# ISIS Neutron and Muon Source

# Celebrating 40 Years

Science and Technology Facilities Council

ISIS Neutron and Muon Source

40 Years

## ISIS Neutron and Muon Source:

# Celebrating 40 Years

## 1984 — 2024

# Contents

# Foreword

The 40th anniversary of ISIS's first neutrons provides an opportunity to look back on the remarkable achievements that accompanied the inception, construction and development of ISIS, and look forward to future opportunities and successes. ISIS has a tremendous history of technical innovation and scientific productivity, enabled by strong partnerships and collaborations; and it also has a bright future. Forty years on, ISIS remains in the vanguard of global neutron and muon facilities. Over the next ten years, we will be renewing 30% of the ISIS instrument suite, continuing to develop the accelerator and target stations and, looking further into the future, planning for the next generation source.

When the concept of ISIS was first developed in the 1970s, the UK already had a well-established, university-based neutron science community. Building on this, leaders at the Rutherford and Appleton Laboratory developed the vision of a world-class facility using accelerator technology. From the beginning, ISIS benefitted from being embedded at the Harwell Campus, with all the resulting growth and opportunities for technology transfer – from physics and space science to computing – which has kept ISIS at the forefront of innovation. A prime example was the development of Target Station 2 in the 2000s, expanding the range of instruments available to the community and establishing new fields of research.

ISIS has changed the way that the world views neutrons and muons. It has nurtured a spectrum of international collaborations, bringing together ideas and expertise from around the globe. It has also set the pattern for the future, with new accelerator-based neutron and muon sources in Europe, Asia and the USA.

ISIS is a remarkable achievement, and remarkable achievements require remarkable people. We are incredibly fortunate to have benefitted from such talent in the past and to be continuing to benefit from the expertise and commitment of outstanding teams and individuals – both within the facility and our user community, and with our international partners.

It is a great privilege to work in such an environment and an even greater privilege to lead ISIS. We pay tribute to all who made and continue to make ISIS what it is today.

**Andrew Taylor**

**Robert McGreevy**

**Roger Eccleston**

"My career at ISIS stretched from the development of the concept, through its design, construction and commissioning to its realisation as a world-leading user facility. As a young scientist, I worked on the neutronics of the target-moderator-reflector design and the layout of the initial instrument suite. A secondment to Los Alamos, where an early spallation source was already in operation, gave me invaluable experience to bring to the commissioning and initial operation of ISIS, as part of the team of instrument scientists brought together by then Director Alan Leadbetter. Later, as Director, I was proud to see the growth of a thriving community of UK and International users, to foster the development of neutron sources through the ICANS collaboration, and to develop the concept for Target Station 2 and deliver its funding."

**Andrew Taylor**

"I started doing neutron experiments in 1978 as a user at Institut Laue-Langevin and Harwell, and I was then one of the very first users of ISIS, being employed at the time as a postdoc for that specific task! Throughout my career, I have been very involved in international collaborations related to both neutrons and research infrastructures. It has always been clear to me that the strength of ISIS is as a user facility par excellence. This does not mean just providing a service to users, it means leading and developing that service and the technologies and applications that underpin it – and this requires leading staff."

**Robert McGreevy**

"ISIS has been a part of my career since I arrived as a placement student shortly before Prime Minister Margaret Thatcher officially inaugurated the facility in October 1985. Although I have worked elsewhere over the last 39 years, ISIS has always been part of my working life. I feel like I have grown up with ISIS. I have observed, and sometimes contributed to, the important scientific and technical developments and innovations that have shaped ISIS and I have been able to witness the outstanding technical and scientific prowess, innovation, ambition, determination and leadership that have been required to make ISIS the success it is."

**Roger Eccleston**

# Directors over the years

## Alan Leadbetter

1982–1988

"Alan's appointment to the Rutherford Appleton Laboratory at this critical time was an inspired choice and set the foundation for the eventual world-leading success of the ISIS facility."

George Stirling, former Group Leader, ISIS Exploitation, Annual Review 1988

## David Gray

1989–1990

David inspected the synchrotron concrete pouring and decided to add some Hollywood glamour to the occasion, 22 September 1980.

"It is the visible output of science which inspires people like myself to make sure that the facilities to do the science are made available. However important the physical facilities may be, it is the dedication, enthusiasm and professionalism of the people involved which has ensured the success of ISIS."

David Gray's final foreword, Annual Review 1990

## Bob Voss

1991–1993

Alan Leadbetter (right) with Bob Voss (left) at the latter's retirement presentation in the foyer of Target Station 1, 30 April 1993.

"I have been privileged to be associated with ISIS and its impressive experimental programme. I must pay a particular tribute to my colleagues in ISIS; their dedication and enthusiasm know no bounds. I am confident that the years to come will bring all of you yet greater successes."

Bob Voss' final foreword, Annual Review 1992

## Andrew Taylor

1993–2012

Andrew Taylor in June 1993 at the start of his 19-year tenure as ISIS Director.

"The history of ISIS is populated by remarkable contributions, but it is fair to say that Andrew's contribution throughout the last 40 years has been critical to ISIS's success. His commitment to ISIS is unquestionable, and his vision and energy have carried us all forward for more than 40 years. I am always hoping to get 2/10."

Roger Eccleston, ISIS Director

## Uschi Steigenberger

2012

"In 1994, Uschi became the first female Division Head at ISIS, responsible for a suite of instruments covering half of the facility's science programme. She subsequently became Director of ISIS Operations, a key role, that she carried out with dedication for ten years, retiring as Director of ISIS in 2012. She brought her wisdom to the overall governance of RAL, including making the case to government for funding for science, and mentoring and championing women in senior roles."

