of plant biodiversity had occurred since European settlement and the disappearance of Indigenous fire management practices. Many of the less flammable plant species have disappeared and have been replaced by highly combustible eucalypts.

THE IMPACT

The study of Australia's bushfire history provides authorities with valuable information on how to manage the Australian landscape to reduce the likelihood of future catastrophic bushfires. Southeast Australian forests are now much denser and more flammable. Coupled with climate change, this shift in biodiversity creates conditions that will result in larger and more catastrophic bushfires. Understanding cultural burning practices undertaken by Indigenous peoples of Australia over tens of thousands of years could be the key to mitigating future bushfire risks.

Research Priorities

Indigenous knowledge

ANSTO Capabilities

- Radiocarbon dating with Accelerator Mass Spectrometry
- Lead-210 dating with Alpha spectrometry &
- Gamma spectrometry
- Micro-X-ray Fluorescence

ANSTO Instruments

ITRAX X-Ray Fluorescence (XRF) Core Scanner

Collaborators/Client

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Prof Guo Jun Liu
Prof Richard Banati

Publications

doi.org/10.1016/j.quascirev.2021.106824
doi.org/10.1111/gcb.14609
doi.org/10.1130/G39661.1
doi.org/10.1111/jbi.13040

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Traditional Indigenous burning.

Protecting the world's oldest rock art

Understanding and minimising the impacts of climate change on early rock art

Australasia is home to some of the oldest rock art in the world with one painting on the Indonesian island of Sulawesi dating to at least 45,500 years old. The effects of climate change in tropical latitudes have resulted in the blistering and deterioration of rock art.

THE CHALLENGE

This research explored the mechanisms of decay affecting ancient rock art panels at 11 sites in Sulawesi's Maros-Pangkep region. These prehistoric artworks have been scientifically dated to between 20,000 and 40,000 years. The team found that deterioration had become worse in recent decades, a trend likely to continue with accelerating climate change. Given these artworks have survived such a vast period of time, it is evident that more recent environmental factors are causing rapid erosion of the painted limestone cave surfaces. Attempts at preserving rock art must be led by an understanding of what factors are causing the damage.

THE SOLUTION

This work used a combination of scientific techniques, including high-powered microscopes, chemical analyses, and mineral identification methods. These techniques revealed that salts growing both on top of, and behind ancient rock art, can cause it to flake away. Salts are deposited when moisture that has built up on rock surfaces begins to evaporate, leaving behind salt crystals. The salt crystals swell and shrink as the environment heats and cools, generating stress in the rock. In some cases, the stone surface can crumble into powder. Using the powder diffraction beamline at the Australian Synchrotron, researchers characterised paint pigments and the salts that were destroying the art allowing them to determine how and why the rock art was deteriorating so quickly.

THE IMPACT

This research improved our knowledge of how early rock art developed and spread in South-East Asia and provided strategies on how to best preserve the up to 45,500-year-old rock art. It was found that minimising the impacts of climate change is a major factor in preserving the incredible artworks left by Australasia's earliest people.

Research Priorities

Indigenous knowledge

ANSTO Capabilities

- Synchrotron X-ray diffraction

ANSTO Instruments

Powder Diffraction (PD) Beamline

Collaborators/Client

Griffiths University

ANSTO Contributors

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Publications

doi.org/10.1038/s41598-021-87923-3

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Rock art panels (between 20,000 and 45,500 years old) from Sulawesi, Indonesia.

Preserving connection to country

Digital preservation of Indigenous hand stencils

Hand stencils are a common motif in Australian Indigenous art. A hand is placed against the rock surface, left for women (ngai) and right for men (guri), and a mouthful of coloured clay is spluttered to make the stencil. These hand stencils were previously reproduced at regular intervals, but this is no longer the case. The remaining hand stencils provide continuing connection to Country and so require conservation.

THE CHALLENGE

Over time, Australian Indigenous hand stencils are degrading due to environmental exposure. There is a need to preserve this important connection to Country with a non-destructive approach.

THE SOLUTION

This work was made possible through a collaboration between Indigenous and Western science techniques. The Kimberly Foundation, ANSTO, and the University of Wollongong teamed up to capture images of Kimberly Rock art non-destructively using drone technology. The captured data was converted into 3D blocks, which allowed further investigation of the site and the potential identification of features difficult to discern with the naked eye.

