HIA
HEAVY ION ACCELERATORS

2024 HEAVY ION ACCELERATORS IMPACT REPORT

Australian National University

THE UNIVERSITY OF MELBOURNE

NCRIS
National Research Infrastructure for Australia
An Australian Government Initiative

Acknowledgements

Heavy Ion Accelerators acknowledges and pays respect to all Aboriginal and Torres Strait Islander peoples and communities across Australia. We recognise that the land from which we benefit holds an ancient, rich and sacred history.

We honour the lands on which The Australian National University's Acton campus stands, acknowledging that it always was and always will be Ngunnawal and Ngambri Country. We extend this recognition to Wurundjeri Woi-wurrung and Bunurong Country, where the University of Melbourne's Parkville campus stands. We acknowledge the Traditional Owners of these lands and pay our respects to Elders.

Our $150M facilities for high-energy ion beam research represent decades of strategic investment in the national interest by the Australian Government, The Australian National University, The University of Melbourne and our industry partners.

Since 2009, HIA has been funded under the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS) to support high-quality research driving greater innovation in the Australian research sector and the broader economy. HIA acknowledges the continued support of NCRIS, which provides critical funding for the accelerator network and its professional staff.

We also acknowledge and deeply value the unique and essential role played by the host universities for their support, including academic staffing. This support is essential for delivering research outcomes, driving continued innovation in research infrastructure and fostering collaboration locally and globally.

Australian National University

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NCRIS National Research Infrastructure for Australia An Australian Government Initiative

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Leadership reflections

The inaugural Heavy Ion Accelerators (HIA) Impact Report arrives at a historic moment for HIA. The 2023-2024 financial year saw a substantial increase in funding to HIA staff and facilities at The Australian National University and the University of Melbourne, thanks to the National Collaborative Research Infrastructure Strategy (NCRIS). This is a tremendous boost for HIA, enabling us to upgrade essential infrastructure, and for the first time in more than a decade, we are increasing the technical and user support workforce at all three nodes. We have already increased the professional workforce by 50 per cent, including new technical and support staff to ensure HIA facilities remain world-class.

This boost to HIA's capabilities comes at a time when the need for sovereign nuclear facilities and a nuclear-skilled workforce has become a national priority. HIA has treasured, time-honoured and mutually-reinforcing partnerships with its host universities in the delivery of hands-on nuclear science education: a mission of national importance for nuclear medicine, advanced materials, quantum technology, agriculture, critical minerals, space and defence. In this context we are excited to partner with the ARC RadInnovate Industrial Transformation Training Centre to foster and grow the workforce Australia urgently needs.

Strengthening our domestic and international relationships is also a priority over the next 24 months. Recently-signed memorandums of understanding with ANSTO, the University of Melbourne, the Australian Synchrotron and Los Alamos National Laboratory in the United States are both recognition of existing strategic partnerships and open many new future opportunities for multidisciplinary, world-class research.

It is our vision that HIA develops as a truly national network with an international presence, delivering unique impact in the service of Australia's National Science and Research Priorities for decades to come.

Kate Lundy

Chair of the Heavy Ion Accelerators

As the Chair of the Board of Heavy Ion Accelerators, it is my great pleasure to present the inaugural HIA Impact Report.

Since taking on the role of Chair in early 2021, I have been constantly inspired by the incredibly diverse contributions HIA makes to research and industry, across fundamental physics, medicine, defence, climate and environment, quantum technologies, materials science and the space sector. This is not just a story of the ion accelerators that enable the research: it is a story that belongs to the people who have made it possible over more than five decades—professional and academic staff working together to achieve remarkable breakthroughs. It is a profound journey of scientific innovation, engineering and technical excellence over many decades.

In this first report, we highlight the impact of HIA's capabilities on Australia's National Science and Research Priorities, powered by the National Collaborative Research Infrastructure Strategy. But we also tell the story of the people who are making this impact possible, including technical staff, students, early-career researchers and senior leaders in their fields. Above all, this is the story of HIA drawing people together, creating a community of innovators who harness the unique power of ion accelerators to achieve remarkable breakthroughs.

HIA, as part of NCRIS, is making an increasingly important contribution to Australia's national scientific, industrial and strategic interests.

I would also like to acknowledge and thank my fellow advisory board members, and we commend this report to you.

Tom McGoram

Chief Executive Officer, Heavy Ion Accelerators

It is my great privilege to be the inaugural CEO of Heavy Ion Accelerators, and present to you our first Impact Report.

As a PhD student of nuclear physics at the Heavy Ion Accelerator Facility in the 1990s, I could never have imagined I would be fortunate enough to return to lead this remarkable team of people who make such a profound impact on the national and international research and industry landscape. Returning to HIA after more than two decades in defence and national security, it became immediately clear to me that HIA is not simply world-class research infrastructure: it is a unique strategic asset for Australia that helps power our knowledge advantage across multiple scientific and industrial domains: space, medicine, nuclear science, quantum technology and the dramatic changes in our climate and environment.

The ethos of HIA is one of dedicated people coming together to solve the hardest problems in the national interest, powered by the unique capabilities of heavy ion accelerators. To the HIA team located across The University of Melbourne and The Australian National University and led by our wonderful Node Directors: thank you for your passion, drive, teamwork and determination that has made possible the achievements highlighted in this Impact Report. Thank you also to Kate Lundy and the HIA Board, for their constant encouragement and support, and to my truly inspirational friend and colleague, Professor Mahananda Dasgupta. Together, we look forward to the impact HIA will continue to have for many years to come.

The accidental physicist who's now a world leader in nuclear research

FEATURED PROFILE

Mahananda Dasgupta

Director, Heavy Ion Accelerator Facility, Research School of Physics, Australian National University

Professor Mahananda (Nanda) Dasgupta wears so many different 'hats', you might wonder how she finds the time for them all.

As well as being the Director of the Heavy Ion Accelerator Facility, she is an experimental physicist at the ANU Research School of Physics; a Fellow of the Australian Academy of Science, Australian Institute of Physics, and the American Physical Society; and sits on the National Science and Technology Council for Australia, advising the Prime Minister on nationally important science and technology issues.

In 2017, she established a Mentoring and Guidance in Careers Workshop for early-career women and gender-diverse researchers in science, together with Professor Nalini Joshi, as part of an Australian Laureate Fellowship. She is also the Director of a new ARC Industrial Transformation Training Centre in Radiation Innovation (RadInnovate), a multi-institutional collaboration that delivers hands-on training for Masters and PhD students in nationally important areas of nuclear and radiation science, policy and governance.

But despite the lengthy list of jobs and accolades, she says taking meaningful action is far more important than roles and titles.

"Leadership can come from any level—the foundational idea is that you make a change for the better and take action," she says.

Professor Dasgupta's professional journey as a world leader in nuclear physics research is particularly impressive for someone who initially didn't plan to be a nuclear physicist: "I wanted to join the Civil Service in India and change the world," she says with a smile.

But after a vacation scholarship opportunity introduced her to the world of nuclear physics, she pursued a PhD instead.

"It was addictive and great fun—I liked working with my hands, so I parked changing the world for a moment."

That PhD led her to a job offer at ANU in 1992, where she intended to stay for two years. When she arrived in Canberra, she was the only woman at HIAF. Later she was the first woman to be tenured in the ANU Research School of Physics. Thirty-two years later, she's still at HIAF, where changing the world looks a little different.

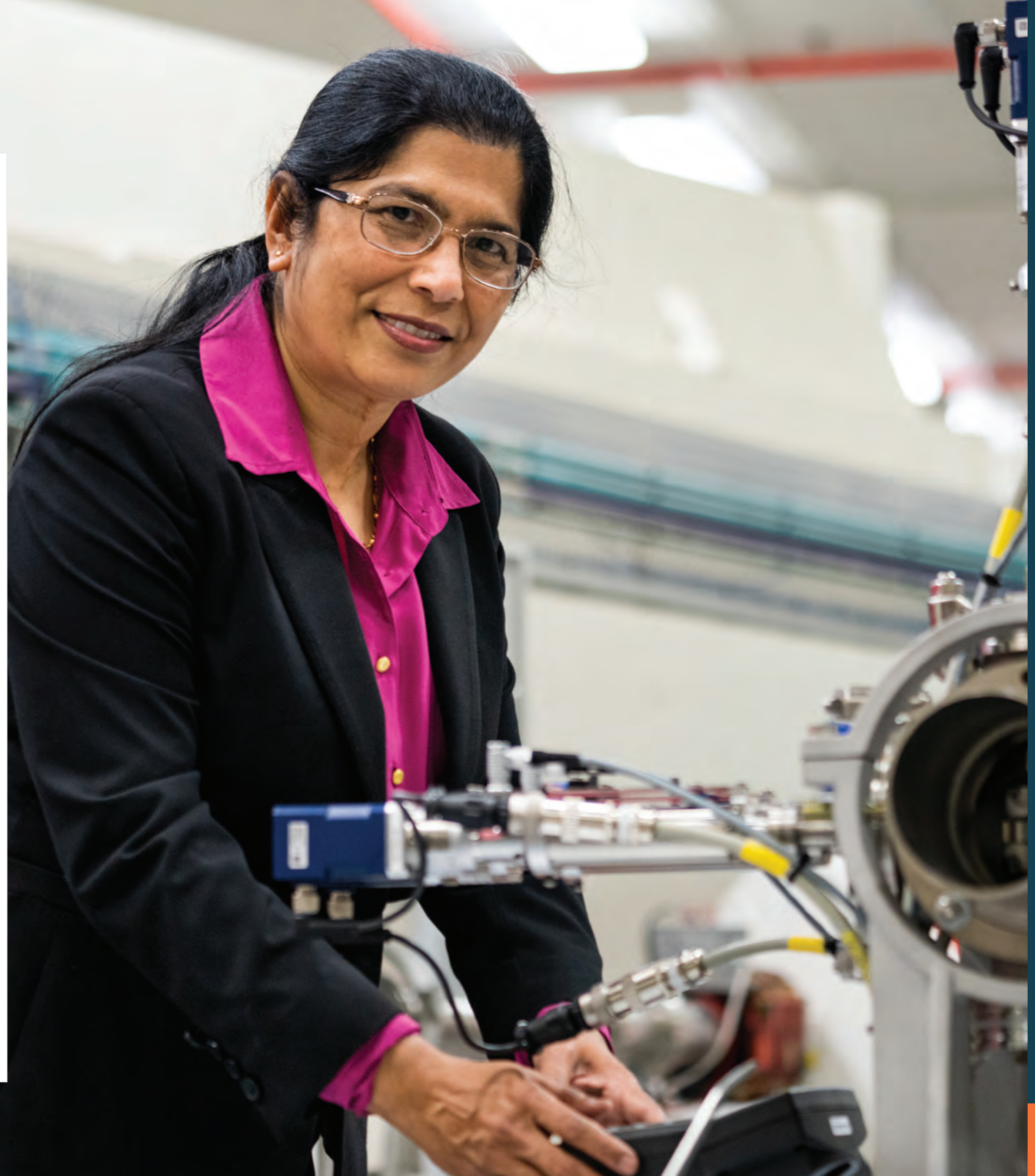
"The workplace culture at the time, at least for the research sector, was very different and certainly not as diverse," she says. "Furthermore, traits of being very forthright and direct were perhaps unexpected in a woman from the Indian subcontinent."

Now, as the facility's Director, Professor Dasgupta has helped shift the workplace dynamic to a supportive environment where all researchers can thrive, instilling values of respecting other opinions and strengths, attention to detail, and helping people grow their confidence in problem-solving and public speaking.

"Now we have more diversity: of people, opinions, ideas," Professor Dasgupta says. "Out of my entire career, I'm most proud of the people we have trained and what they have gone on to achieve."

"They're in such a wide range of careers around Australia and they are excelling!"

> *Now we have more diversity: of people, opinions, ideas. Out of my entire career, I'm most proud of the people we have trained and what they have gone on to achieve.*
>
> *—Mahananda Dasgupta, Director of Heavy Ion Accelerator Facility*



2024 HIA IMPACT REPORT | LEADERSHIP REFLECTIONS

Introduction to Heavy Ion Accelerators

VISION

Provide world-leading accelerators for science and industry.

MISSION

The Heavy Ion Accelerators NCRIS project operates world-leading particle accelerators for a wide variety of scientific and industrial applications, for users from Australia and around the world.

OBJECTIVES

1. Provide world-class facilities for accelerator ion beam research and its applications by Australian and international researchers.
2. Support research activities in sectors of national priority, including quantum computing, space and astronomy, advanced materials, environment and climate, cancer therapies, minerals exploration and nuclear technologies.
3. Provide resources for advanced research training for students and early-career researchers in science and technology.
4. Support and enhance Australia's sovereign capabilities in nuclear physics, and in ion beam and radiation applications.
5. Build technical and research linkages with other leading national and international ion beam accelerator laboratories.

The Heavy Ion Accelerator Facility towers over the ANU Research School of Physics.

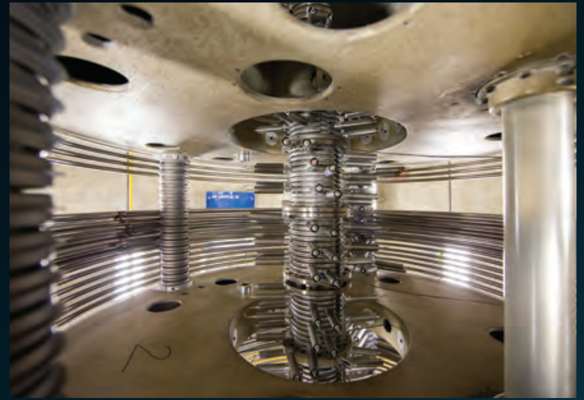
ABOUT

The capabilities of the Heavy Ion Accelerators network are unique in Australia and rare in the world. Our network of accelerators consists of three nodes: two in Canberra, hosted by The Australian National University (ANU), and one at The University of Melbourne. Each facility has unique capabilities that cater for distinct yet complementary areas of research and applications.

HIA enables researchers to build our fundamental understanding of nuclear physics, develop novel cancer therapies, perform fundamental studies of ion–solid interactions and materials science. Researchers can fabricate and prototype novel devices, support quantum technology, and monitor and protect the environment. HIA's testing capabilities can emulate space radiation to support applications in the space industry and the life sciences.

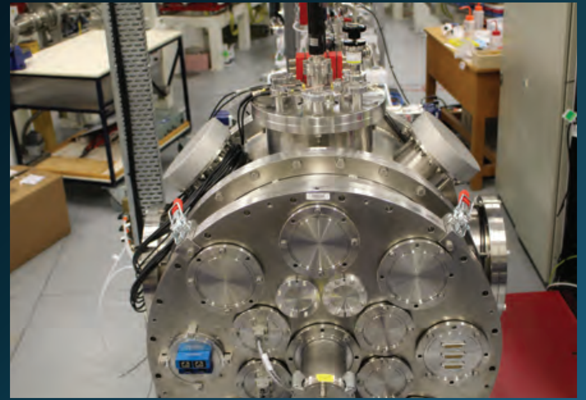
Hosted at the ANU and The University of Melbourne, HIA enjoys a long-standing and collaborative relationship with the research community in these institutions. Together with NCRIS-funded professional staff, we work with Australian and international researchers, industry and government professionals to develop new technologies, grow scientific knowledge and support Australian industry. By providing students access to world-class research infrastructure, we support the host universities to deliver hands-on teaching and training for the next generation of scientists, industry-based researchers and the broader nuclear-literate workforce through a range of undergraduate, postgraduate and short course study options.