Keith McEwen, University College London (Uschi's husband) and Andrew Taylor

## Robert McGreevy

2012–2021

Robert McGreevy, upon becoming Director of ISIS, in Target Station 2, 7 November 2012.

“Robert’s leadership and vision were exemplary: he understood ISIS’s strengths and succinctly identified opportunities and targets. His foresight in terms of medium/long range planning led on to progressive plans that strengthened ISIS’s role within STFC’s portfolio of scientific enterprises. The current concepts of Endeavour and ISIS-II are testament to careful stewardship in his time at the helm. And he’s a nice guy too!”

David Lennon, University of Glasgow, long-term user at ISIS

## Roger Eccleston

2021–present day

Roger Eccleston giving a staff update on 10 May 2022.

“Roger’s extensive experience with ISIS since the early 1990s has shaped his role as director today. At the heart of his leadership is a continuous drive to maximise the impact and relevance of our facility, to strengthen and grow the communities we support and to empower ISIS staff. His work to strengthen the depth and breadth of our skill base today coupled with a clear strategic direction will ensure a bright future for ISIS for the next forty years.”

Sean Langridge, Associate Director, Science

ISIS staff come together to celebrate the facility's 40th anniversary in July 2024.


Harwell Campus
Target Station 2 excavation
Egyptian goddess, Isis
Synchrotron vacuum system

# History of ISIS

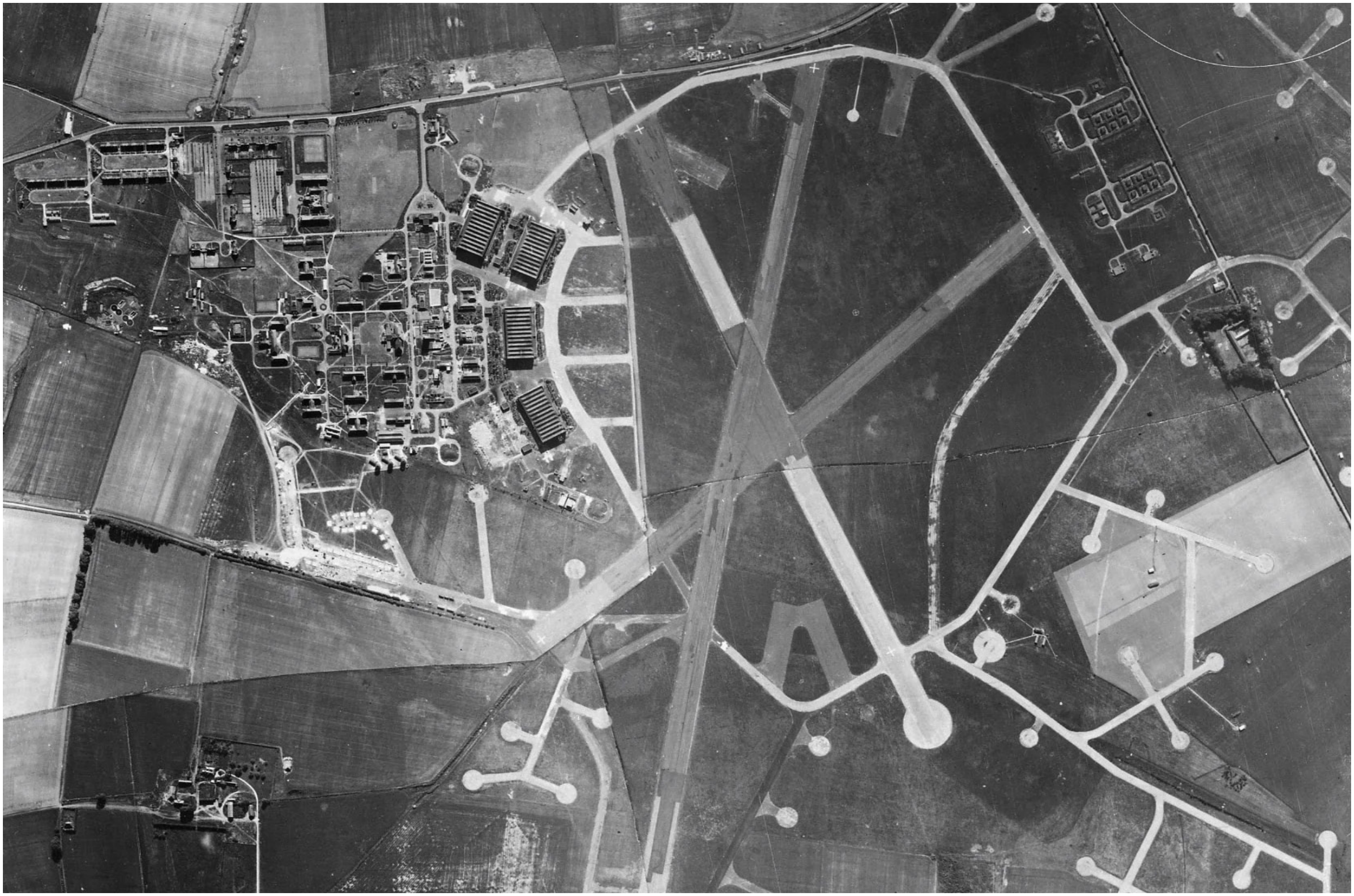
**The Harwell Campus was originally a Royal Air Force base, established in 1935. In 1946, it became the Atomic Energy Research Establishment (AERE), being close to nuclear physics expertise in Oxford. The first reactors were GLEEP (1947) and BEPO (1948), but most important for the development of neutron scattering in the UK were Dido (1956) and Pluto (1957). While the very first neutron scattering experiments by external users were carried out at BEPO, the programme was significantly expanded at Dido and Pluto, and formalised with the setting up of the UK Neutron Beam Research Committee in 1966. This early development of an expert user community underpinned the future success of ISIS.**

In 1957, the Rutherford High Energy Laboratory for particle physics was established next to AERE, based on the Nimrod proton synchrotron which operated until 1978. It was renamed as the Rutherford Laboratory after merging with the Atlas Computer Laboratory in 1975, and as the Rutherford Appleton Laboratory on merging with the Appleton Laboratory in 1979.