This same technique was applied outside the Kimberly region on hand stencils at Manly Vale. Drone image data identified at least five hand stencils, some of which may be from children. Digital enhancement of the images indicates there are more stencils which have been eroded over time.

THE IMPACT

This work allows a continuing connection to Country, particularly for those unable to travel to the site. It enhances the public understanding of culture without risking damage to the site through overuse or vandalism. Importantly, these cutting-edge scientific techniques digitally preserve significant cultural sites for future generations and research.

Research Priorities

Indigenous knowledge

ANSTO Capabilities

- Centre for Accelerator Science

ANSTO Instruments

3D Drone Photogrammetry

Collaborators/Client

Guringai Tribal Link Aboriginal Corporation
Uncle Neil Evers (Bungoree and Cora)
NSW Manly Hydraulics Laboratory

ANSTO Contributors

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Publications

Originally published in Elimatta – ASGMWP https://asgmwp.net/elimatta/

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(Top) 3D rock wall block; (Bottom) Neil Evers and Brett Rowling with drone.

Enhancing food production and agriculture

With the overwhelming majority of food sold in Australia grown and supplied by Australian farmers, maintaining and sustaining a successful agricultural system is essential to Australia's prosperity.

Nuclear and isotopic techniques are particularly useful in studies of agricultural and aquaculture products, as well as the production and analysis of food.

Studies address challenges linked to soil quality, limited rainfall and other environmental factors.

Food security and sustainability concerns are also a focus.

Improving food quality

Developing stabilised emulsions for functional food

Emulsions are combinations of substances that do not mix and are inherently unstable, for example, a mixture of oil and water. Emulsifiers are used to prevent the components of emulsions from separating. There are several ways to stabilise emulsions. In food systems, the use of molecules such as proteins or food-grade surfactants is the most common way to stabilise emulsions. Emulsifiers are commonly used in foods such as milk, cream, salad dressings, and sauces.

THE CHALLENGE

Solid particles can be used to form so-called Pickering emulsions. In this method, solid particles stabilise emulsions by attaching themselves to the interface between various droplets, such as oil and water. These particles have been produced from milk whey proteins to form 'primary' emulsion droplets. The primary emulsion droplets can effectively behave as solid particles to stabilise even larger micron-sized droplets. However, the particle arrangement and stabilisation mechanism of this emulsification method were unknown.

THE SOLUTION

The team used neutron scattering instruments Bilby and Kookaburra at ANSTO to determine the packing arrangement of whey protein particles, the primary emulsion droplets, that coat the surface of, and stabilise, larger micron-sized oil in water droplets. By gaining knowledge of the whey protein structure, scientists developed a better understanding of the emulsion stabilisation mechanism.

THE IMPACT

Featured on the cover of the journal Langmuir, this work has enormous potential for the development of functional foods. Stabilised emulsions could aid in increased delivery and enhanced uptake of dietary nutrients to help fight malnutrition and extend shelf-life. Food emulsions such as these deliver greater product stability, thereby reducing food waste and enhancing sustainability.

Research Priorities

Health

ANSTO Capabilities

- Neutron Scattering

ANSTO Instruments

Bilby
Small Angle Neutron Scattering

Kookaburra
Ultra Small Angle Neutron Scattering

Collaborators/Client

Riddet Institute
Qilu University of Technology (China)

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Publications

doi.org/10.1021/acs.langmuir.9b01966

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Oil in water emulsions employing whey protein nanoparticles as stabilisers to enhance shelf-life.

Improving human and animal nutrition

Understanding the distribution of nutrients in soils and plants to improve cereals

For billions of people worldwide, cereal-based foods such as bread, rice, and noodles, provide a significant proportion of daily calories and energy. Approximately two billion people worldwide suffer from iron and zinc deficiency due to the lack of these micronutrients in cereal-based foods.

THE CHALLENGE

Around a decade ago, researchers identified a subset of genes in rice that 'switch on' when the plant is low in iron. The team developed a way to keep this gene 'switched on' to create iron and zinc biofortified rice. This same approach using the rice gene also worked exceedingly well in wheat. Researchers have recently sought to better understand micronutrient distribution in soil and plants and improve cereal plant health and yield. The development of biofortified wheat and rice is vital to improving public health worldwide.