Equipment and expertise



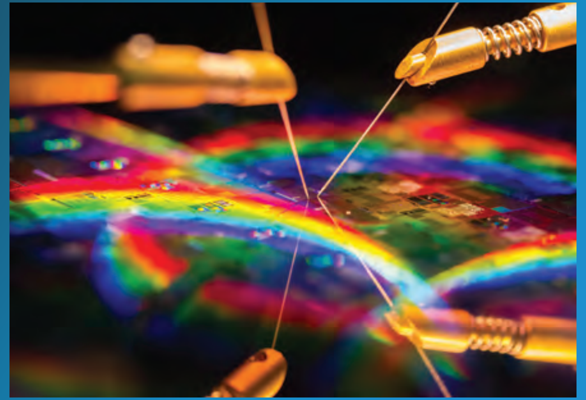
15MV ION ACCELERATOR AND LINAC

We operate two coupled heavy ion accelerators: a 15 million volt 14UD Tandem van de Graaff accelerator and a 6 million volt equivalent superconducting linac booster. The facility runs 24/7 for between 3,500 and 5,000 hours per year and delivers beams of nearly any element to one of 11 beam lines, each with specialised instrumentation for fundamental and applied research and analytical measurements.



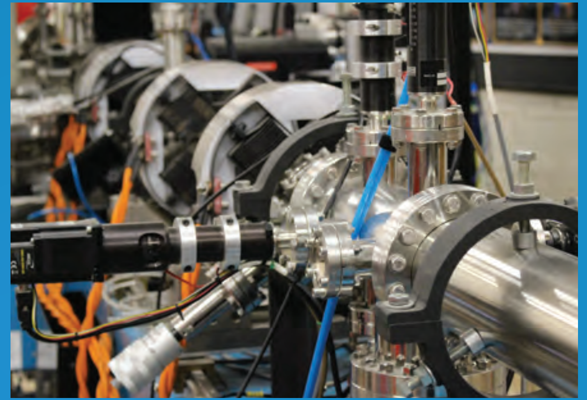
SPACE IRRADIATION BEAM LINE

The state-of-the-art Space Irradiation Beamline at the Heavy Ion Accelerator Facility (HIAF-SIBL), developed with the support of the Australian Space Agency, provides the essential radiation testing the space industry needs. HIAF-SIBL emulates the radiation conditions in space in a dedicated chamber where space equipment can be placed and tested for specific mission requirements, allowing industry to test for the most damaging radiation that their equipment will be exposed to. We offer the highest-energy heavy ion space radiation testing facility in Australia, providing a unique opportunity for the space industry to understand and reduce mission risks.



ION BEAM ANALYSIS AND ION IMPLANTATION

We are the only facility in Australia for controlled implantation of a broad range of atomic species into a wide range of materials. This capability supports research in areas such as microelectronics, optoelectronics, photonics, materials science, quantum computing and sensing devices. We operate three electrostatic accelerators to modify and analyse materials with ion beams. The high-energy ion implanter can produce ions with energies up to 10 MeV, while the low-energy ion implanter operates in the energy range 15–150 keV, each implanting ions from a broad range of elements into cooled or heated (77–670 K) samples.



EXPERIMENTAL CONDENSED MATTER PHYSICS ACCELERATOR

We operate an NEC 5U tandem electrostatic accelerator operated as a proton microprobe, delivering ion beams to three beamline instruments including the world-leading MAIA X-ray pixel detector array for materials analysis. We also operate a low-energy Colutron ion implanter in a clean room capable of implanting argon, nitrogen and phosphorus ions. We partner with the ARC Centre for Excellence for Quantum Computing and Technology (CQC2T) and collaborate with the CSIRO Division of Exploration and Mining on geological materials analysis. Our partnerships and facilities have enabled researchers to develop the blueprints for a large-scale quantum computer, and ultra-sensitive magnetic probes to detect the electromagnetic signal of cellular processes in biology.

NUCLEAR EDUCATION AND TRAINING

With the nation's highest-energy ion accelerator and its internationally-recognised team of scientists and technicians, we are uniquely placed to support Australia's sovereign skills base in nuclear science. Our facilities support the provision of education and training for a wide range of skill levels, educational backgrounds and contexts. They include dedicated instruments and equipment for nuclear physics experiments, including fusion, fission, nuclear structure, astrophysics and electron spectroscopy.

Diverse days and high-tech repairs

FEATURED PROFILE

Thomas Tunningley

Accelerator Research and Development Specialist, Heavy Ion Accelerator Facility, Research School of Physics, Australian National University

When you work with the advanced equipment available at the Heavy Ion Accelerator Facility, no two days are the same, according to HIAF Accelerator Research and Development Specialist, Thomas Tunningley.

"One moment, you might be at your desk working on some computer-based design work or beam simulations, the next, you could find yourself elbow-deep in a vacuum chamber, tools in hand, rescuing an experimental run," he says.

Tunningley has been keeping HIAF's equipment running since 2011. He's always been interested in "all things design and technology", bringing his background in industrial design and mechanical engineering, plus experience working in the defence industry, to his role at HIAF, which he finds "fascinating and enjoyable".

"The work at HIAF is incredibly diverse—there are long-term projects, emergency repairs and everything in between," he says.

Over the next few years, he'll be focused on two major upgrades to the facility's tech, alongside a team of 15 other technical staff.

"A new ion source and electrostatic analyser will require a total reconfiguration of the injection level of the facility," he explains. "And within the accelerator itself, we will be replacing all of the existing insulating structure and components."

These two projects will enhance the capability, performance, and reliability of HIAF and further cement its place as the top facility of its kind in the world.

The high voltage terminal at the heart of the 14UD Pelletron Heavy Ion Accelerator, providing accelerated ion beams at HIAF

Part of the acceleration tube inside the 14UD Pelletron Accelerator at HIAF. The small cylinders emerging from the tube are a unique, high-performance resistor design developed by the HIAF technical team used to create a voltage gradient from the 15 MV terminal.

Engagement, outreach and capacity building

At HIA, we lead community engagement and outreach activities from local to international scales, with a strong lineup of events and sponsorship arrangements that build connections and share the value of nuclear science.

Throughout the year, our staff lead immersive tours and open days at our facilities in Canberra and Melbourne, showcasing our research, equipment and expertise. At HIAF ANU, we host around 50 tours annually, welcoming a diverse range of visitors—from school students to high-ranking government officials. Our open days, run during National Science Week in August, are fantastic opportunities to connect with the local community.

Professor Mahananda Dasgupta gives a tour of the Heavy Ion Accelerator Facility at the Open Day during the 2024 National Science Week.

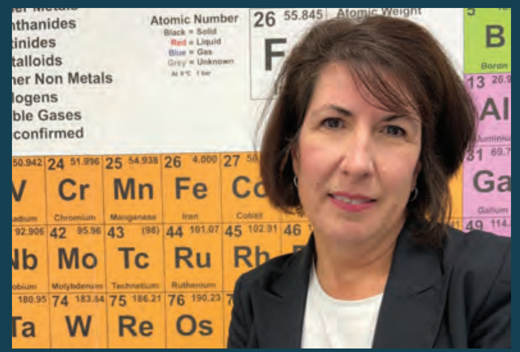
Every year over 300 visitors keen to explore the world of nuclear science come for our tours and interactive science demonstrations.

In 2023, one of our nodes, the Heavy Ion Accelerator Facility, marked its 50th anniversary with a series of special events that brought together Canberra staff, students, alumni, government officials and industry leaders, that celebrated our achievements and strong community ties. We are looking forward to running a number of community events in 2025 to celebrate another milestone—the 50th anniversary of the Pelletron facility at The University of Melbourne.

HIA's presence extends beyond our facilities. We proudly sponsor and exhibit at key conferences such as the Quantum Australia Conference, at the Australian Institute of Physics (AIP) events, the 30th International Conference on Atomic Collisions in Solids, and the 12th International Symposium on Swift Heavy Ions in Matter. Our staff also contributed to the Australian Collaboration for Accelerator Science through various speaking engagements.

HIA is excited to lead the 2024 Heavy Ion Accelerator Symposium on Fundamental and Applied Science in Canberra in November. This event will bring together researchers and industry experts to explore the latest advancements in ion accelerator technology.

We're committed to shaping the future of nuclear science, building bridges between research, industry and the wider community while inspiring the next generation of scientists and innovators.



Inspiring new generations of STEM enthusiasts and their teachers

FEATURED PROFILE

Paula Taylor

Assistant Director, Academy of Future Skills, ACT Education Directorate,

President, Science Educators' Association, ACT (SEAACT)

HIA's role in teaching and training goes far beyond the students who enrol in tertiary-level courses—it also leaves a lasting impression on much younger students and their teachers.

The Heavy Ion Accelerator Facility at The Australian National University runs tours for primary- and secondary-school students, showcasing the facility and how its research contributes to a range of industries in Australia.

That experience and expertise in engaging with school students was a perfect fit for ACT STEM educator Paula Taylor, when she started planning a week-long conference to teach public school students about the space industry earlier this year.

"As the organiser, I knew that HIAF would be ideal as it has a broad appeal for teachers and students alike across many science disciplines and year levels, but also in demonstrating that science is a human endeavour, a concept that we must teach as part of the Australian Curriculum," Taylor says.

The conference itself—the 2nd annual ACT Space Industry Work Exploration Program—was a huge success. A PhD student from HIAF spoke on a careers panel to share her journey with students into this field, and Taylor said she did a "wonderful job".

"She showed how HIAF is an enabler across many disciplines and fields," says Taylor. "She was very relatable to the young students given her youth and enthusiasm for her work at the centre."

Taylor has a strong history of collaboration with HIAF. In her other role as the President of the Science Educators' Association, ACT (SEAACT), she found the facility and its staff could offer a range of educational opportunities for teachers, who are required to conduct 20 hours of professional learning annually to maintain their registration.

Last year, HIAF staff delivered a workshop for Science Educators' Association members that included explicit teaching of radioactivity, the applications and benefits to society, and a tour of the facilities that explained how the instruments work and the research being conducted there. It was one of the SEAACT's highest-attended events "in a very long time".

Taylor was impressed to learn how many industries and research areas HIAF supports: "It's truly multidisciplinary, enabling scientists to solve complex problems from a large range of fields," she says.

"Radiation is an engaging and interesting topic with many societal benefits that teachers and students can relate to, so it is a great 'hook' to a STEM pathway."

Supporting Australia's National Science and Research Priorities

The enduring strength of ion accelerators is their flexibility in meeting the science and research challenges of the day. Australia has played a driving role in the development of accelerators since the 1930s, thanks to the pioneering work of Sir Mark Oliphant, who invented the world's first synchrotron accelerator and created Australia's first accelerator facilities at The Australian National University in the 1950s. Accelerators power both scientific discovery and developments in industry, and repay their investment by stimulating the growth of core expertise and a skills base in new technologies used in cutting-edge manufacturing and engineering.

In our first Impact Report, we have selected six thematic impact domains, each of which, in turn, support at least one of the Australian National Science and Research Priorities. Underpinning all of these priorities is the support of HIA for research in fundamental nuclear science. The quest to understand the essential nature of the nucleus has driven evolution and innovation in accelerator physics for more than 70 years. Without these fundamental discoveries pushing the boundaries of accelerator science and nuclear physics, we would not be able to make related advances in medicine, quantum, space science and other sectors.

Priority 1: Transitioning to a net-zero future

The capabilities of HIA in environment and climate research play a unique role in understanding Australia's geological climate record, improving climate models, understanding impacts on the marine environment, and making direct measurements of fossil-fuel emissions, which in turn support policy decisions by the state and Commonwealth governments to safeguard Australia's net-zero carbon future. Ion accelerators also play a unique role in wildlife forensics, helping to protect our remarkable biodiversity.

Priority 2: Supporting healthy and thriving communities

HIA makes unique contributions in medical research. HIA continues to drive innovation in support of the wellbeing of Australians by conducting research into novel particle beam cancer therapies, by working to understand the potential of new techniques such as Auger electron therapy for highly-targeted treatment of tumours, and by producing solid-state nanopore devices for the early detection of Alzheimer's disease.

Priority 3: Elevating Aboriginal and Torres Strait Islander knowledge systems

HIA will continue to support science and research outcomes. The National Science and Research Priorities emphasise the need to improve the lives of Aboriginal and Torres Strait Islander peoples with policy that is shaped by science, research and strong partnerships with Aboriginal and Torres Strait Islander peoples and their communities.

HIA's proven capabilities to support environment and climate research will support developing policy relevant to Aboriginal and Torres Strait Islander peoples that is underpinned by science, research and strong partnerships with these communities. For example, the ability of HIA to detect the radionuclide products of uranium mining in bush foods in the Kakadu region helps keep our First Nations peoples safe, protecting their traditional way of life. Our capabilities to monitor the movement of soil sediments in Australia's waterways help to protect our rivers, estuarine environments and coastlines, and support traditional ways of life for First Nations peoples.

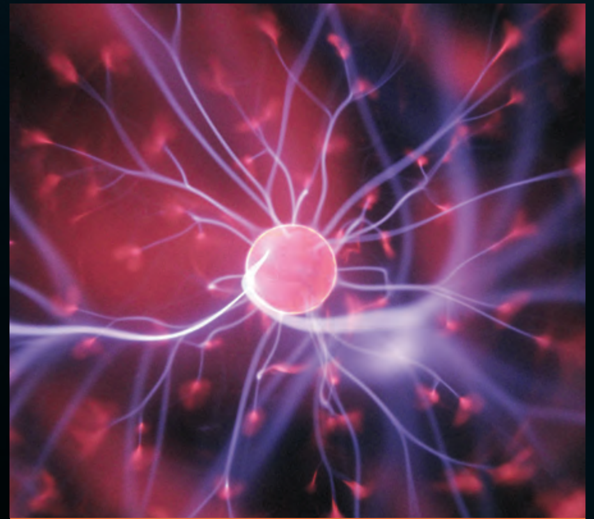
Priority 4: Building a secure and resilient nation

The capabilities of HIA in enabling research into quantum technologies, the space industry and advanced materials are all essential for the transformation of Australia's economy to ensure we have a secure and resilient nation. HIA plays a critical national role in creating exquisitely-crafted qubits for quantum sensing, communication, navigation and computing applications as well as producing isotopically-pure silicon 28—an essential base material for Australia's quantum industry. Our space irradiation testing capabilities—part of Australia's National Space Qualification Network—are essential for Australia's space industry to understand the hazards of space radiation and build resilient space-based technologies. Our ion implantation facilities develop unique optoelectronic devices, novel solar-cell technologies and support developments in neuromorphic computing and nanotechnology, all key to growing sovereign knowledge and embracing and driving innovation in support of our economy.

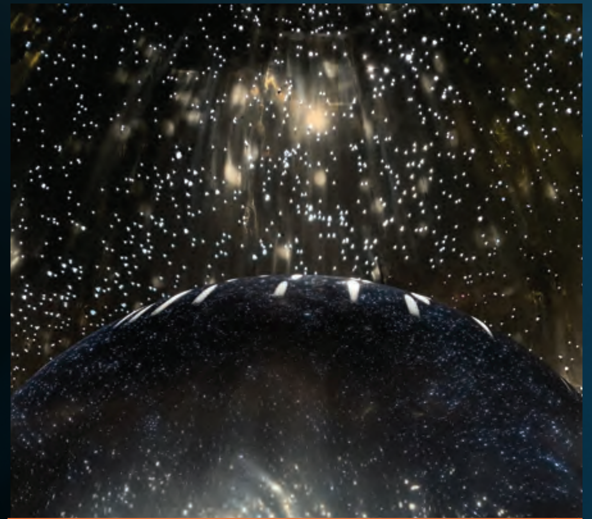
Priority 5: Protecting and restoring Australia's environment

With over 50 per cent of Australians living within 7 km of the coastline, climate-change induced changes to the coastal environment are compounding human-induced impacts on habitat loss, natural resource systems, lifestyle, culture and livelihood. As part of its suite of environment and climate capabilities, HIA is contributing its unique soil-sediment tracing capability to a coalition of 13 NCRIS organisations as part of a cohesive, national approach to better understand the impacts of climate change on our coastal environment, thereby empowering decisions by individuals, local communities and governments at all levels to improve national resilience.