A proposal to build a high-flux research reactor at the Rutherford Laboratory was abandoned in 1973, following the UK's decision to join the Institut Laue-Langevin in France. However, this was soon replaced by a proposal to build an accelerator-based neutron source using some of the Nimrod infrastructure, originally known as the Spallation Neutron Source (SNS). In 1975, construction began on Helios, the fourth electron linac at Harwell. Built to support the UK nuclear power programme, Helios included a target cell providing a pulsed neutron capability for condensed matter studies. Expertise gained there played a crucial role in the design of ISIS instruments.

The Neutron Beam Research Unit, set up at the Rutherford Laboratory in 1974, provided the core expertise for the development of accelerator-based neutron scattering techniques. Construction of ISIS began in 1979, using buildings and some second-hand hardware from Nimrod and elsewhere. First neutrons were recorded on 16 December 1984, with the experimental programme beginning in June 1985. ISIS was formally inaugurated and renamed on 1 October 1985.

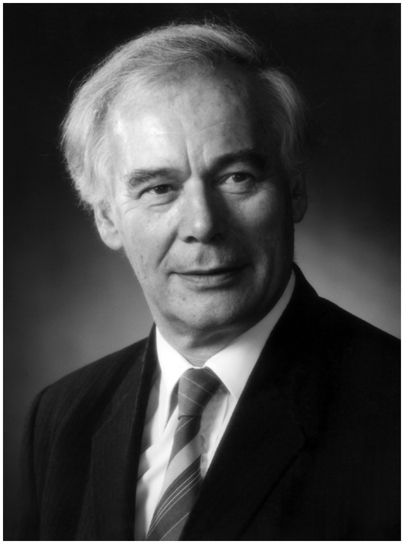
From the late 1990s, plans were developed for a second target station optimised for cold (i.e. low-energy) neutrons; construction started in 2003 with first neutrons being produced on 3 August 2008. ISIS is still the only spallation neutron source in the world to have two operational target stations — though other sources have plans to follow suit.



The Harwell site when it was still an airfield in 1946. The former runways are many of the campus roads today.

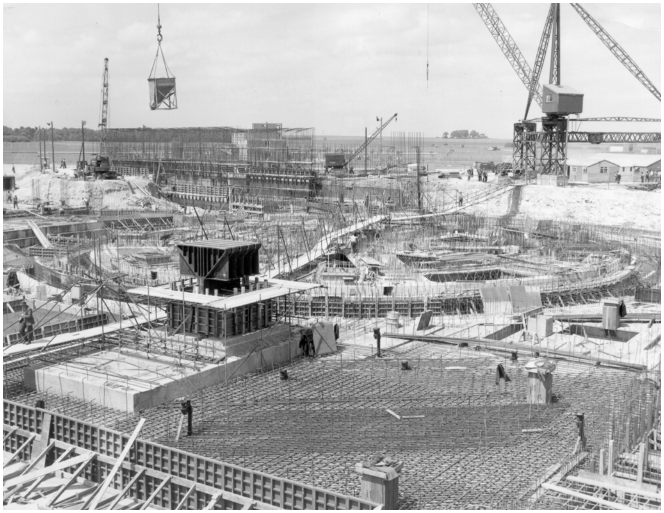
The locations of all the key neutron facilities since 1949 are within a stone's throw of ISIS.


1. ISIS 2. Helios 3. Dido 4. Pluto

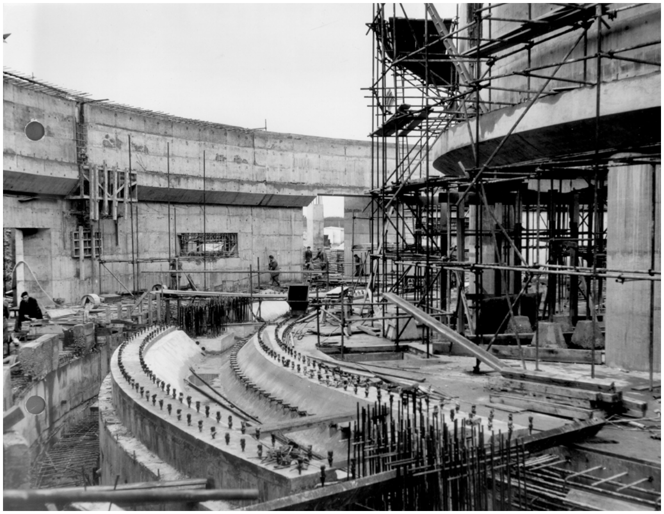




Gordon Squires (left) and Bill Mitchell (centre), two of the earliest university users of neutrons, and Peter Egelstaff (right), who worked at Harwell and was the first local contact.