THE SOLUTION

The team used the Australian Synchrotron's X-ray fluorescence microscopy (XFM) beamline to directly image the quantity and location of micronutrients, such as iron, zinc, and phosphorus, within biofortified wheat, rice, and barley cereal grains. To investigate cereal plant health and micronutrient uptake, the team used X-ray fluorescence microscopy (XFM), infrared microspectroscopy (IRM), and soft X-ray spectroscopy (SXR). With these techniques, the team measured the distribution of nutrients in soils and plants to understand chemical changes in the nutrients, which is critical in determining nutrient bioavailability.

THE IMPACT

This research has helped to combat human iron and zinc deficiency due to nutrient-poor cereal-based foods. Outcomes from this work include approaches to examine the spatial variability of nutrients available in soils, the uptake and movement of fertilizers in living plants, heavy metal and other contaminant behaviour in soils, and nutrient distribution in cereal grains. This research will ultimately lead to improvement in the size, growth, and health of seed crops for improved human and animal nutrition, particularly in developing countries. Field trials have been successful for newly developed biofortified rice in the Philippines and Colombia, and biofortified wheat trials across Australia.

Research Priorities

Health

ANSTO Capabilities

- Synchrotron X-ray Spectroscopy
- Synchrotron X-Ray Fluorescence

ANSTO Instruments

X-ray Fluorescence Microscopy (XFM) Beamline
Infrared Microspectroscopy (IRM) Beamline
Soft X-ray Spectroscopy (SXR) Beamline
X-ray Absorption Spectroscopy (XAS) Beamline

Collaborators/Client

University of Melbourne
University of South Australia
University of Queensland
Grains Research and Development Corporation (GRDC)
HarvestPlus

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doi.org/10.1111/pbi.13074

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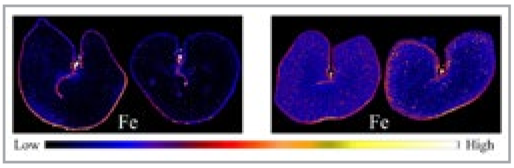

FIGURE 1:
Synchrotron X-ray fluorescence microscopy images of conventional (left) and biofortified (right) wheat grain cross-sections. Biofortified grain has more iron in the inner endosperm tissue.

Protecting Indigenous enterprises

Establishing Kakadu Plum provenance and market chain traceability

The Kakadu plum is an iconic native bushfood of Australia, which First Nations people have been harvesting for nearly 60,000 years. Worldwide demand for the Kakadu plum is soaring through increasing global recognition of its unique benefits as a potent source of Vitamin C and antioxidants. In 2019, the Kakadu plum sector was estimated to be valued at $1.6 million (farmgate) and is expected to increase to $3.5 million by 2025.

THE CHALLENGE

As the Kakadu plum demand and popularity grow, particularly in international markets, fraudulent products are beginning to appear overseas as Kakadu plum extracts. There is a need for provenance studies to assure that Indigenous enterprises also benefit from the sale of this traditional food.

THE SOLUTION

ANSTO is collaborating with the Northern Australia Aboriginal Kakadu Plum Alliance Ltd (NAAKPA) and Mamabulanjin Aboriginal Corporation for the Indigenous Bushfoods Certification Project funded through the Department of Agriculture, Fisheries, and Forestry (DAFF). The project aims to develop an isotopic and elemental fingerprint database of the Kakadu plum, its composition, and its provenance to protect and underwrite Australia's growing Kakadu plum industry.

The Kakadu plum contains unique naturally occurring isotopic and chemical fingerprints that reflect the region where it was grown. The team used mass spectrometry (EA-IRMS) and micro-X-ray fluorescence (µ-XRF) at ANSTO to acquire high-precision isotopic and elemental fingerprints. Using the Kakadu plum fingerprint data and machine learning, ANSTO's provenance technology can accurately identify the geographical source of origin and provide assurances in the supply chain.

THE IMPACT

This project provides a vital reference database that Aboriginal Kakadu plum producers can use to trace provenance and verify claims of Aboriginal sources. As an emerging industry, the Kakadu plum is in a good position to expand its fingerprint database as the industry grows. The threat of Kakadu plum plant tissue being exported overseas is a very real prospect given its international demand. This technology is helping to position the Australian Kakadu plum as the preferred and dominant source in the global marketplace.