Research outcomes and impact



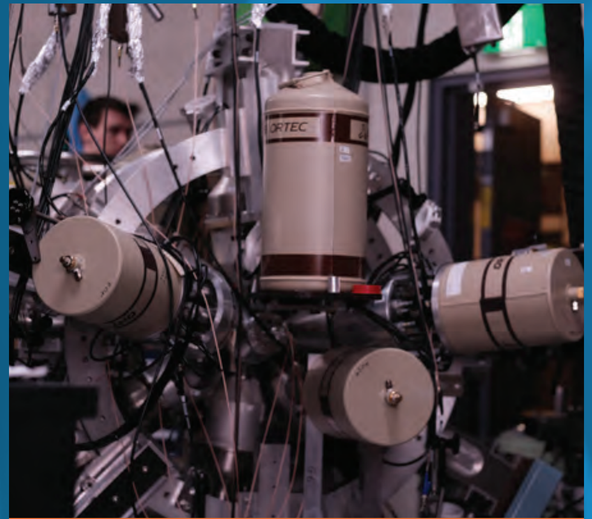
QUANTUM TECHNOLOGIES AND ADVANCED MATERIALS MANUFACTURING



SPACE TECHNOLOGY

ENVIRONMENT AND CLIMATE

MEDICAL RESEARCH



FUNDAMENTAL PHYSICS

SUPPORT FOR HIGHER EDUCATION AND TRAINING

2024 HIA IMPACT REPORT | RESEARCH OUTCOMES AND IMPACT

QUANTUM TECHNOLOGIES AND ADVANCED MATERIALS MANUFACTURING

High-tech hub sums to a great whole

Some of the highest tech facilities in Australia are tucked away by a shady creek, under the shadow of Canberra's Black Mountain.

Here on ANU campus, there are six NCRIS facility nodes within half a kilometre of each other: the Heavy Ion Accelerators (HIA) and the Australian National Fabrication Facility (ANFF) nodes in the Research School of Physics; Microscopy Australia and Phenomics Australia nodes in the John Curtin School of Medical Research; Access-NRI in the Research School of Earth Sciences, and the National Computing Infrastructure.

The integration between these NCRIS-funded core capabilities adds up to a whole much greater than the parts, says Professor Rob Elliman, the Director of HIA's Ion Implantation Lab.

"The integration with other materials processing and characterisation capabilities enables us to support a broad range of applications, ranging from quantum technologies, electronic and photonics to the materials science of nuclear reactors."

As an example, the material research into future night-vision technology (featured on page 24) is underpinned by the team's ability to explore and select the most appropriate nanofabrication techniques from a wide range of options, including ion implantation, thin-film deposition and etching, thermal processing and photo- and electron-beam lithography.

But the nanofabrication techniques would be limited without the ability to carefully analyse the experimental materials created. In this arena, the locale boasts Rutherford backscattering and channelling, cross-sectional electron microscopy, Raman spectroscopy, atomic force microscopy and X-ray diffraction amongst its arsenal.

"It's a unique and comprehensive package," Professor Elliman says.

ANU Centre for Therapeutic Discovery, Phenomics Australia.

Using a transmission electron microscope at the Microscopy Australia ANU facility.

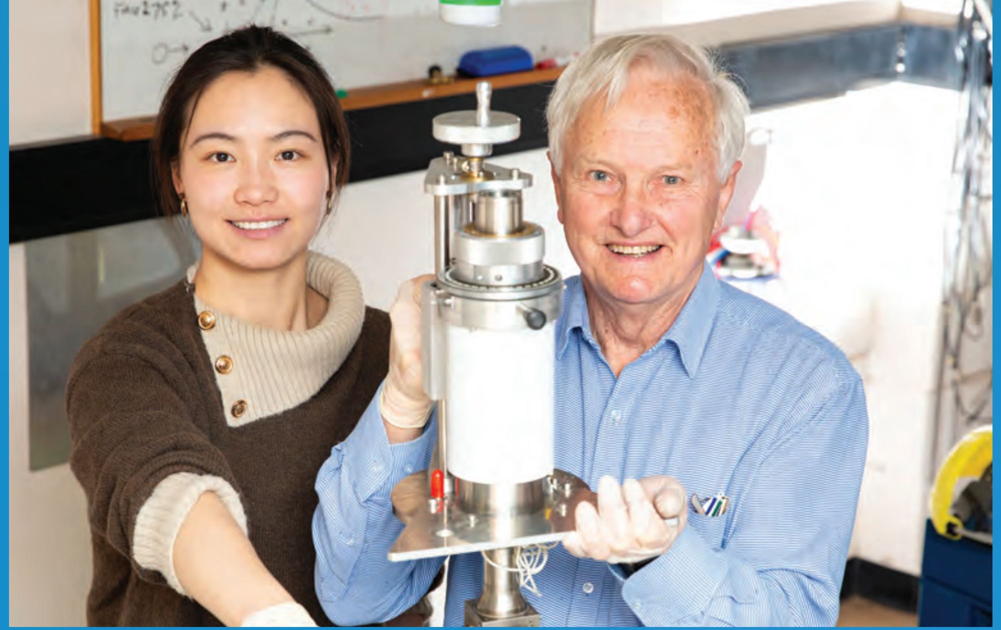
Dr Xingshuo Huang with Professor Hoe Tan at the ANU node of the Australian National Fabrication Facility (ANFF)

Heavy Ion Accelerator Facility, ANU Research School of Physics

ADVANCED MATERIALS MANUFACTURING

CASE STUDY

Beating nature to make a night-vision detector



Dr Xingshuo Huang (left) and Professor Jim Williams.

Scientists have created new improved materials that can detect infrared light—the key to night vision. The new materials promise a substantial improvement in efficiency over current night-vision technology.

The challenge in creating these materials—made of germanium with tin atoms embedded in it—is beating nature, says Emeritus Professor Jim Williams, from the ANU Materials Physics Department.

"Nature wants the material system to come back to balance, or thermodynamic equilibrium. But if you can lock the system out of balance, you can tailor the properties of materials in exciting ways," Professor Williams says.

He and his international team have spent more than a decade devising non-equilibrium processes in the quest to make a semiconductor that, unlike pure silicon or germanium, can efficiently absorb infrared light.

> *It's amazing that we have taken the process from fundamental research of germanium-tin alloys to finally making photodetectors out of them.*
>
> —Dr Xingshuo Huang, Member of the ANU team

Low efficiency is a major hurdle for night-vision technology—current technology is typically less than one per cent efficient. Additionally, it uses compound semiconductor materials that are problematic; the most promising of these materials, mercury cadmium telluride, is not particularly stable at room temperature and is not easy to integrate with silicon electronics.

In contrast, the team's latest publications herald a safe, stable and cheap infrared-sensitive material, which Professor Williams says should soon demonstrate well over one per cent efficiency.

Their success with tin-doped germanium has attracted the notice of the US Army and US Air Force, who have between them funded a string of grants, noting that "a prime reason for this collaboration is to access the unique ion implantation and ion beam analysis facilities at the ANU."

Using liquid nitrogen: the iiLab implanter's flexible capabilities include heating and cooling samples across a wide range of temperatures.

> *These photodetectors can be applied to a wide range of studies, including environmental and life sensing fields.*
>
> —Dr Xingshuo Huang, Member of the ANU team

An advantage of germanium is that it can be grown on silicon, which enables easy connection to conventional electronic circuitry.

The challenge has been getting the tin to stay embedded in the germanium. At thermal equilibrium the maximum amount of tin that will stay dissolved is only one per cent, which is not enough to shift germanium's absorption window from its natural near-infrared region (wavelengths shorter than 1.5 microns) to mid infrared (around 4 microns). This needs tin content above 10 per cent.

But the team found that concentration, if allowed to come to thermal equilibrium, results in tin separating and pooling on the surface like oil on water.

To trap it in place, they use two methods.

One is to deposit a layer of the mixture from a chemical vapour, below 300 degrees, to suppress equilibration. But this method results in material that is quite defective. The second way, unique to the team, is to implant tin ions into the germanium at cryogenic temperatures. This has the side effect of damaging the germanium crystal, but it can be healed with flashes of laser light that momentarily melt the top layer, allowing it to re-crystallise with far fewer defects.

Analysis showed both fabrication techniques result in material defects—but quite different defect types and amounts.

So, the ideal method looks to be a hybrid, starting with chemical vapour deposition, and finishing off with icing made from an ion-implanted, laser-melted layer. Using this approach, the team has achieved low defect-density material with over 10 per cent tin.

"It's amazing that we have taken the process from fundamental research of germanium-tin alloys to finally making photodetectors out of them," says Dr Xingshuo Huang, a member of the ANU team.

"These photodetectors can be applied to a wide range of studies, including environmental and life sensing fields."

S. Q. Lim et al., "Remote plasma-enhanced chemical vapor deposition of GeSn on Si: Material and defect characterization," Journal of Applied Physics, vol. 133, no. 23, p. 235302, Jun. 2023, doi: 10.1063/5.0149483.

X. Huang et al., "Comparison of GeSn alloy films prepared by ion implantation and remote plasma-enhanced chemical vapor deposition methods," Journal of Vacuum Science & Technology B, vol. 42, no. 4, p. 044001, Jun. 2024, doi: 10.1116/6.0003668.

QUANTUM TECHNOLOGIES

CASE STUDY

How ion accelerators helped build quantum accelerators

Quantum Brilliance staff working at Quantum Brilliance's quantum computing prototyping and production site at the ANU Campus, Canberra.

Dr Marcus Doherty believes that in the future, when you shop for a new laptop, you'll be comparing not how many CPUs and GPUs they have, but how many diamond-based quantum accelerators.

"Quantum accelerators are compact modular quantum computers. One day they will be the same size as GPU and CPU cards and will be everywhere that classical computing is, integrated into computers just like graphics cards," says Dr Doherty, Chief Scientific Officer of Quantum Brilliance, a company spun out of ANU Research School of Physics.

"That's a very different vision for quantum computing compared to other companies."

Consulting company McKinsey estimates the quantum computing industry could be worth more than $45 billion by 2040. Many large

> *A prototype has now been installed at the Pawsey Supercomputing Centre in West Australia, where it is being used to develop the methods and tools to hybridise quantum computers with classical supercomputers and test them on simple calculations.*

companies are already offering stand-alone cloud-based quantum computing facilities, such as Google's Quantum AI, IBM's Quantum Experience and Microsoft's Azure Quantum.

One reason these offerings are housed in centralised labs is that they are based on superconducting qubits that require cryogenic temperatures and so are encased in large chambers filled with liquid helium and liquid nitrogen.

In contrast, Quantum Brilliance's quantum accelerators use diamonds with a small flaw in them, known as a nitrogen vacancy (NV). These are robust at room temperature, and, according to the company, can operate anywhere a classical computer can.

Physicists at ANU have been researching the quantum properties of NV centres for decades. NV centres are made up of a vacancy, a gap in the carbon atoms of the diamond lattice, next to an atom of nitrogen. Unlike carbon, which

> *Across these different technologies, these customers will have different needs. Some will be best satisfied via ion implantation at HIA.*
>
> —Dr Marcus Doherty, Chief Scientific Officer of Quantum Brilliance

has four bonding electrons, nitrogen has a fifth one. This extra appendage is left dangling after the nitrogen bonds with the four carbons surrounding it and can be used for quantum calculations.

But the trick is to embed a nitrogen atom into a diamond, get it to sit next to a vacancy, and set this pair of flaws at the right depth so that it can be addressed (have quantum information relayed to it) and then left alone, isolated enough for the quantum calculation to take place without being swamped by noise from the world around it.

Quantum Brilliance turned to the ANU Ion Implantation Lab (iiLab) to help them perfect this technique for their prototypes.

"We engaged iiLab commercially, principally because of the flexibility that ion implantation allows, to do various runs to create the NV centres we needed," Dr Doherty says.

A prototype has now been installed at the Pawsey Supercomputing Centre in West Australia, where it is being used to develop the methods and tools to hybridise quantum computers with classical supercomputers and test them on simple calculations.

Already the hybrid system has been used to identify different features in images using Quantum Machine Learning, and to simulate simple molecules using computational chemistry.

With a successful prototype under their belt, Quantum Brilliance have moved to a different manufacturer for ongoing production.

But they are partnering with HIA for the next venture, developing a quantum diamond foundry for users of quantum diamond for a variety of technologies.

As well as computing, the robust and precise quantum properties of diamond are being leveraged in other industries: for example, globally 50 companies are working on quantum sensors and four on quantum communications.

"Across these different technologies, these customers will have different needs. Some will be best satisfied via ion implantation at HIA," Dr Doherty says.

Assembly of the Quantum Development Kit at Quantum Brilliance's quantum computing prototyping and production site at the ANU Campus, Canberra.

The Quantum Development Kit – the quantum computer that Quantum Brilliance is exporting globally to customers, pioneering the development and use of hybrid quantum-classical supercomputing.

QUANTUM TECHNOLOGIES

Implanting a revolution

Building quantum computers requires manufacturing precision at the scale of atoms. The implantation team at HIA have pioneered doing just that—using astonishing control to create novel materials and structure that are the springboard for the quantum computing revolution.

The team use accelerators at the HIA nodes at The Australian National University and The University of Melbourne to precisely embed atoms into wafers, mostly silicon, to create materials for groundbreaking technology—in many fields, not only quantum computing.

Users come to HIA seeking exquisitely-engineered materials with dopants embedded to very precise specifications for their experiments. Their industries span not only quantum computing, but also novel superconducting and semiconducting materials, and ultra-sensitive quantum magnetic sensors that could, for example, be used for research in material science, neurobiology and geology.

For every project, HIA's manufacturing experts devise a workflow using the HIA facilities to implant samples with ions. This can involve processes to purify the sample, dope it, oxidise it, pattern it, characterise it and test it to exacting standards so it is ready for the next steps in the project.

The linchpin of the manufacturing processes is Dr Shao Qi Lim, who did her PhD at the ANU, during which she developed an encyclopedic knowledge of the capabilities of the ANU HIAF and iiLab accelerators. On completion of her PhD she took up a postdoctoral role at The University of Melbourne, and became an expert in the implantation facilities in the Experimental Condensed Matter Physics (ECMP) group there.

Part of the team's impact comes from their understanding of not just manufacturing, but the wider context of the materials they produce. For example the head of ECMP, Professor Jeffrey McCallum, is a technical adviser for the ARC Centre of Excellence for Quantum Computation and Communication Technology (CQC2T). These kinds of links are crucial, says Dr Lim.

"Jeff has a huge network of collaborators he has built up over decades. He knows the materials; people take his advice and trust him with their samples," Dr Lim says.

"He's known as the Implantation and Materials Guy."

Professor McCallum's networks draw researchers from across the country and the globe to HIA.

One of the longest-standing collaborations is with co-workers in the silicon programs in CQC2T based at UNSW Sydney, who require different atoms placed in precise locations, at precise depths. Other research groups from as close as RMIT in Melbourne, to as far afield as Europe, Scandinavia, the Middle East and North America also queue up for the exquisitely-crafted samples.

"A factory could not do what we do," Dr Lim says. "In a university-based laboratory, we are able to more freely use the HIA facilities for highly innovative experiments that push the boundary of our current knowledge."

Technology to solve real-world problems

FEATURED PROFILE

Dr Shao Qi Lim

Postdoctoral Research Fellow, ARC Centre of Excellence for Quantum Computation and Communication Technologies, University of Melbourne node.

Quantum computing is a revolution in progress, and Dr Shao Qi Lim is excited to be part of it.

"I'm lucky to be part of this revolutionary field," says Dr Lim, a postdoctoral fellow in the ARC Centre of Excellence for Quantum Computation and Communication Technology (CQC2T), based within the Experimental Condensed Matter Physics (ECMP) group at the University of Melbourne.

"This position gives me the unique opportunity to work with not just interesting projects, but many other researchers doing really cool stuff. I get to meet some brilliant scientists," she says.

But Dr Lim, too, is brilliant—at making the scientists' requests a reality with the powerful and precise tools that HIA boasts.