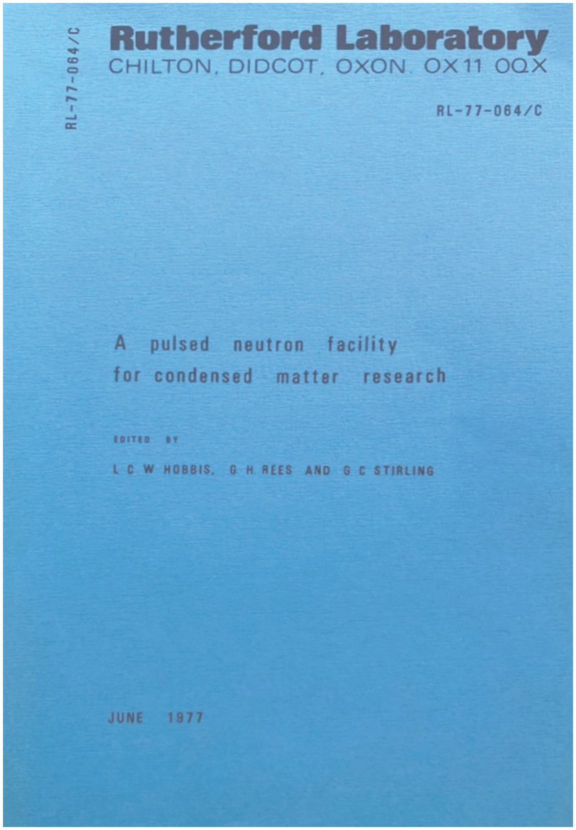
Many students from both Gordon and Bill's groups became long term ISIS users. Bill was highly influential in the UK decisions to join the Institut Laue-Langevin and build ISIS.

Excavation for the foundations of the Nimrod synchrotron, which operated at the Rutherford High Energy Laboratory between 1964 and 1978.




The Nimrod accelerator being installed into the synchrotron hall. Nimrod was a 7 GeV proton synchrotron for particle physics experiments.