Research Priorities

Indigenous knowledge

ANSTO Capabilities

- Elemental Analyser Isotope Ratio Mass Spectrometry (EA-IRMS)

ANSTO Instruments

ITRAX X-ray Fluorescence (XRF) Core Scanner

Collaborators/Client

Northern Australia Aboriginal Kakadu Plum Alliance Ltd (NAAKPA)

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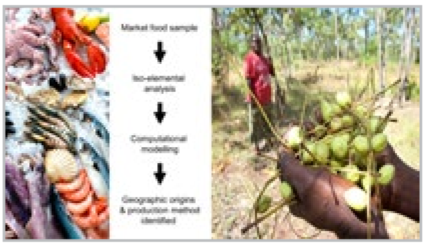

FIGURE 1:
The Kakadu plum, an Australian native bushfood farmed for nearly 60,000 years by Australia's First Nations people.

Discovery science at ANSTO

There are some areas of investigation that don't fall easily into the categories of research that we have grouped in this report.

Nonetheless, they are important to illustrate the great breadth of work undertaken at ANSTO.

Origin of life

Characterising and detecting pre-biotic molecules in Titan's atmosphere

Titan, the largest moon of Saturn, is a rarity in our solar system, having a thick atmosphere dominated by the gases nitrogen and methane; a composition thought similar to Earth's early atmosphere. Exposed to radiation, these chemicals have the potential to form amino acids and DNA nucleobases on Titan, which are the building blocks of life on Earth.

THE CHALLENGE

To understand how life evolved on Earth, studies must investigate if pre-biotic molecules are located elsewhere in our solar system, such as on Titan, and how radiation-driven chemistry can convert these species to biological molecules at low temperature.

THE SOLUTION

To create an experiment that simulates the harshness of Titan's environment, the team subjected a mixture Titan's known atmosphere gases to extreme low temperatures and pressures. Researchers then identified new chemical bonds that formed during their experiment, as well as new crystal structures, using synchrotron techniques. The team compared their results to Cassini-Huygens mission data and theoretical models to show how particles of cyanide-type (acetonitrile and propionitrile) ice form and grow in size in Titan's atmosphere.

THE IMPACT

This work provided independently generated laboratory data to confirm space-exploration data, setting a benchmark for the detection and identification of chemicals in future space missions. Significantly, these techniques can also be applied to the study of other extreme environments found in space and Earth's atmosphere.

Supports

National Science Statement

ANSTO Capabilities

- Synchrotron far infrared spectroscopy
- Synchrotron X-ray diffraction

ANSTO Instruments

Terahertz/Far Infrared (THz – Far IR) Beamline
Powder Diffraction (PD) Beamline

Collaborators/Client

University of Otago

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Publications

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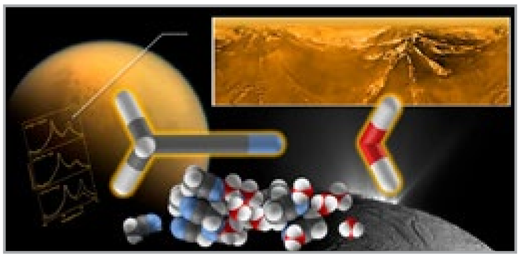

FIGURE 1:
Acetonitrile and water were found to co-crystallise into spherical aerosols in an experiment at the Terahertz/Far IR beamline replicating the extreme conditions found in the atmosphere of Titan.

Computational analysis

Refnx: A new computational tool to analyse neutron scattering data

Extremely small-scale structures, including cell membranes, polymer coatings, and organic films, can only be visualised with extremely powerful instruments such as those which utilise neutron scattering. Scientists acquiring neutron scattering data need efficient and effective computational tools to both analyse and test the validity of their data.

THE CHALLENGE

The reproducibility of complex scientific data, such as neutron scattering, is a well-known issue called the replication crisis. Investigators are often unable to repeat the work of the original scientist as reported in a journal because the necessary data is not always readily available.

THE SOLUTION

To efficiently analyse neutron scattering data, instrument scientists at ANSTO designed ***refnx***. The open source Python package, ***refnx***, runs in an environment, Jupyter, that encourages reproducible analyses. Jupyter contains code, writing, and figures. Scientists use ***refnx*** to construct a model and to create new components if their system has unique requirements.