Her skills come from direct experience at all three nodes of HIA—she worked on the ANU nodes (HIAF and iiLab) during her PhD and then moved to the ECMP node at the University of Melbourne as a postdoc.

She enrolled in engineering and science as an undergraduate, "without the faintest idea that I would eventually be pursuing a physics PhD".

Within a year she realised physics was her calling and proceeded to explore many research fields during her degree, including experimental semiconductor physics, atomic and laser physics, computational nuclear physics and high-energy astrophysics.

"I eventually realised that my long-term interest lies in the technological applications of physics, specifically in semiconductor nano-electronics," she says.

> *It is always exciting to see how the cumulative contributions from smaller projects eventually come together, which can sometimes lead to major breakthroughs.*

"I am grateful to be a part of the forefront of silicon-based quantum technology research. I really enjoy learning about how things work in and outside the lab, and applying what I know to develop new experiments that will help build new technologies and solve real-world problems.

"It is always exciting to see how the cumulative contributions from smaller projects eventually come together, which can sometimes lead to major breakthroughs."

QUANTUM TECHNOLOGIES

Implantation skills take the uncertainty out of qubit manufacture

Dr Malwin Jakob in the HIA's Colutron lab at The University of Melbourne.

It's a mind-boggling task to build a quantum computer: you have to embed individual atoms of a specific kind into silicon chips made from trillions of trillions of a different kind of atom, keep track of them, and connect to them so you can use them for quantum operations.

The team at the HIA's Melbourne node regularly grapples with this challenge—they are at the forefront of ion implantation, and together with UNSW physicists led by Professor Andrea Morello, are developing a process to implant selected atoms to form the qubits that are at the heart of quantum computers.

This Australian collaboration is at the forefront of today's greatest technology race: to realise quantum computing. And a crucial facility in these efforts is the Colutron ion accelerator, because it can implant ions in specific determined locations, says device fabrication specialist, Dr Malwin Jakob.

"The Colutron is the only implanter in the world that can implant single atoms into silicon with the confidence required for state-of-the-art qubits."

"Our process is deterministic—each ion is directed to a specific location," Dr Jakob says.

This newly-developed process, published in *Advanced Materials*, is a landmark in the business of implantation, which to date has often relied on beams with large numbers of atoms, to compensate for the slightly random and uncontrolled nature of previous beamlines.

With the Colutron's precision, the team at UNSW believe their technology based on antimony atoms embedded in a silicon chip, as reported in *Nature Communications*, has the potential to be a big part of the potentially trillion-dollar quantum computing manufacturing industry.

The World Economic Forum estimated in 2022 that global quantum investment, at $35.5 billion, was still growing, with no one technology a clear leader, due to the many challenges of manipulating and connecting entities as small as qubits.

Professor David Jamieson (left) and Dr Malwin Jakob in the Colutron lab.

> *This is because we are one of a few implantation teams worldwide that has close ties with a qubit development team, which is a key to developing a seamless device process flow.*
>
> *—Dr Malwin Jakob, The University of Melbourne*

To be a leader in this race, the UNSW team need to have materials they can rely on, and a seamless workflow. Together, HIA and UNSW teams are continually developing processes that leverage the facilities at the two sites.

Their experiments entail more than just implantation: to make a successful qubit the HIA team need to be materials and nano-electronics specialists, so they can purify the raw material (silicon), implant the antimony qubits precisely, add built-in atomic detectors and isolators, and install the nano-electric circuitry that will deliver quantum information to the embedded atoms and finally receive the results of their calculations.

Work with such barely-perceptible signals is a constant battle against electrical noise, requiring careful design to isolate the whole device from the natural crackles and hum of electrical background noise in the silicon chip. They also had to develop an ultra-low noise amplifier to turn the nano-scale whispers of qubits into signals strong enough for conventional electronics to work with.

The result is a device of exquisite precision that would have been considered impossible a decade ago.

"We are one of a few implantation teams worldwide that has close ties with a qubit development team, which is a key to developing a seamless device process flow," Dr Jakob says.

A. M. Jakob et al., "Deterministic Shallow Dopant Implantation in Silicon with Detection Confidence Upper-Bound to 99.85% by Ion–Solid Interactions," Advanced Materials, vol. 34, no. 3, p. 2103235, 2022. DOI: 10.1002/adma.202103235.

I. Fernández de Fuentes et al., "Navigating the 16-dimensional Hilbert space of a high-spin donor qudit with electric and magnetic fields," Nat Commun, vol. 15, no. 1, p. 1380, Feb. 2024. DOI: 10.1038/s41467-024-45368-y.

D. Holmes et al., "Improved Placement Precision of Donor Spin Qubits in Silicon using Molecule Ion Implantation," Advanced Quantum Technologies, vol. 7, no. 3, p. 2300316, 2024. DOI: 10.1002/qute.202300316.

SPACE TECHNOLOGY

Empowering Australia's space industry

The Heavy Ion Accelerator Facility team named the Academic Research Team of the Year finalist at the 2024 Australian Space Awards.

Space is a harsh place. On Earth, we're protected from extreme radiation by our atmosphere and magnetic field. Spacecraft don't have this protection and are highly vulnerable to radiation damage: one rogue particle in the wrong place at the wrong time can lead to catastrophic mission failure.

HIA is taking a leading role in making space missions safer thanks to new testing facilities. Testing space payloads, components and electronics before they are launched into space helps make missions more successful. However, until recently, Australia lacked the facilities to conduct this kind of testing on home soil, and facilities overseas were struggling to meet demand.

Often, that meant testing simply didn't happen, or spacecraft weren't built to withstand the space environment. That resulted in repeated mission failures, especially for the kinds of smaller satellites that are the focus of Australia's space industry: some estimates suggest roughly 40 per cent of these fail upon launch or shortly afterwards.

> *"Rather than just launching spacecraft into space and hoping for the best, we can now start testing to much higher standards to find vulnerabilities before launch.*
>
> *—Dr Lauren Bezzina, Industry Engagement Fellow at HIAF*

The idea for a dedicated beamline for space testing was born from discussions with CSIRO and Defence Science and Technology Group (DSTG), who approached HIA to ask about the kinds of testing they needed. Some initial ad hoc solutions proved so successful that they inspired a purpose-built capability to enable testing into the future.

Funded by a $2.5 million grant from the Australian Space Agency's Space Infrastructure Fund, the Space Irradiation Beamline (HIAF-SIBL) was officially launched on 15 August 2023 at the ANU Heavy Ion Accelerator Facility. It's the 11th beamline available at the facility and offers the highest-energy heavy ion space radiation testing facility in Australia. The ongoing operation of the HIAF-SIBL is enabled by the Heavy Ion Accelerators (HIA) project funded through the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS).

In contrast to the other beamlines available at HIAF, which focus intense beams onto very small areas, the space beamline has a wide cross-section covering 40 mm in diameter and a larger range of beam intensities. That gives users flexibility to test devices of variable shapes and sizes, but also the precision to pinpoint exactly where an electronic device might be vulnerable to radiation—right down to which specific component on a tiny electronic chip.

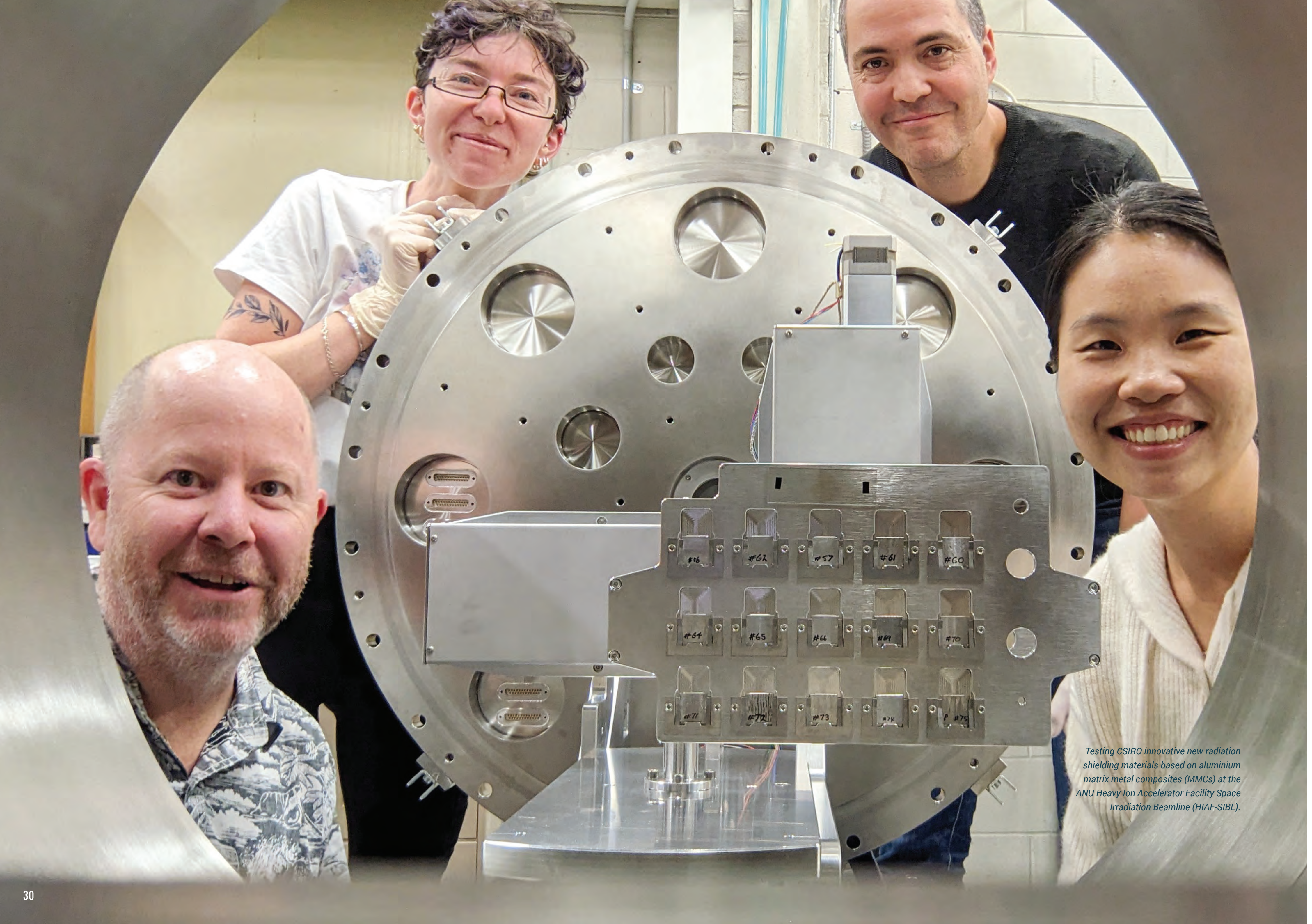
It fills a much-needed gap to bring space radiation testing capability onto Australian soil and complements other Australian facilities as part of the National Space Qualification Network.

"Suddenly, this network of space testing is available in Australia that's never been available before," says Dr Lauren Bezzina, Industry Engagement Fellow at HIAF.

"Rather than just launching spacecraft into space and hoping for the best, we can now start testing to much higher standards to find vulnerabilities before launch."

That paves the way to more Australian-made technologies in space and faster innovations in materials science—and HIAF's newest beamline is already enabling some exciting developments.

The target chamber of the Heavy Ion Accelerator Facility Space Irradiation Beamline (HIAF-SIBL).



Testing CSIRO innovative new radiation shielding materials based on aluminium matrix metal composites (MMCs) at the ANU Heavy Ion Accelerator Facility Space Irradiation Beamline (HIAF-SIBL).

SPACE TECHNOLOGY

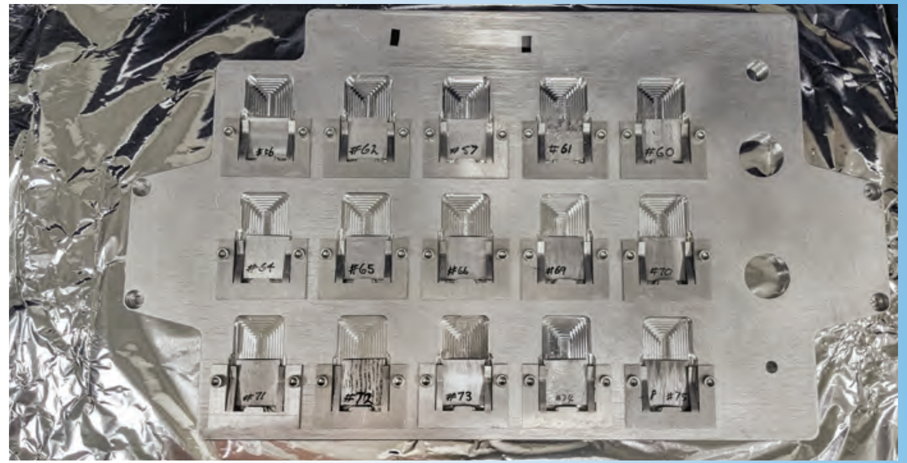
CASE STUDY

Taking new shielding materials from concept to reality

Spacecraft electronics need effective shielding materials to keep them safe from the intense radiation environment in space. Researchers from CSIRO have been developing innovative new radiation shielding materials based on aluminium matrix metal composites (MMCs), which are more effective and resilient to the hazards of space environments.

The new material aims to provide better protection against space radiation compared to traditional space-grade aluminium alloys without adding extra weight or bulk to a spacecraft. The material can also be easily produced in large quantities with a process called friction stir additive mixing, which helps to evenly mix ceramic and metallic alloy particles very tightly together.

The high concentration of particles and refined structure of the material makes it more effective at shielding electronics from harmful radiation while also being harder—similar to some steels—and more resilient. Tests at HIAF have shown that the shielding performance of CSIRO's MMCs surpasses that of conventional space-grade aluminium alloys, as reported in the *Journal of Materials Engineering and Performance.*



Aluminium matrix metal composites (MMCs) samples mounted in the HIAF-SIBL materials test frame.

Dr Daniel Liang, materials scientist at CSIRO, says it was far cheaper and faster to test the materials at HIAF compared to their previous testing methods, which involved sending samples to the USA.

"Sending the sample overseas for testing is incredibly time consuming to process through regulatory and compliance procedures. It can then be many months before a report with results is issued," he says.

"It was a lot simpler to use a local facility. An added bonus was that the HIAF staff were able to help us analyse our results."

"We could work together as a team to combine our materials science knowledge with their physics knowledge, and problem-solve together."

The CSIRO team are looking forward to testing their new materials in low Earth orbit.

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Yan, S et al., 2022. Multifunctional Metal Matrix Composites by Friction Stir Additive Manufacturing, J. of Materi Eng and Perform 31, 6183–6195. DOI: 10.1007/s11665-022-07114-7

SPACE TECHNOLOGY

CASE STUDY

Binar CubeSats pioneer radiation detection technology

Mr Jacob Cook in the Binar labs at Curtin University.

CubeSats—small satellites roughly 10cm in size—punch above their weight when it comes to space research. Their low weight and affordable components make space research cheaper and more accessible, and they are especially popular for Australian research institutions.

The Binar space program, based at Western Australia's Curtin University, specialises in CubeSats running on a single circuit board for space research and exploration. Researchers have recently launched the Binar 2, 3 and 4 missions, which will test innovative new materials and technologies.

One of these new materials is a matrix metal composite (MMC) developed by CSIRO, which is designed to enhance radiation shielding for spacecraft. While initial tests of this material at HIAF in 2022 showed it was more effective than other conventional materials, the Binar missions in 2024 will provide the first opportunity to test the material in space.