RL-77-064/C

**Rutherford Laboratory**
CHILTON, DIDCOT, OXON. OX11 0QX

RL-77-064/C

A pulsed neutron facility
for condensed matter research

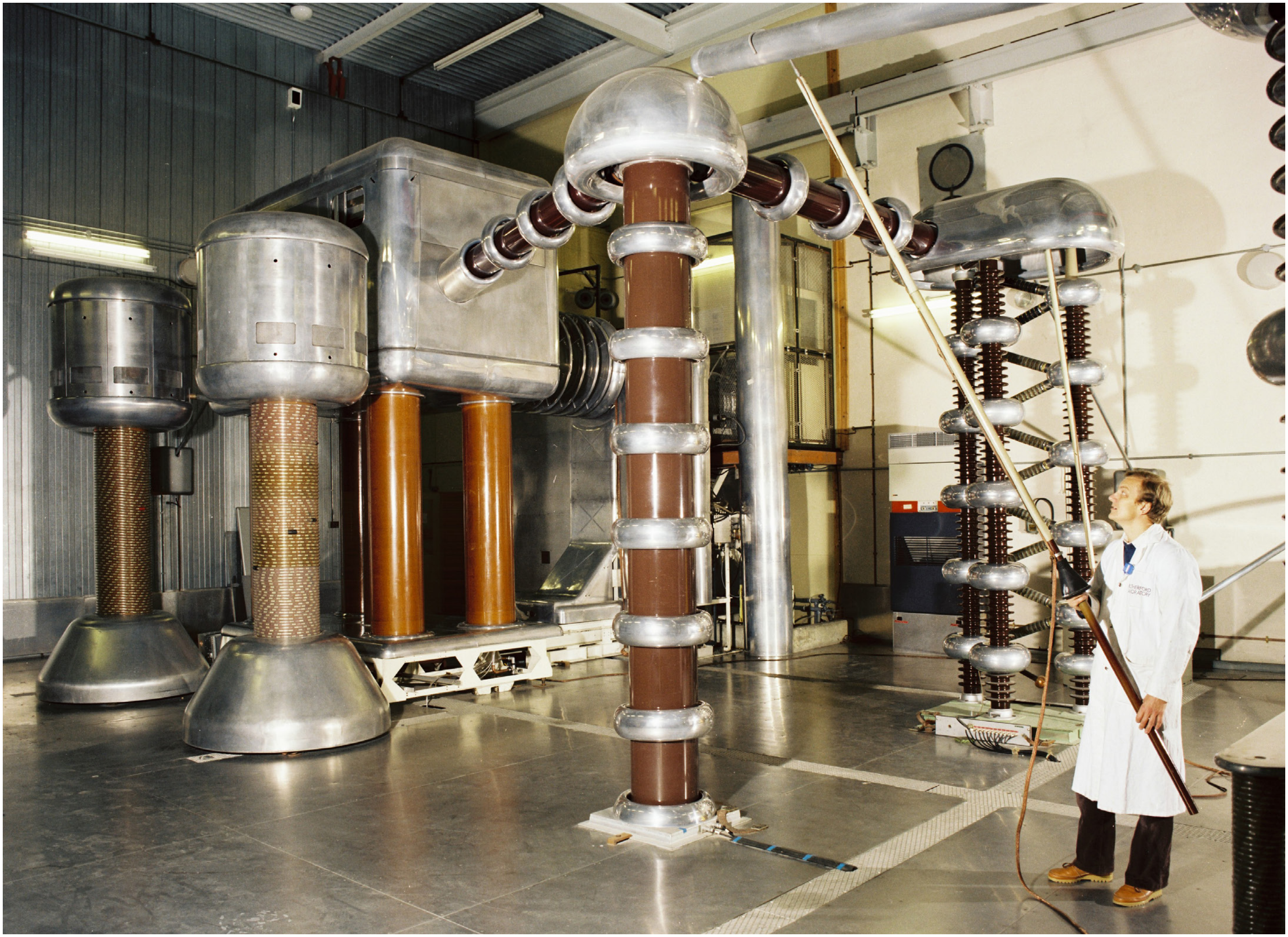
EDITED BY

L C W HOBBIS, G H REES AND G C STIRLING

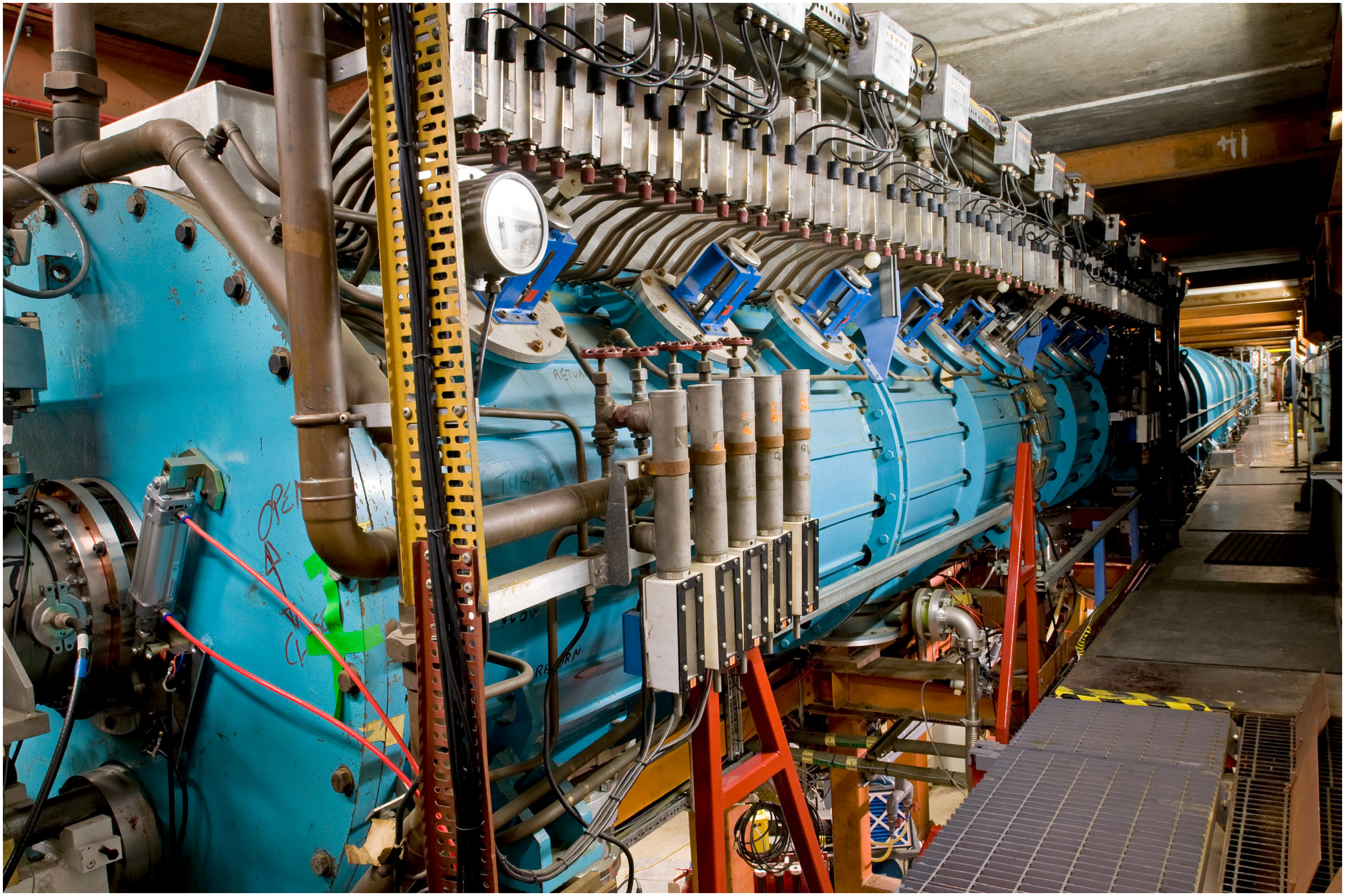
JUNE 1977

With the imminent closure of Nimrod, a proposal was written in June 1977 by LCW Hobbis, GH Rees and GC Stirling to build a pulsed neutron source for materials science. The support of Godfrey Stafford, the Laboratory Director, was critical in obtaining funding from the start. He was succeeded as director of Rutherford Laboratory by Geoff Manning who saw the project through to completion.

ISIS is not an acronym but follows the classical naming tradition of other facilities at Harwell. The Egyptian goddess, Isis, is associated with resurrection (in this case an allusion to the resurrection of the Nimrod accelerator) and has been used as the name of the river Thames in Oxford. The name ISIS was chosen through an internal competition. This image depicts Queen Nefertari being led by Isis (The Met, Open Access).



Various elements of Nimrod and other recycled systems were used in the construction of the new neutron source, making it highly cost effective. This image is the Cockcroft-Walton 665 kV high-voltage generator, developed for an upgrade of Nimrod although never actually used there. It was used as the pre-injector for ISIS for 20 years, being replaced by the radio-frequency quadrupole system in 2004.



View down the south side of the ISIS linac. This linac was ramped up from its original approximately 1 pulse per second (pps) intended role as a replacement injector for Nimrod to its new 50 pps role for ISIS. It incorporates two tanks from the Proton Linear Accelerator (PLA) (*fl.* 1959–1969).