Once a reasonable model is established, scientists can understand the model's uncertainties. ***refnx*** uses Bayesian statistics, as implemented by the ***emcee*** and ***pymc*** Python packages to quantify results and allow a comparison of two models. ***refnx*** can then help researchers decide which model is better.

Since ***refnx*** is Python-based, it can leverage the wide range of tools available in its data science ecosystem, allowing scientists to conduct their analyses in an electronic notebook. These electronic notebooks substantially aid scientific reproducibility by allowing others to readily repeat the original research.

THE IMPACT

refnx enables an efficient computational analysis and reproducibility of complex neutron scattering data. There is high global demand for these powerful computational tools. ***refnx*** gives free access to these tools. A large proportion of scientific studies that contain neutron reflectometry data will use ***refnx***. The extendable nature of ***refnx*** allows scientists to create their own code and analyse much more complex datasets. The open-source nature of ***refnx*** means that those changes can be fed back into the project for others to use and test. The movement towards more reproducible research is made possible by ***refnx***.

Supports

National Science Statement

ANSTO Capabilities

- Australian Centre for Neutron Scattering

Collaborators/Client

University of New South Wales

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Publications

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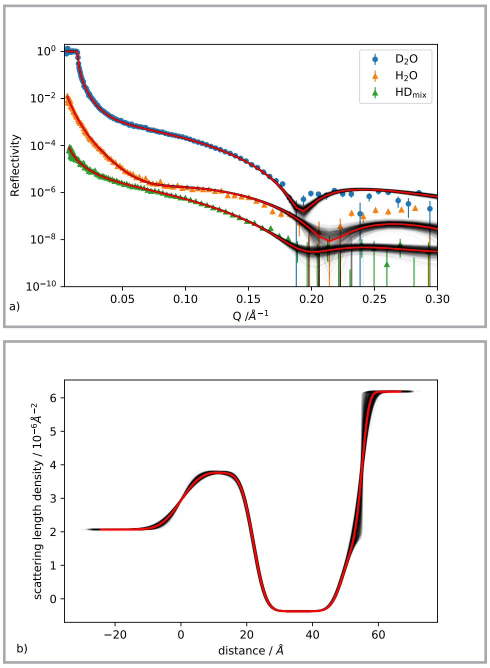

FIGURE 1:
refnx allows the simultaneous analysis of several ("multi-contrast") datasets. In this case, a lipid membrane at a surface. Co-refinement decreases ambiguity in the derived interfacial structures. In nanoscience, it's important to understand the uncertainty in model structure, so *refnx* uses Bayesian statistics to estimate uncertainties. The grey lines show the range of models (top) consistent with the data (bottom).

Enhancing Australia's strategic response to nuclear threats

Nuclear forensics training for Australia's emergency personnel

Australia's current terrorism threat level is listed as POSSIBLE. Australian state and federal police force and response agencies recognise the importance of maintaining speciality skills such as chemical, biological, radiological, and nuclear (CBRN) interagency response. Given that most hazardous material crimes are chemical/explosive in nature, emergency personnel may have limited operational experience with radiological threats and benefit from receiving relevant training. ANSTO is regarded as a leader in the provision of practical training on nuclear forensics and radiological crime scene management in the region.

THE CHALLENGE

It is important to design realistic radiation scenarios so that emergency personnel become familiar with hazardous radiological environments. ANSTO's experience in this area is key to providing this specific, high-stake training.

THE SOLUTION

ANSTO has decades of experience in safely transporting and handling radioactive sources. ANSTO's access to radioactive material ensures that trainees get real-time, hands-on experience. By providing expert guidance and supervision, the ANSTO team can create a safe and secure environment for trainees to detect and respond to a real radioactive contamination threat using their agency-issued specialised detectors in a simulated crime scene 'hot zone'. These workshops are unique compared to chemical, biological, and explosives training scenarios, where threats are generally notional only. Training courses are facilitated by ANSTO radiation experts, who can provide emergency personnel support with safety assessments, essential equipment, and provision of radiological sources to include in the scenarios.