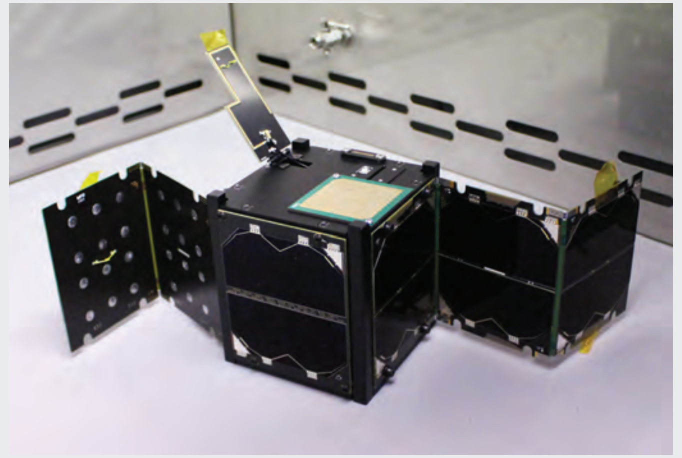
To do this, the Binar team developed a suite of three sensors for a radiation detector, specifically tailored to integrate with the Binar CubeSat platform, that would give them the data they need about the new shielding material after launch. The detector actively monitors the radiation environment within the spacecraft's shielding, providing valuable insights into the effectiveness of the new shielding material compared to traditional aluminium in a space environment.

Before launching into orbit, it was crucial to understand the payload's response to known radiation exposure levels. That's where the HIAF space irradiation beamline came into play, creating a simulated space environment by mimicking the proton radiation levels encountered in low Earth orbit.

The particle energies required for this testing were so high that only the capabilities of HIAF could meet the challenge. "We could not have performed the testing at any other facility in Australia," says Jacob Cook, Instrumentation Engineer for the Binar Space Program.

The testing provided crucial data needed to understand how the detector would perform throughout the mission's lifetime, ultimately determining the mission's success.

The information gathered from this mission will not only aid in refining CSIRO's radiation shielding material but also contribute to advancing our understanding of space radiation effects on satellite instrumentation.



The Binar CubeSat qualification model is used to test commands on Earth before sending them to the satellites in space.

FEATURED PROFILE

Mr Jacob Cook

Instrumentation Engineer, Binar space program, Curtin University

As an eight-year-old, Jacob Cook saw a rover land on Mars and decided there and then he wanted to send something into space. Pursuing that dream led him to studying electronics and finally becoming an engineer with Binar.

So when Binar launched their first satellite in 2021 containing instruments he had helped develop, it was a dream come true. A SpaceX rocket ferried the satellite to astronauts on the International Space Station, who deployed the cubic unit, a mere 10 cm per side, into orbit.

"It was a pretty weird feeling seeing the photos of it being deployed—that's the last time I'll see that satellite!" Cook says.

The CubeSat sent back pings of data before burning up on re-entry almost exactly a year later.

With that success under their belt, Binar is set to launch another three satellites, testing enhanced shielding, developed by CSIRO. Cook's tiny instruments are central to the project, monitoring how much of the different types of space radiation gets through the shield.

And to test it worked before launch, he came to the new space testing beamline at HIAF.

"It was nerve-wracking turning on my instruments for the first time! There was a bit of relief when they responded the way they are supposed to."

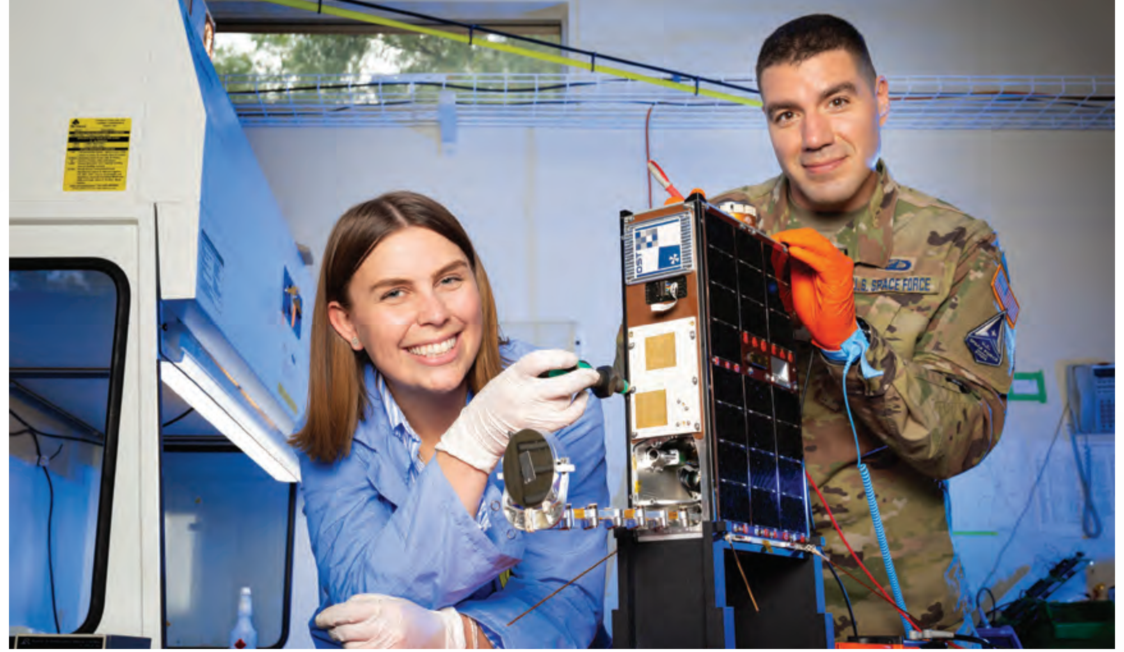
In the end they finished the allotted experiments with time to spare, and then stayed late into the night improvising a whole lot of extra measurements irradiating different parts of the unit.

"My boss was really pleased—the staff at HIA were professional and so flexible, able to accommodate our requests on the fly," Cook says.

SPACE TECHNOLOGY

CASE STUDY

Liquid lenses for better satellite monitoring



DSTG scientist Franke Agenbag and US Major Chris Rocker with the Buccaneer CubeSat.

The Heavy Ion Accelerator Facility's Space Irradiation Beamline (HIAF-SIBL), hosted at The Australian National University, has played a vital role in an exciting first for the Australian space industry: the first time that Australian space radiation testing has been done on an Australian space payload.

The occasion? Testing innovative liquid lenses that enable a satellite to take a selfie.

Cameras on satellites, including CubeSats, are nothing new. They're typically included to take photos of the Earth and monitor climate patterns. However, Defence Science and Technology Group (DSTG) is about to send a satellite into orbit with a camera that also looks back at the satellite itself.

DSTG's newest satellite, called the Buccaneer Main Mission, includes a special deployable arm that can extend out and retract, and a rotatable mirror with two surfaces, one aimed towards Earth and the other at the satellite.

> *In space, if you have two metal components touching each other, they weld together and don't move, so focusing a lens by mechanically moving something is very difficult to do.*
>
> —Chris Peck, Defence Science and Technology Group

Making sure the satellite's key antennae deploy properly and stay stable is important for the mission to succeed, so DSTG made a unique piece of imaging equipment to look at the antennae and the satellite itself. Without it, there's no way to examine the satellite to check for failed antennae deployments, and damage from radiation, micro-meteorites or other space hazards.

However, the camera from that system also needs to focus on things much further away—like Earth. That wide range of focus brings some challenges in space.

"In space, if you have two metal components touching each other, they weld together and don't move, so focusing a lens by mechanically moving something is very difficult to do," explains Chris Peck, who leads resilient spacecraft development at DSTG.

The solution was to use a liquid lens: a cell with two liquids that change shape when a voltage is applied, which changes the lens's focus without any moving parts. The lens can adjust focus quickly and precisely, allowing it to focus on faraway objects like Earth or nearby objects like the satellite itself.

Liquid lenses weren't initially designed for space, but they have a lot of benefits. They provide a wide range of focus with precise adjustment in a small space and are relatively cheap and robust, with no mechanical parts to break.

Since it's never been used in space before, DSTG had to thoroughly test their liquid lens technology to make sure it could handle the harsh conditions.

To see how the lens reacts to damage from radiation, different lens samples were exposed to increasing intensities of high-energy proton beams at HIAF, the only facility in Australia that can produce such beams.

"HIAF is the only place we could go to do this level of testing at the energies we needed," Peck says.

None of the lenses showed any degradation in their optical performance after the tests, indicating they could handle the kinds of radiation they would be exposed to during the mission—good news for DSTG and the future of the Australian space industry alike.

Buccaneer CubeSat, Defence Science and Technology Group.

From student to space engineer: finding new solutions for Australian space tech

FEATURED PROFILE

Franke Agenbag

Space Systems Engineer at the Defence Science and Technology Group.

When Franke Agenbag first learned how radiation can damage electronic components onboard spacecraft, and how challenging it is to diagnose and fix problems after launch, she knew there had to be a better solution.

"Currently, we pre-emptively try to avoid radiation damage with shielding or hardening components, but these have limitations, like being too heavy or expensive," she says.

Agenbag started her career in the Australian space sector by pursuing a Bachelor's degree in Electrical and Mechatronic Engineering from the University of South Australia. She studied liquid lens technology, as part of her Honours research—the results of which will launch onboard the Defence, Science & Technology Group's (DSTG) Buccaneer Main Mission CubeSat.

> *HIAF is able to accommodate Single Event Effect testing, and can test the effectiveness of a novel solution on the ground by emulating the conditions in space.*
>
> *—Franke Agenbag, Space Systems Engineer at DSTG*

"I realised there was no modular system available that can respond autonomously and in real time, detecting potentially damaging events before they impact the spacecraft and taking action to prevent or fix problems."

She decided to dig deeper into the worlds of astrophysics and electronic engineering to find a solution—and the results of her work are set to be launched into space.

Now, Agenbag works for DSTG as a Space Systems Engineer, while pursuing her doctorate at the University of South Australia. Her PhD research aims to investigate in-orbit mitigation of radiation effects in real time.

"Electronics on spacecraft can be damaged instantly by a single charged particle event, or cumulatively over time after too much radiation exposure in space. We need systems that can detect and fix problems autonomously to keep spacecraft reliable and operational, as radiation damage often disrupts missions," she says.

DSTG, the University of South Australia, and SmartSat CRC are working together to develop a modular system that can automatically detect, analyse and respond to radiation events in real time.

The ANU Heavy Ion Accelerator Facility plays a crucial role in her research by enabling future testing of Agenbag's payload—testing that has previously only been available at overseas facilities such as the NASA Space Radiation Laboratory.

"HIAF is able to accommodate Single Event Effect (SEE) testing and can test the effectiveness of a novel solution on the ground by emulating the conditions in space," Agenbag explains.

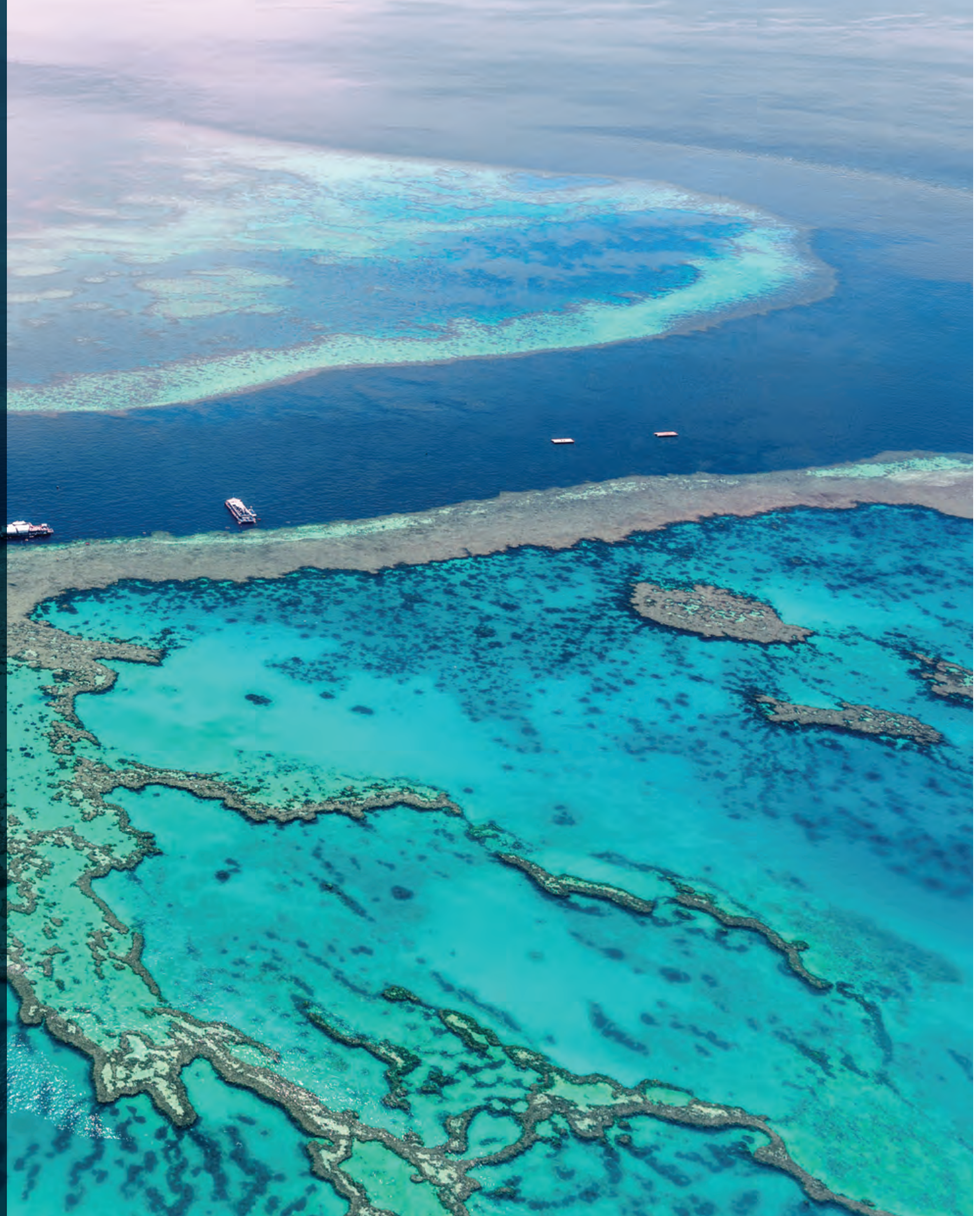
Agenbag says she enjoys working with industry partners who can bring new perspectives to her research.

"Collaborating with extremely intelligent people has been fascinating. Working in the space and defence sector has been remarkable; every day brings a new set of exciting and interesting challenges."

DSTG scientists Alex McDonald and Franke Agenbag working on the Buccaneer CubeSat.

ENVIRONMENT AND CLIMATE

How nuclear physics helps protect the environment



Nuclear physics probably isn't the first thing that comes to mind when most people think about environmental protection. Yet researchers at the ANU Heavy Ion Accelerator Facility have helped protect the Great Barrier Reef from pollution, assessed bush foods at sites impacted by uranium mining, and mapped precious underground water sources.

Researchers like Associate Professor Stephen Tims and his team use HIAF's ultra-sensitive accelerator mass spectrometry (AMS) "atom counting" methods to track, trace and date our resources using rare radioactive isotopes in the environment.

Accurately identifying the source and movement of pollutants from activities like mining—or even nuclear weapons testing from the 1950s—helps scientists to better understand key ecological processes and advise on action to protect or restore contaminated environments.

In the 1950s and 60s, nuclear weapons tests around the globe released radioactive material into the atmosphere, which eventually fell back to Earth. Miniscule quantities of these isotopes remain in the environment, attached to soil particles.

These isotopes proved to be vital in studying excess sediment polluting the Great Barrier Reef. Associate Professor Tims's team measured plutonium isotope concentrations in surface soil and river sediment from different land uses and locations. Plutonium is a radioactive element that didn't exist on Earth before the start of the nuclear era, making it an ideal chronological marker.

"About 25 years ago, nuclear physicists at HIAF pioneered measuring plutonium isotopes with the accelerator, enabling measurements at ultra-trace levels needed—that hadn't really been done before, anywhere in the world," says Associate Professor Tims.