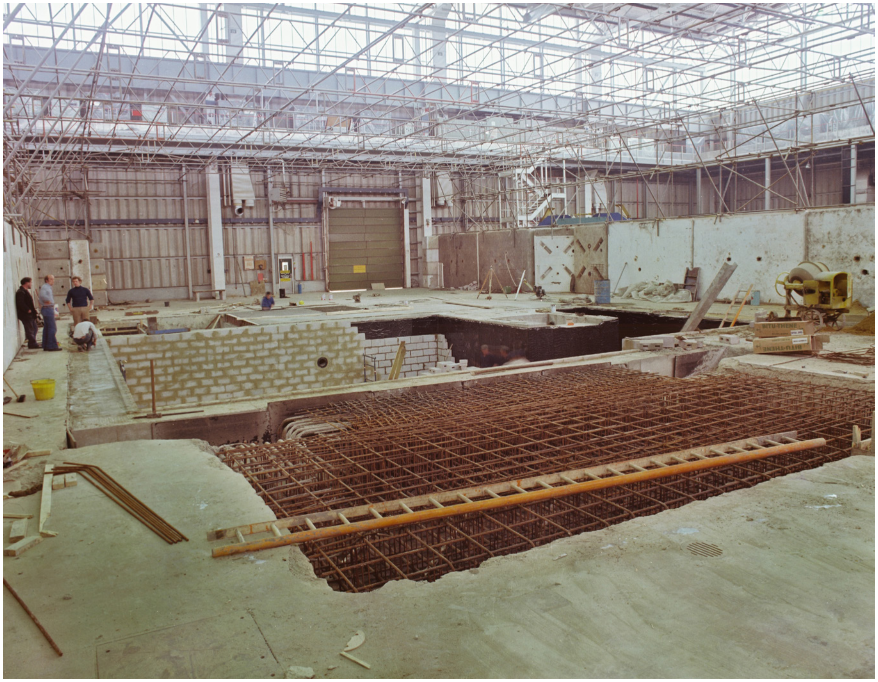
> "It was an amazing technical achievement to ramp up the performance of the linac to meet the requirements of ISIS."
>
> **David Findlay**
> former Head of the Accelerator Division


Retired engineer John Wix, who helped design the original ISIS linac, visited ISIS in January 2017. John was a design engineer with Metropolitan-Vickers who built the linac tanks 2 and 3, which are still in use today.

> “The Accelerator and Target teams were mostly made up from Nimrod staff. They worked for five years designing, building and installing the ISIS systems with quite limited resources. Fifteen year old ex-Nimrod power supplies were modernised and reused along with many Nimrod magnets. The teams had a great spirit and were delighted when their efforts were rewarded in December 1984.”
>
> **Ian Gardner**
> former Head of the Accelerator Division

The synchrotron hall had to be completely emptied, with the centre of the hall walled in to provide an inner shielded area for services, power supplies and controls. The new ISIS proton synchrotron could then be installed.

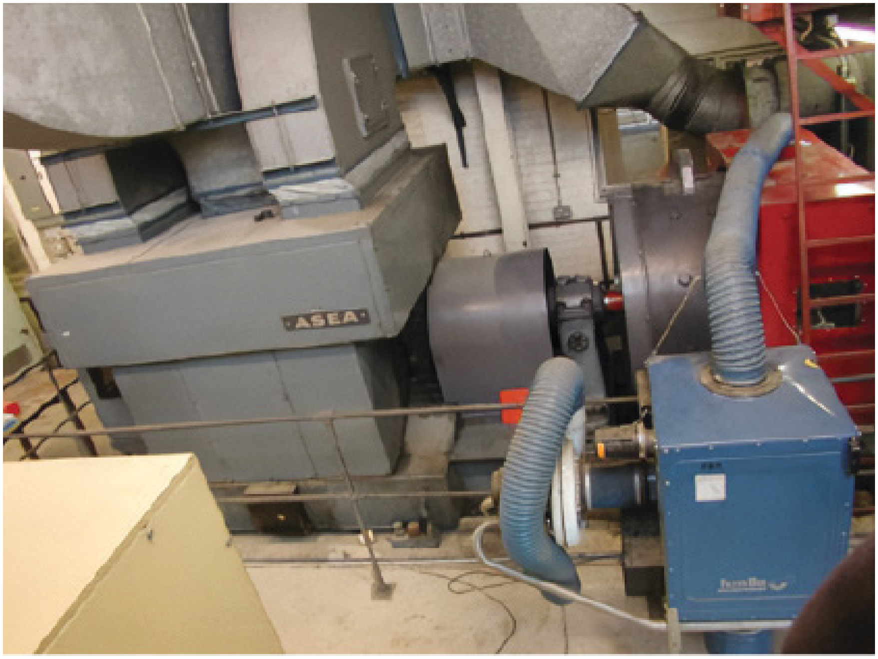
Gerry Whittaker and Dave Wootton look at the ISIS accelerator, ready for operation.