THE IMPACT

This work prepares frontline emergency responders to operate in hazardous radiological environments strategically, confidently, and competently. Demystifying radiation strengthens the responder's abilities to safely manage a radiation event and navigate counter-terrorism security procedures on a state and national level. Partnering with law enforcement agencies to deliver this essential service enhances interoperability and builds trust in sovereign capabilities. This work also enables the frontline responder and the scientist to best identify technological development opportunities to further enhance Australia's strategic responses to extreme threats. Implementing International Atomic Energy Agency (IAEA) training courses and partnering with regional neighbours in knowledge exchange activities further enhances ANSTO's contribution to strengthening regional nuclear security.

Research Priorities

Secure nation

ANSTO Capabilities

- Nuclear Forensics

Collaborators/Client

Australian Federal Police
NSW Police Force

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ANSTO's expert facilitators guide trainees during a radiation exercise.

Revolutionising palaeontology with neutron imaging

Neutrons reveal crocodile predation on dinosaurs

Reconstructing the history of life on Earth provides information about evolutionary and environmental trends, which can inform future developments. However, the fossil record is biased, information can only be gained from the selection of organisms that have been preserved. Scientists that study Earth's history are continually seeking new techniques to help extract as much information as they can from the fossil record.

THE CHALLENGE

Fossils from the Cretaceous age (66 – 145 million years ago) in the Winton Formation in central-western Queensland are often recovered from high-density, iron-rich geological samples. This matrix is very hard, making extraction extremely difficult. In 2010, researchers found the remains of a 2 to 2.5-metre-long crocodilian, Confractosuchus sauroktonos. The fossil, embedded in a concretion, was moved by a front-end loader causing it to shatter. During a two-year effort to reassemble the fossil, Australian Age of Museum staff reached out to ANSTO for assistance in 3D imaging a single piece of this rubble to determine where it belonged in the specimen.

THE SOLUTION

Instrument scientists at ANSTO used neutron imaging on the Dingo instrument which achieves both the necessary penetration and contrast to image fossil bone inside rock. Serendipitously, the rock that was imaged also contained the remains of a juvenile ornithopod dinosaur. The juvenile displayed clear evidence of oral processing, dismemberment, and bone fragmentation—all hallmarks of modern crocodile feeding behaviour. The unique 3D images recorded by Dingo, and the high-resolution imaging and medical beamline (IMBL) at the Australian Synchrotron, yielded sufficient evidence to prove that the dinosaur remains were the abdominal contents of the ancient crocodile. These ornithopod bones represent the first skeletal remains of its kind from the Winton Formation, and the first direct evidence that crocodiles, or any other animal, ate dinosaurs.

THE IMPACT

Prior to this work, the application of neutron imaging for palaeontological samples was hindered by the perceived risk of long-term radioactivation of museum specimens. The Australian Age of Dinosaurs Museum was the first museum to entrust ANSTO with the neutron imaging of vertebrate fossil remains. As a result of this work, ANSTO has become the global centre for the application of neutron imaging for palaeontology and enhanced the international reputation of the Dingo instrument, its staff, and the availability of complementary neutron and synchrotron X-ray imaging at ANSTO. This work continues to attract high-profile palaeontological and museum studies to ANSTO and to foster increasing positive social engagement with the public.

Supports

National Science Statement

ANSTO Capabilities

- Neutron Imaging
- Synchrotron X-ray Imaging

ANSTO Instruments

Dingo
Neutron Imaging

Imaging and Medical Beamline (IMBL)

Collaborators/Client

University of New England
Australian Age of Dinosaurs Museum
University of California

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Publications

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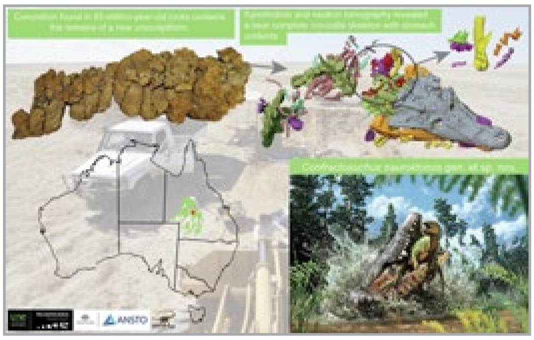

FIGURE 1:
Concretion found in 93 million year old rock contains the remains of a new crocodyliform synchrotron and neutron tomography revealed a nearly complete crocodile skeleton in the stomach contents *Confructosuchus sauroktonos*.

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Australian Government

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LOCATIONS

LUCAS HEIGHTS
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