"Now, we can use that to track soil erosion and sediment movement, and devise plans that minimise the flow of sediment onto the Great Barrier Reef, because we know where to take action to prevent it."

Meanwhile, atom-counting techniques are being deployed elsewhere in the country to monitor the environmental and human health impacts of uranium mining, helping to guide environmental rehabilitation and monitor for potential radioactivity exposure.

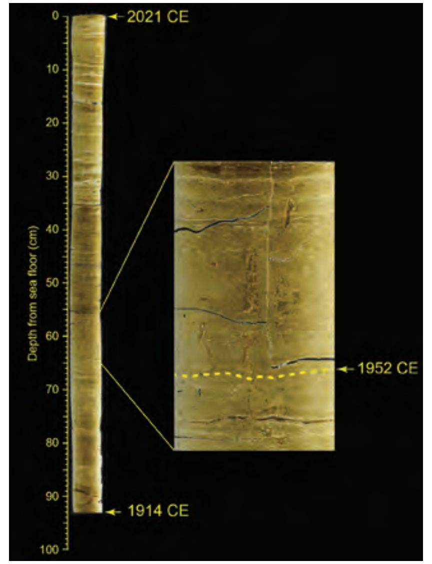
It's vitally important work for local Aboriginal communities living in and around current and former mine sites. Researchers are measuring levels of radioactivity in bush foods and native plants and animals in areas of cultural and environmental significance.

PhD student Peter Medley has developed the methods needed to assess some of the most difficult radioactive atoms to measure. He has been able to quantify their presence in a selection of bush foods, with results to be included in his thesis due to be submitted in late 2024.

HIAF's capabilities are also being used for environmental monitoring around the globe including at sites in Canada, the USA and Japan. The facilities at ANU have the best sensitivity in the world for measuring a rare natural radioisotope of chlorine that falls to Earth in rain, and then seeps into groundwater.

Measuring this isotope helps researchers to determine groundwater age and map out where it flows, which has applications in water resource and nuclear waste management.

"We've been working with many international scientists to make these precision measurements for almost 30 years, and it's only possible because of the facilities we have at HIAF," says Associate Professor Tims.

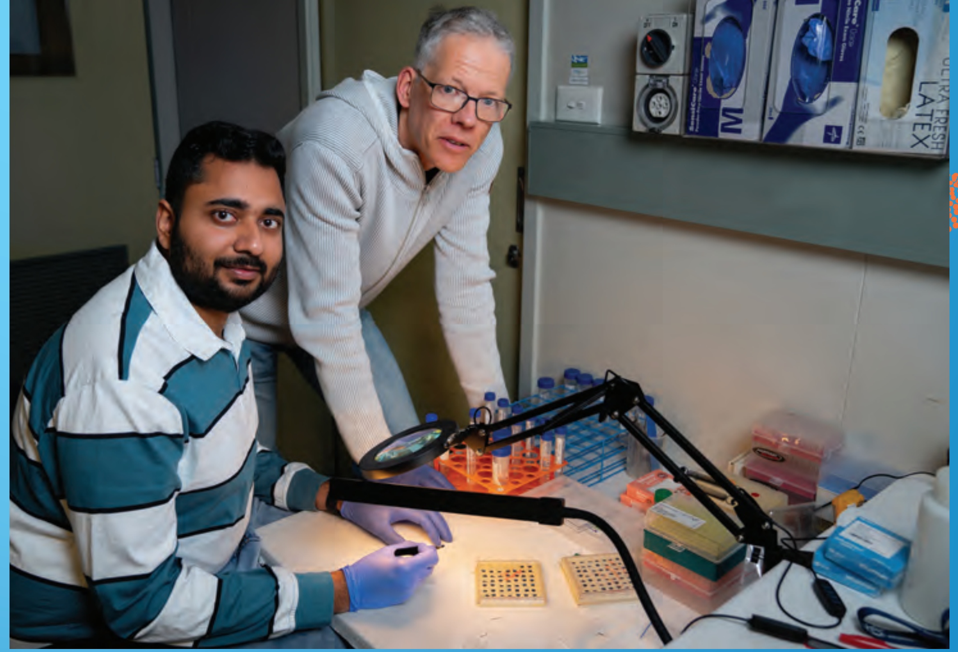


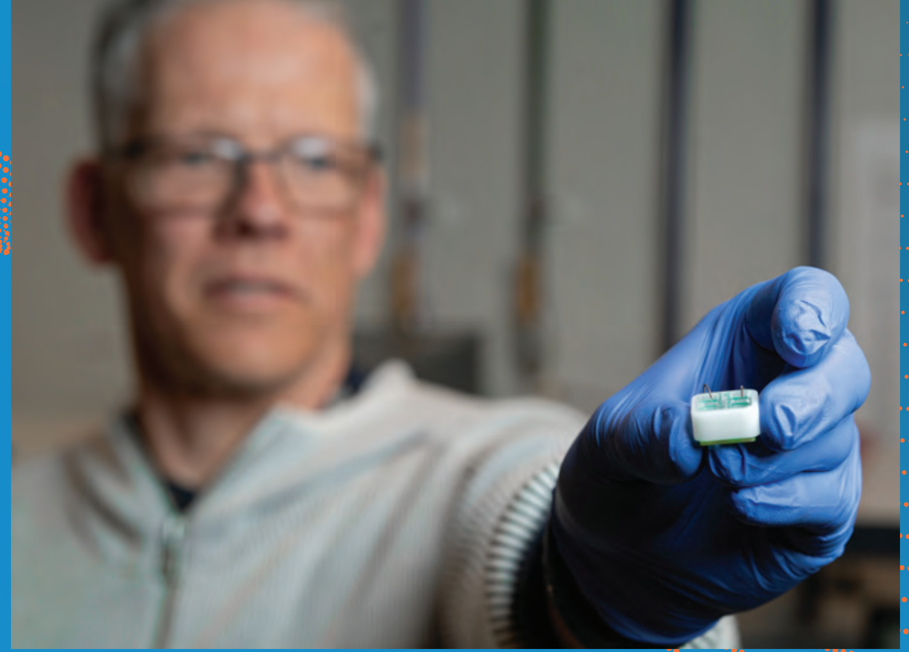
Sediment core measured at HIAF showing the first appearance of plutonium in 1952, Beppu Bay, Japan.
IMAGE CREDIT: M. Kuwae, Ehime University, Japan.

MEDICAL RESEARCH

CASE STUDY

Picking out proteins with pore-powered science





Blasting holes through pieces of glass sounds like a pretty destructive way to employ a 15-million-volt accelerator, but Professor Patrick Kluth insists he is doing it for good reasons.

"Pores like these in silicon dioxide can be used for bio-sensing: to find and filter proteins. They also can be used for micro-fluidic systems, for example as pumps that deliver precise amounts of a drug, or even to generate power osmotically," says Professor Kluth, from ANU Research School of Physics.

Professor Kluth and his team have already demonstrated remarkable speeds at filtering proteins from blood, using a pore around 1,000 times smaller than a human hair, coupled with analysis done by an artificial intelligence (AI) algorithm.

> *"HIAF's ion bombardment can be controlled with exquisite accuracy to create tracks through the membrane that can generate a wide variety of pore shapes after subsequent etching.*
>
> *–Professor Patrick Kluth, ANU Research School of Physics*

They have set their sights on neuro-degenerative diseases: initial tests suggest they could detect proteins related to Alzheimer's disease, Parkinson's disease, multiple sclerosis and amyotrophic lateral sclerosis (ALS), up to 20 years before symptoms show.

It's vital research: Alzheimer's disease is the second leading cause of death for Australians. It's estimated around 300,000 Australians are living with the disease, with that number expected to more than double by 2058.

"Current methods to diagnose Alzheimer's involve invasive and expensive hospital procedures such as a lumbar puncture," Professor Kluth says.

"We hope to replace this with a simple test by GPs, needing only a small blood sample, eliminating the need for a hospital visit—especially convenient for people living in remote areas. Better still, patients could receive their results in near real time."

Recently the team set a record, measuring 1.8 million proteins through a single 10-nanometre pore. Initial experiments used pores created with electrical discharge—not created at HIAF—but the team are developing a fabrication technique at HIAF that will lead to more stable devices and more accurate results.

"HIAF's ion bombardment can be controlled with exquisite accuracy to create tracks through the membrane that can generate a wide variety of pore shapes after subsequent etching," Professor Kluth says.

To identify proteins, the filter is placed between two chambers of conducting solution containing the sample. A current through the solutions creates flow: this current dips as individual proteins pass through the pores, momentarily blocking them.

Each protein's dip has a unique signature, which the AI algorithm can use to find evidence of disease, amongst the tens of thousands of proteins in blood—a task that current technology cannot achieve.

The team have found conical nanopores in thicker membranes yield best results—a slower and more detailed current-dip profile. The goal is to create a filter with only one hole, for maximum detail, which Professor Kluth hopes to soon achieve with HIAF's Space Irradiation Beamline, operating at extremely low beam current.

The flexibility of the Space Irradiation Beamline would then enable automated production of up to 50 single-pore membranes in a single run.

The research has attracted much interest, with a grant of computer equipment from Nvidia, and support from medical device company MicroDiag, who have partnered with the researchers for the international patent application. Other partners have included GSI Helmholtz Center for Heavy Ion Research in Germany, the Australian National Fabrication Facility and machine learning specialists Thaum.

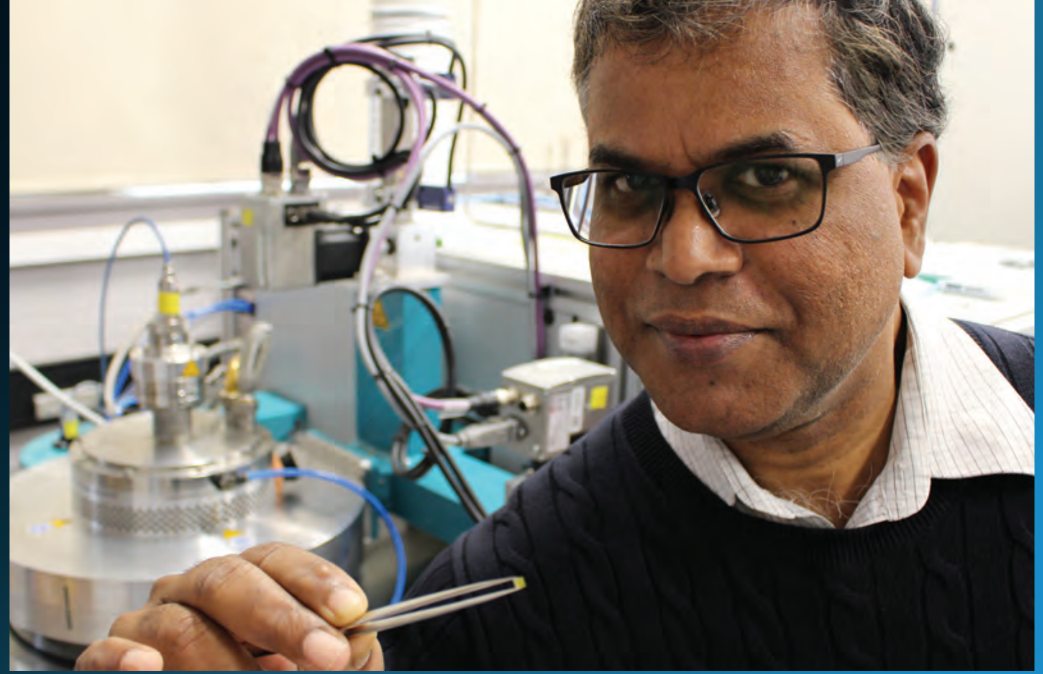
S. Dutt, H. Shao, B. Karawdeniya, Y. M. N. D. Y. Bandara, E. Daskalaki, H. Suominen, P. Kluth, High Accuracy Protein Identification: Fusion of Solid-State Nanopore Sensing and Machine Learning. Small Methods 2023, 7, 2300676. https://doi.org/10.1002/smtd.202300676

IMAGES: PhD student Shankar Dutt (far left) and Professor Patrick Kluth show off their samples in the labs at the ANU Research School of Physics.

MEDICAL RESEARCH

CASE STUDY

The true value of a pure diamond



Dr Kumar Ganesan manipulates diamonds at the HIA's Colutron facility at The University of Melbourne.

Professor Steven Prawer wants everybody to have diamonds. Not for jewellery, but for quantum computers and health monitors.

The same clarity and purity that make diamonds sought-after for jewellery could enable efficient laser guidance, measurement of faint flashes from a quantum calculation, or identification of individual strands of DNA or proteins from a drop of blood to screen for cancer.

Beyond their clarity, a specific defect in a diamond's lattice can give rise to remarkable quantum properties. The defect, known as an NV centre, occurs when a nitrogen atom is substituted for a carbon and sits alongside a vacancy in the lattice.

"It's got lovely properties—you can see a single atom shine brightly in a diamond, and tell what its quantum spin is, and manipulate it," says Professor Prawer from the School of Physics, The University of Melbourne.

Unlike silicon, quantum computers based on diamond would not need to be cooled to cryogenic temperatures—a major boon in the race for dominance in the quantum computing industry, which promises to be a multi-billion-dollar concern.

And diamond could be important in another billion-dollar industry. With the cost of health care skyrocketing, Professor Prawer says long-term investment in research into personalised, take-home, early-detection technology "is a no-brainer."

In the last decade, Professor Prawer and his team have honed a technique to carve shapes in diamond with ion implantation, using the Pelletron accelerator at The University of Melbourne.

They use the Pelletron to bombard diamond in precise patterns, converting the diamond to graphite that can be etched off with acid, leaving clean diamond nanostructures.

The bombardment damages the quantum properties of these nanostructures, but they can be used as a template for growing a thin layer of new diamond that is quantum active. The template is then removed using another ion bombardment technique, reactive ion etching, exposing the newly-grown diamond.

The result is an incredibly smooth layer, as thin as 250 nanometres. The team have also used a mosaic of large diamonds as seeds to create multiple copies, demonstrating that scaling up to industrial volumes is possible.

Professor Prawer sees these precisely-engineered diamond layers as the analogue of the metal and semiconductor electronic components that sit on a silicon chip around a silicon qubit. In a light-based quantum computer, diamond would be manufactured into shapes to trap and steer light around, carrying information to and from the qubits at the heart of the quantum processor.

"What we've done here is the missing element of the technology road map: how to capture the light and route it around," Professor Prawer says.

"This ion beam at HIA gives us an essential part of the diamond nanofabrication toolkit."

Professor Prawer also envisages sophisticated biological applications.

Tiny pores through a diamond layer could be used as sensors if they match the size of molecules produced by diseases, which might be in a drop of bodily fluid.

"You could detect the passage of a molecule, such as a protein or DNA through the pore with luminescence. The diamond NV centre is very sensitive—a magnetically tagged molecule would see a large signal.

"Imagine if we could use this to screen the entire population's health, say for cancer.

"If we're going to improve quality of care cost-effectively, we need to exploit advanced technology to make health care more focused on personalised medicine and prevention.

"We need to think differently!"

Dr Kumar Ganesan manipulates diamonds at the HIA's Colutron facility at The University of Melbourne.

FUNDAMENTAL PHYSICS

Unlocking stellar secrets: Investigating how heavy elements are formed

The origin of the heavy elements, from iron to uranium, remains as one of the great unanswered questions of physics. Dr Zuzana Slavkovska, a postdoctoral fellow at the ANU Research School of Physics, is one of the many scientists working to answer that question, or at least to find a missing piece (or two) from the puzzle.

To understand how these elements are formed, scientists need to know how probable certain nuclear reactions are under extreme environmental conditions, like those in stars, where temperatures are millions of degrees higher than on Earth. They rely on theoretical models and, with the right facilities capable of producing high-energy particle beams, experimental observations.

Dr Slavkovska is studying a key astrophysical process called the s-process. This process occurs in late stellar burning phases and is responsible for creating about half of the heavy elements beyond iron.