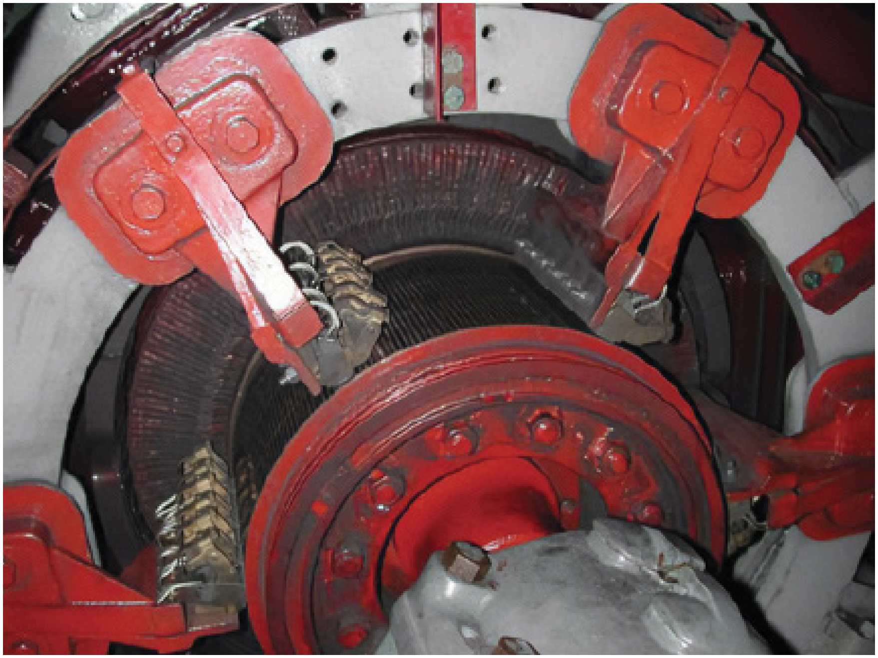
The ISIS target station and experimental hall was built in the old particle physics experimental hall, now known as Target Station 1. The floor had to be reinforced to take the weight of the target station and new service tunnels had to be added. This meant cutting out a large section of the old floor to allow for the reconfiguration.

Centuries-old building techniques still underpin technologically advanced facilities such as ISIS. Here, the shutters that allow users to switch on and off their neutron beams are being filled with concrete in 1980.

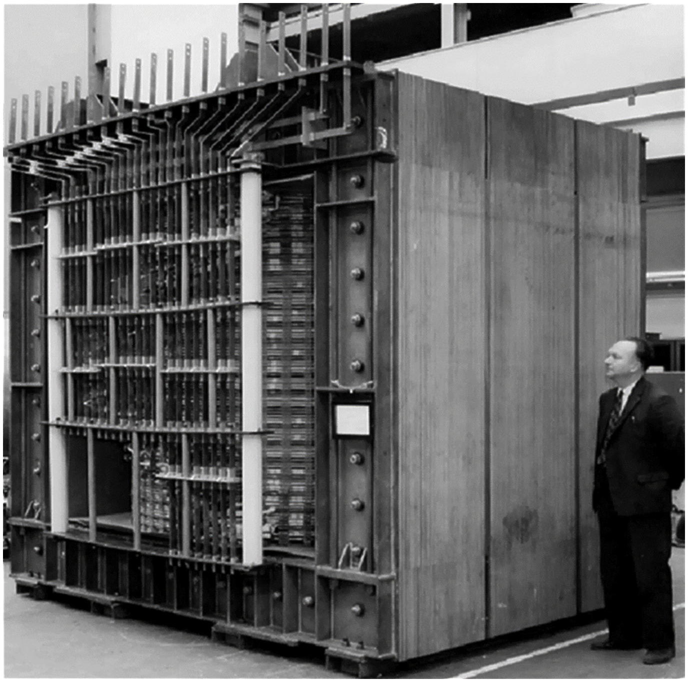
By 1983, the target station and its service areas were beginning to take shape.



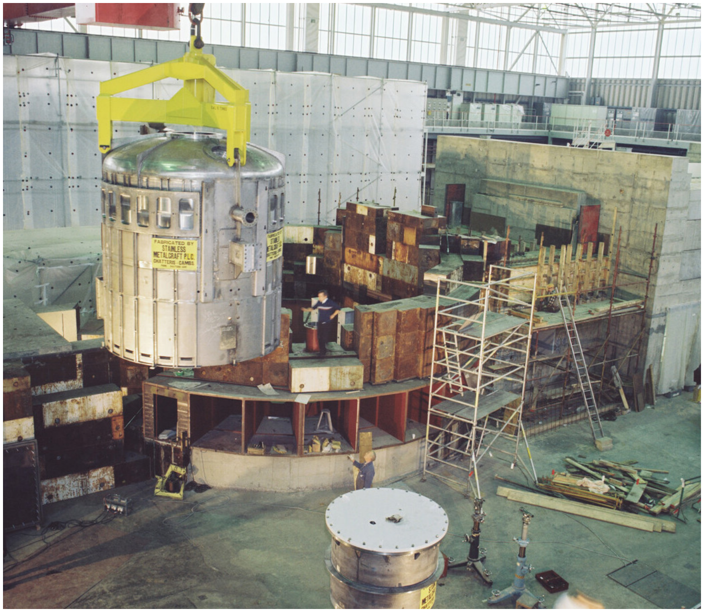

A sizeable number of the power systems needed for ISIS were second hand.



A motor-alternator set, which was used to power the ISIS synchrotron magnets until the 2000s, was previously used by a Swedish tram system and a Sheffield steel works.



The ‘big choke’ that split the drive from the motor-alternator set amongst the ten sets of synchrotron magnets. This was recycled from the Daresbury NINA electron synchrotron (*fl*. 1964–1977).



The target void vessel being installed at the centre of Target Station 1, July 1983. The interior contains the target and moderator assembly surrounded by a stainless steel containment vessel filled with helium. For maintenance, the target assembly can be withdrawn into a service area with remote handling equipment.

"I attended the Neutron Summer School during the summer of 1983. We visited Target Station 1 during our visit. Nowadays it is packed, but then it was almost empty. They had just started constructing the circular target station and there were forklift trucks manoeuvring the concrete blocks. I was just about to start my PhD at Reading, and I didn't think about anything further in my future at that time but three years later, I was a member of staff at ISIS."