> *It's quite amazing to have this opportunity to do several steps in such a complex experiment in one place—preparing the samples, chemical processing of the irradiated samples, and then counting the reaction products—but that is possible at HIAF.*
>
> *—Dr Zuzana Slavkovska, ANU Research School of Physics*

There are two methods to measure reactions in the s-process: using a high-energy neutron beam and measuring how quickly neutrons travel over a certain distance (time-of-flight) or bombarding a sample with neutrons and then analysing the resulting reaction products with accelerator mass spectrometry (AMS).

For years, however, scientists have observed a systematic discrepancy between these two techniques, which Dr Slavkovska's team is investigating. "We believe we understand how this reaction works, but then when we use two different methods to observe what happens, the AMS method consistently produces results that are 10 to 15 percent different to the time-of-flight method," Dr Slavkovska says.

She performed an AMS measurement at the ANU Heavy Ion Accelerator Facility (HIAF) and obtained measurements of the number of the atoms produced with 2 per cent accuracy, which she described as "amazing".

The research, undertaken in collaboration with the Frankfurt Neutron Source (FRANZ) and the Helmholtz-Zentrum Dresden-Rossendorf in Germany, will improve our understanding of processes that occur in stellar environments.

It's not just the accelerator itself that played such a crucial role in Dr Slavkovska's research: the chemistry laboratories at HIAF were important, too. The labs provide researchers with a clean and well-equipped space to prepare and process samples free from contamination while staying on site.

"It's quite amazing to have this opportunity to do several steps in such a complex experiment in one place—preparing the samples, chemical processing of the irradiated samples, and then counting the reaction products—but that is possible at HIAF," says Dr Slavkovska.

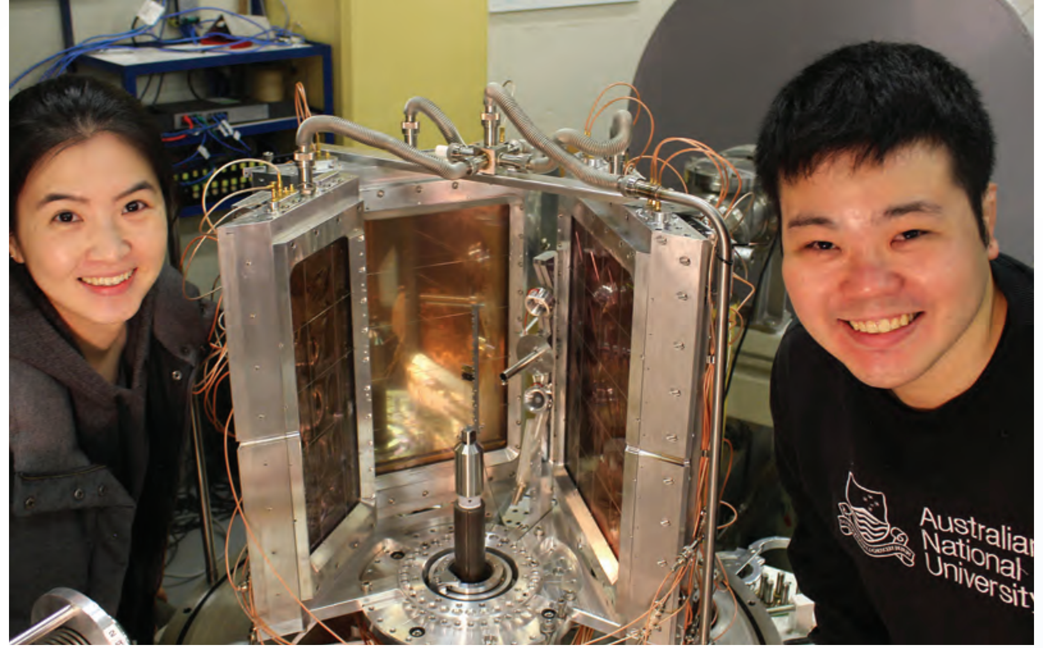
As well as contributing to vital fundamental physics research, Dr Slavkovska's work has implications for applied environmental science research. Techniques developed in the chemistry lab can analyse environmental samples like soil and water, while HIAF's accelerator advances and refines measurement methods.

"AMS is an astounding technique already, picking up individual atoms in samples with high precision," says Dr Slavkovska. "Now, we're pushing the limits of the technique to make it work even better!"

Ion source at the Heavy Ion Accelerator Facility.

FUNDAMENTAL PHYSICS

Putting together the pieces to make new superheavy elements



Dr Yun Jeung and Dr Taiki Tanaka with the CUBE detector system used in superheavy element research at the Heavy Ion accelerator Facility, ANU

The nuclear scientists in HIA are modern alchemists. They don't transform base metals into gold, they instead seek to transform lighter elements into the rarest elements in the universe, much rarer than gold: superheavy elements that have never been seen by humans before.

These modern alchemists have pushed the boundaries further than their forerunners could dream; four new elements were added to the Periodic Table in 2016. The landmark additions were made only after the new elements were created by a number of different collaborations—one of which involved HIA's Heavy Ion Accelerator Facility (HIAF) at ANU.

And now the quest continues to create even heavier elements, leveraging HIAF's unique combination of precise, high-energy beams and flexible, exquisitely sensitive fragment detectors.

Scientists make superheavy elements by slamming two lighter elements together. The challenge is that superheavies are so unstable they usually break apart during the formation process itself, which lasts only tens of zeptoseconds (10^{-21}s). On the rare occasions they do stick, superheavies survive at most seconds—often much less—before undergoing radioactive decay into lighter elements.

To work out the exact conditions to get superheavies to form—known as fusion—the scientists need to carefully analyse those collisions that didn't stick. Amazingly, during these zeptosecond connections, protons and neutrons whiz back and forth, and after the collision the two pieces emerge as different elements.

Except sometimes it's more than two pieces, it turns out.

Experiments at HIAF have indicated there are missing fragments flying out of these almost-fusion reactions. As well as literally a missing piece in the puzzle, these observations have solved a decades-long conceptual puzzle.

The conundrum surrounded the iconic element lead, the most stable heavy element. In collisions attempting to make superheavy elements using targets heavier than lead (radioactive actinide elements), a peak in the yield of the target-like elements is always observed at lead, with much fewer elements closer to the target mass.

In contrast, with targets lighter than lead, several experiments at ANU had yielded no peak, just a smoothly increasing distribution up to the target mass.

In an effort to resolve the two results, HIA's Professor David Hinde wanted to test a suggestion from a paper from the 1980s that had never received much attention. Because the actinide elements are themselves quite unstable, the paper reasoned, collision products heavier than lead might break up by nuclear fission, resulting in three fragments.

Going back to their existing data taken at HIAF, Professor Hinde's team found there were three-fragment outcomes amongst the data and they matched the missing yields of elements heavier than lead.

The next step is to develop a new analysis tool to perform a complete analysis of these three-fragment events to see if the extra-stable lead plays any role in how fusion forms superheavy elements.

"The current result ties decades of measurements together quite satisfactorily," Professor Hinde said. "The new analysis will be completely decisive."

"It changes what's important in the quantum dynamics of fusion, which will change the models, and help us make better predictions of how to create still heavier elements on Earth."

> *It changes what's important in the quantum dynamics of fusion, which will change the models, and help us make better predictions of how to create still heavier elements on Earth.*
>
> *—Professor David Hinde, Heavy Ion Accelerators*

Professor David Hinde setting up the accelerator beamline before an experiment.

FUNDAMENTAL PHYSICS

HIAF and Los Alamos join forces to enhance dark matter detector precision

Simulating 100 million years of cosmic ray exposure is, quite literally, all in a day's work for ANU partner Los Alamos National Laboratory in the United States.

This data, measured at their Los Alamos Neutron Science Center (LANSCE), in collaboration with the ANU Heavy Ion Accelerator Facility, has played a vital role in improving our understanding of the nuclear physics that underpins the search for elusive dark matter.

It was all made possible thanks to a formal partnership between the two institutions that was announced in October 2023. The partnership enables researchers and PhD students to access both world-leading facilities, including the expertise of their staff, while undertaking research projects and hands-on training in safely using nuclear science and technologies.

Dr Yi Yi Zhong was one of those PhD students. Her research, supported by the ARC Centre of Excellence for Dark Matter Particle Physics, explored how cosmic rays interact with sodium iodide crystals, which are used in highly specialised equipment designed to detect dark matter.

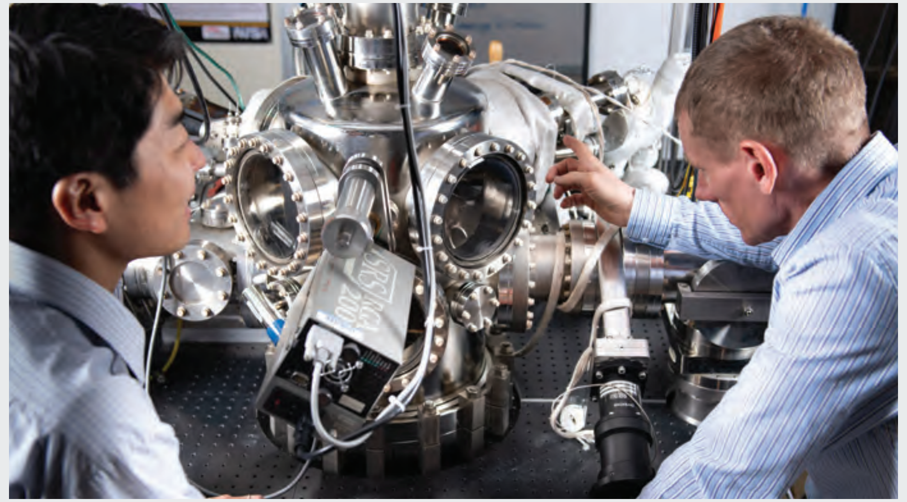
Earth's surface is constantly bombarded by cosmic rays, which can create small amounts of radioactive materials when they interact with stable materials. It's hard to predict how much of these radioactive materials will be produced, as different theoretical models and existing data sets give very different results.

However, understanding the precise rates of radioactive particle production is crucial for dark matter detection. Scientists need to know exactly how much radioactivity has been introduced into detector materials before they're placed in dark matter detector equipment located deep underground.

"If we want to search for dark matter, we need very sensitive detectors, and we need to understand very precisely how they work," says Dr Lindsey Bignell, Research Fellow at the ANU Research School of Physics and ARC Centre of Excellence for Dark Matter Particle Physics.

The project used the ICE House Flight Path 30L at the Los Alamos LANSCE facility. The energy of the neutron beam mimics the effects of cosmic rays hitting Earth's atmosphere, but at much higher intensities (over a million times higher). Researchers used this to simulate 100 million years of cosmic ray exposure in a sodium iodide crystal, creating various isotopes, with iodine-124 being especially important for calibrating detection efficiency.

IMAGE CREDIT: Los Alamos National Laboratory, aerial photo.



However, using existing nuclear data for iodine-124 led to inconsistencies, suggesting that the data might be incorrect. Researchers used the facilities at HIAF to produce the isotope they needed so they could take more detailed measurements supporting the work already undertaken at Los Alamos.

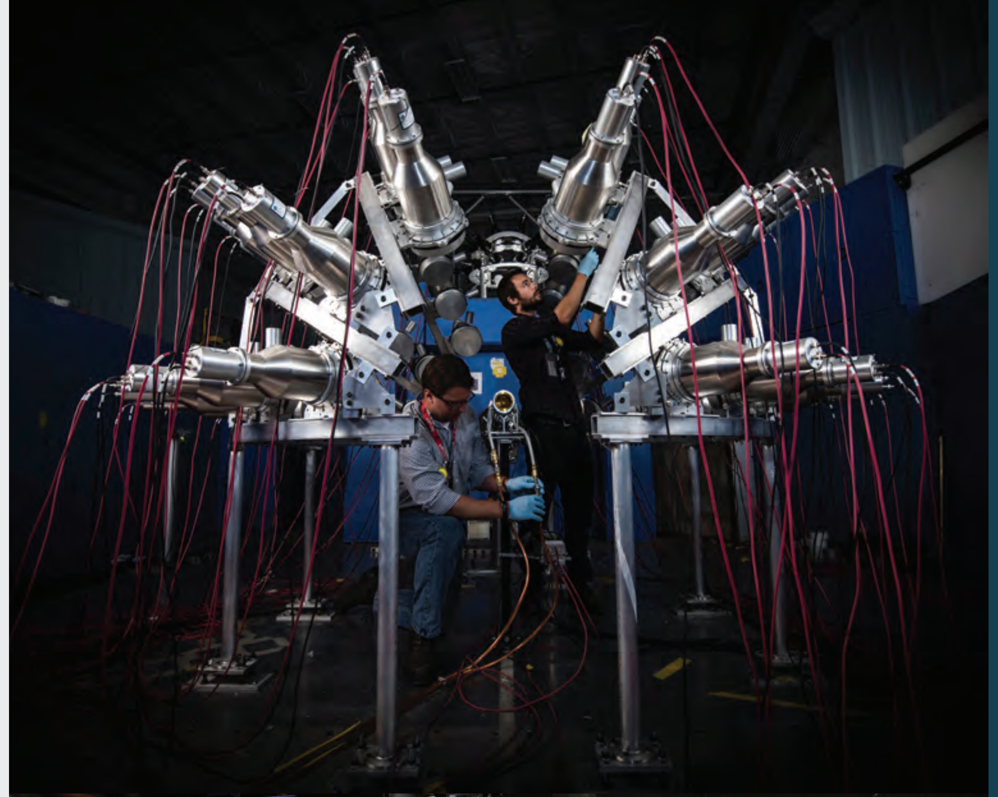
The research was truly collaborative: LANSCE's neutron source was vital to irradiate the crystal, but Dr Zhong needed HIAF's high-precision capabilities to produce the target isotope efficiently and take detailed measurements.

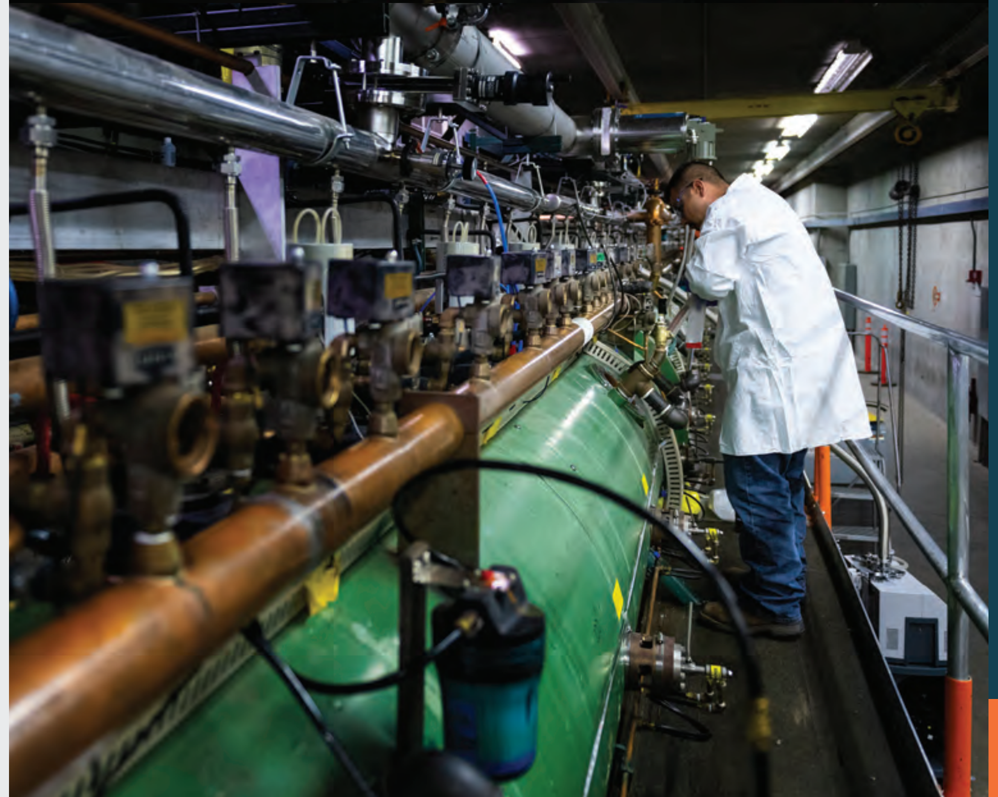
"No other Australian university has the same level of technical capability, both in facilities and staff, that we have at HIAF," said Dr Bignell. "That's a big part of what we bring to all our collaborations with other institutions."

The work has already resulted in one publication in nuclear physics journal *Physical Review D*, with a second publication on the way, and both results are also reported in Dr Zhong's thesis. She's now exploring postgraduate opportunities in Australia and overseas.

R. Saldanha et al., "Cosmogenic activation of sodium iodide," Phys. Rev. D, vol. 107, no. 2, p.022006, Jan. 2023. DOI: 10.1103/PhysRevD.107.022006.

IMAGES: Los Alamos Neutron Science Center (LANSCE) tube linac and other laboratories.





HIGHER EDUCATION AND TRAINING

Working together to learn how nuclei stick together

In 2013 a group of US researchers travelled halfway around the world to do a set of experiments at ANU.

Despite being from a world-leading nuclear physics facility at Michigan State University (MSU), the best place for the experiments they needed—studying a series of closely-related chromium nuclei with different numbers of neutrons—was in Canberra, at the Heavy Ion Accelerator Facility (HIAF).

They needed HIAF's combination of a high-energy beam, and the world's most precise collision detector, called CUBE, plus the expertise of the researchers and technicians who know how to run it.

The experiments were a success, a paper was published, and a relationship was born.

Over the ensuing decade there has been regular traffic of students and staff between HIAF and MSU's National Superconducting Cyclotron Laboratory, which became the Facility for Rare Isotope Beams (FRIB).

More than a dozen individuals in numerous separate visits, and three MSU PhD students, have taken all their data at HIAF.

Dr Kaitlin Cook says the complementarity between the two facilities is what has made for such a fruitful collaboration. FRIB is the world's highest power accelerator of radioactive ions, where HIAF is pre-eminent in experiments with stable isotopes of every kind: from the lightest, hydrogen, up to lead.

The next collaborative project is looking at the collisions that make superheavy elements, through fusion. Or rather, that almost make superheavies, but instead break apart after connecting briefly, a process called quasi-fission.

Dr Kaitlin Cook with an ANU Research School of Physics student.

Dr Kaitlin Cook with collaborators at Michigan State University, East Lansing, Michigan, USA

A big goal of superheavy element research is to make more neutron-rich superheavy isotopes. This is because they are thought to be much more stable than those discovered so far. But to make them, you need to use more neutron-rich beams. These beams are radioactive. Hence a collaboration, measuring reactions with stable isotopes at ANU, and comparing to reactions with unstable isotopes at FRIB is beneficial, says Dr Cook.

"It's only by doing mixed stable-radioactive beam experiments that we can really push the state of the art forward, it gives us fundamental physical understanding.

"With a radioactive beam, we can go way out away from stability, with lots of neutrons—it's never been possible before. Will the success of fusion go right up?

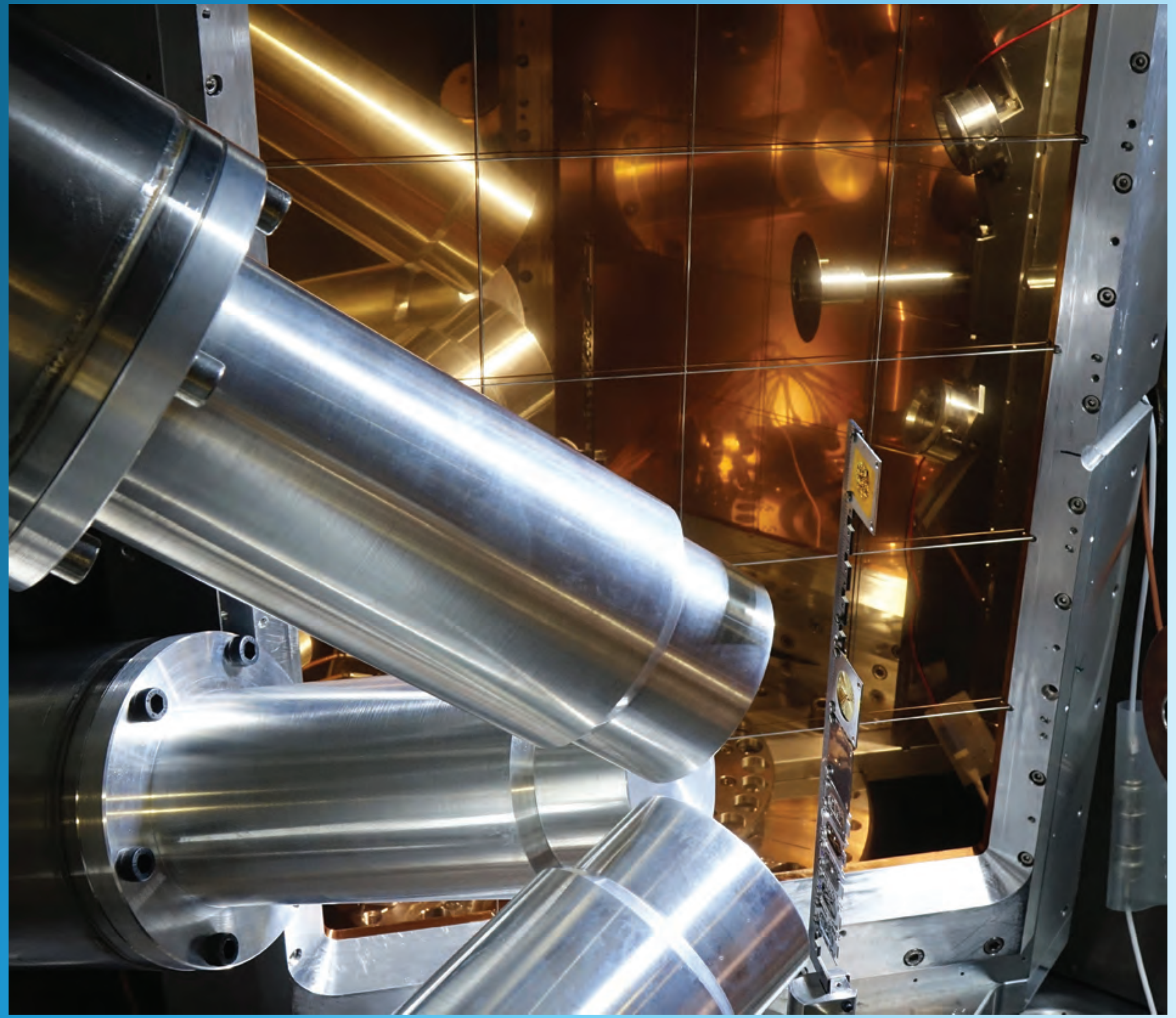
"FRIB have a wider palette of isotopes, but, because their beams are radioactive, their intensity is about a million times lower than ours, so their measurements can never be as precise as ours.

"We have a beam that is intense, and precisely located in energy, time and position. And CUBE is the best detector in the world for doing this: our measurements are at the frontier of precision.

"This collaboration is an important way to push forward on how to make superheavies."

The collaboration will give Australian students at HIAF an education at the centre of cutting-edge science, Dr Cook says.

"That's a great opportunity—but more importantly, the data we will obtain will be important education for the worldwide nuclear community."



CUBE fission detector system, ANU Research School of Physics.

K. Hammerton et al., "Reduced quasifission competition in fusion reactions forming neutron-rich heavy elements," Phys. Rev. C, vol. 91, no. 4, p. 041602, Apr. 2015. DOI: 10.1103/PhysRevC.91.041602

HIGHER EDUCATION AND TRAINING

CASE STUDY

ANU experts training future leaders in the Asia-Pacific region

Researchers from the Heavy Ion Accelerator Facility at ANU are sharing nuclear science knowledge and expertise with fellow nations in the Asia-Pacific region, training new leaders and educating the next generation of nuclear scientists.

Most recently, the International Atomic Energy Agency (IAEA) approached ANU staff to participate in a Technical Cooperation Project in Asia and the Pacific, to assist with building capacity and sharing knowledge in Cambodia.

ANU staff were approached thanks to their internationally-recognised excellence in nuclear science research and education. Their prior experience engaging with other nations in the region—Myanmar in 2017, and Timor-Leste in 2018—meant that they were "a natural fit" for the project, according to Professor Greg Lane from the ANU Research School of Physics.

"There's a need for nuclear science expertise to expand across the Asia-Pacific region, but local knowledge in some countries is limited," says Professor Lane.

"ANU has the staff and equipment, we have decades of experience in education and outreach, so we're well-placed to support training their educational leaders."

Dr AJ Mitchell, also from the Research School of Physics, first visited Myanmar as part of a collaboration to grow research capacity in physics and engineering.

"I spent two weeks at the University of Yangon in Myanmar teaching and developing experiments used to train students," says Dr Mitchell.

"Then, at ANU, we hosted the head of their physics department for two weeks here, showed them what we do at HIAF, and discussed how we could collaborate further in future."

A subsequent visit to Timor-Leste in 2018 had similar themes, with Dr Mitchell training local high-school science teachers.

Those visits were noticed. In 2023, the IAEA asked HIAF staff to contribute their expertise to develop a new postgraduate nuclear science program and teaching laboratory at the Royal University of Phnom Penh, Cambodia.

> *The IAEA is trying to build nuclear expertise around the world, and they want to leverage the places that have expertise and bring it to places that don't.*
>
> *—Professor Greg Lane, ANU Research School of Physics*

Two senior Royal University academics visited HIAF's facilities at ANU in February 2023.

"We were able to demonstrate some of the exercises we do here with radiation detectors and nuclear measurement in our teaching laboratory here," says Professor Lane.

A reciprocal visit to Cambodia is being planned, and both Professor Lane and Dr Mitchell say they're looking forward to future collaborations with south-east Asian countries as technological infrastructure continues to develop in the region.

"The IAEA is trying to build nuclear expertise around the world, and they want to leverage the places that have expertise and bring it to places that don't," says Dr Mitchell.

"That's why they came to us."

Research School of Physics, ANU

HIGHER EDUCATION AND TRAINING

CASE STUDY

HIA supports hands-on approaches to build Australia's nuclear educated workforce

ANU students learn how to operate equipment at the Heavy Ion Accelerator Facility control room.

Australia's nuclear science industries are growing rapidly, and they need people. There are exciting developments every day like new medical diagnostics and treatments, a growing presence in space, new climate and environmental research, advances in critical minerals extraction and processing, and defence applications arising from the AUKUS partnership.

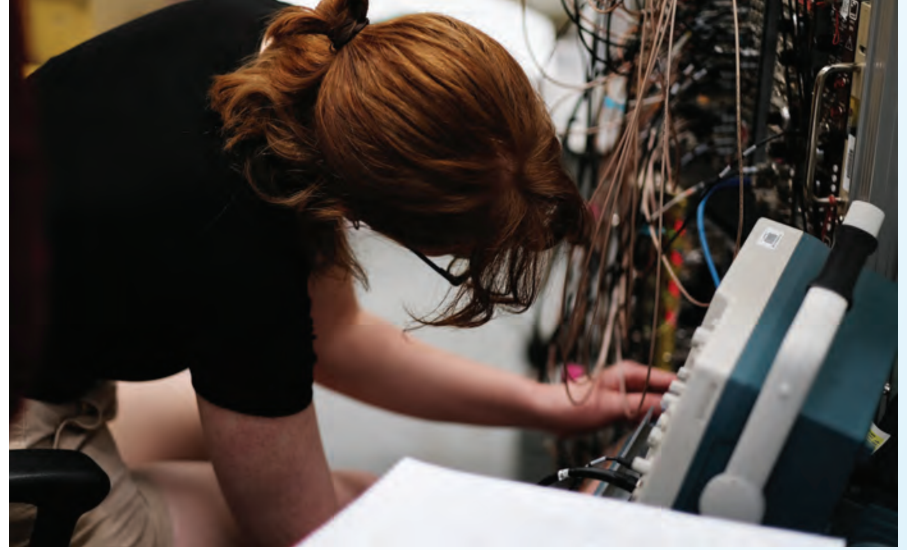
To support all these new industries, we need people who are educated in nuclear science—which means we need training and education opportunities to build that knowledge base.

"At the moment, there just isn't a significant nuclear-educated workforce in Australia," says Dr AJ Mitchell, Senior Lecturer at the ANU Research School of Physics. "We need to change that, to find those people and train them."

The Australian National University is uniquely placed to meet that need thanks to the HIA's Heavy Ion Accelerator Facility (HIAF) it houses. The ANU is the only university in Australia that offers postgraduate education in nuclear science: the Masters of Nuclear Science course has been running for almost 20 years, offering opportunities for hands-on training and research projects using HIAF's equipment and data.

It's also the only Australian university with direct access to the accelerator capabilities available at HIAF, and the teaching expertise of researchers who use the facility every day.

"We have hands-on laboratories for each postgraduate nuclear science course, and dedicated courses on accelerators and measurement



ANU Research School of Physics student monitors an oscilloscope during a measurement at the Heavy Ion Accelerator Facility.

techniques where students actually use the accelerator equipment," says Dr Mitchell.

"Students can get into the lab, work with radiation detectors, plug cables in to look at signals and analyse data…they can go through that whole process and have the confidence to work in that environment."

In 2022, ANU launched the Graduate Certificate of Nuclear Technology Regulation in response to AUKUS. The course has had 20 enrolments so far, with more on the way, and its first graduates are now working in the defence industry.

"It really hits that sweet spot in terms of providing fundamental nuclear physics knowledge together with an understanding of how nuclear technology works in society, and how these are regulated," Dr Mitchell says.

For those who don't have time to study a full qualification, there's also a range of intensive short courses to build skills through practical workshops in the HIAF teaching laboratory.

"We've had over 150 public servants trained in the Nuclear Science and Applications course since 2018," says Dr Mitchell.

> *"It's not just a focus on one particular industry in Australia, it's about developing a large pool of workers—including scientists, engineers, first responders, medical personnel, tradespeople, and policy makers—who know how to work in radiation environments.*
>
> —Dr AJ Mitchell, Senior Lecturer, ANU Research School of Physics

As enrolments in these courses continue to grow, the course convenors are exploring new offerings that are tailored to meet specific needs for Australia's nuclear science industries.

As Dr Mitchell points out, the more people with a solid grasp of the concepts, the better.

"It's not just a focus on one particular industry in Australia, it's about developing a large pool of workers—including scientists, engineers, first responders, medical personnel, tradespeople and policy makers—who know how to work in radiation environments," he says.

"We need that kind of breadth of awareness to have a fully equipped, nuclear-educated workforce in Australia."

In addition to the ANU efforts, Professor Dasgupta, HIAF Scientific Director, is leading a new ARC Industrial Transformation Training Centre in Radiation Innovation (RadInnovate). The centre is a multi-institutional collaboration delivering hands-on training for Masters and PhD students in nationally important sectors underpinned by nuclear and radiation science, policy and regulation. This is a collaboration between the ANU, the University of South Australia and the University of Adelaide, and a range of industry and Commonwealth partners.

HIA collaborators featured in the report

ANFF
Australian National Fabrication Facility

Australian National University

Centre for Quantum Computation & Communication Technology
Australian Research Council Centre of Excellence

ARC Centre of Excellence for Dark Matter Particle Physics

BINAR | Curtin University

CSIRO
Commonwealth Scientific and Industrial Research Organisation

Australian Government
Defence

HZDR
Helmholtz Zentrum Dresden Rossendorf

Los Alamos National Laboratory

Quantum Brilliance

The University of Melbourne

UNSW Sydney
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