**Alex Hannon**
Instrument Scientist, Disordered Materials Group

Brian Culley and Colin Thomas check that a shutter assembly will fit during neutron beam shutter installation in 1983. Personal protective equipment and working from heights were less regulated in the early construction.

Peter Parry assembling part of the vacuum system during synchrotron build progress, June 1983.

> “On joining ISIS in the early days, we had to think of everything. I was involved in designs for target, moderator, shielding and the beam collimation, including in the shutter. I calculated the angles and hoped I’d got it right!”
>
> **Spencer Howells**
> former Instrument Scientist

The south side of Target Station 1, showing the HRPD guide and the LAD diffractometer (transferred to ISIS from Helios). LAD was later completely rebuilt as GEM. On the left is the KARMEN blockhouse, a neutrino experiment funded by Germany.


The north side of Target Station 1 showing, from foreground backwards, LoQ, Iris, TFXA, and HET instruments. Most instruments were still not complete at first neutrons in 1984; this took a number of years to accomplish.


Finally, the construction was completed and the first neutron beams were produced at the Spallation Neutron Source (now known as ISIS) on 16 December 1984 at 7:16pm. Geoff Manning (smiling in the centre) was the laboratory director who successfully led ISIS's construction and its first operation.

“There was a small crowd of us in HRPD waiting for neutrons to arrive down the almost 100 m curved neutron guide. At 7:16pm, phones started ringing with the great news of first neutrons but we saw nothing for several minutes. A couple of nifty keystrokes and the neutron spectrum appeared exactly as predicted, bringing huge relief and lengthy celebrations. For me, it felt just like NASA Houston in 1969 in the moments after the Eagle had landed. I will always remember that moment and I actually shed a tear.”

**Bill David**
former HRPD Instrument Scientist

“We were trying every weekend as it was cheaper to run! Then it was the last weekend before the Christmas holiday. We worked in 12-hour shifts. We were stood down in the afternoon after a small fire erupted in the linac! The fire engine arrived, quickly put it out and I drove home feeling down and shattered. I lived half an hour away but when I got to the door, my wife said there'd been a phone call asking me to go back. Back I went, into the Iris cabin and I pride myself that Iris, which I helped to design and build, was one of the first instruments to record neutrons. I printed it out and took it up to Geoff and Alan to confirm and that's when we started to cheer. I got everyone to sign that piece of paper. I framed it and took it with me when I became Director of the Institut Laue-Langevin some years later and again when I was Director of the European Spallation Source. It was a great day and such an achievement. It was something that in a way defined your life.”

**Colin Carlile**
former Head of Spectroscopy Division Instruments and User Support

"That evening will be with me forever, to be at the start of such a great adventure was a once-in-a-lifetime event. We had been waiting for some time for the call to say that the first beam to target would happen. We all dashed to the lab and assembled in the various cabins, avidly waiting for the first counts to arrive. Andrew was pacing about on the phone to everyone in turn, checking and rechecking that we were all ready, shutters open, everything on and waiting. I was in HET cabin. I had spent many months assembling HET—installing the shielding and setting up the detectors—it was all very hands on. Then it happened and counts were there on the screen. Being young and naive, I didn't appreciate that it was truly amazing that everything worked first time!"

**Zoë Bowden**
former Head of Operations

"I was unable to join in these celebrations as I was in the bunker on a night shift. I needed sleep, so I went home. Two hours later, Ian Bailey, one of the technicians, rang and back in I went, but it didn't happen for quite a while. I think it wasn't until the following morning until I saw the first neutrons and stayed on for ages until I saw a diffraction pattern. A sleepless couple of days but worth it!"

**Spencer Howells**
former Instrument Scientist

"In the evening, the instruments, electronics and software all seemed to work, despite the fact that we had had very limited opportunities to test them beforehand. It was an evening (and early morning) of joy and immense relief!"

**Mike Johnson**
former Head of Instrumentation Divison

“Immediately after this photo was taken, I, being a Scotsman, had brought some whisky in a hip flask. I brought it out and indicated it to our director Alan Leadbetter. Alan made a face at me as if to say ‘tut-tut’ and pulled out an **enormous** bottle of whisky and we all celebrated!”

**Ian Gardner**
former Head of the Accelerator Division

Geoff Manning explaining ISIS technology to the Rt. Hon. Margaret Thatcher, then Prime Minister, who attended the ISIS inauguration on 1 October 1985.

> “It was in the field of the structure of materials that I myself carried out some very modest research. Admittedly, that was a few years ago and using only X-rays and long before the age of computers. I think some of the work which took quite a long time then could have been done with the help of this source in a picosecond or two. If only I could have something like this in Number 10. I sometimes look back nostalgically to the days when I worked in the realms of logic and reason.”
>
> **Rt. Hon. Margaret Thatcher**
> former UK Prime Minister, 1 October 1985

ISIS's Experimental Hall in July 2003 showing that ISIS was at capacity. This was the year that the construction of Target Station 2 started.

During the late 1990s and early 2000s, plans had been developed at ISIS for a second target station optimised for cold neutrons.


Andrew Taylor and ISIS staff on the day of the funding announcement for Target Station 2 in June 2003.


Due to the high cost of transporting such a large volume of soil off site from the excavation of Target Station 2, heavy equipment was used to move the mound created during the original Nimrod construction. This cleared space for Target Station 2 in September 2003.

Aerial view of the area cleared for the building of Target Station 2 in October 2003.

Target Station 2 build progress, showing the steel work at dusk in March 2005.


Re-configuring the old Nimrod Hall 1, now the link building between the Target Station 2 experimental hall and Target Station 1.


The completed proton beamline and refurbishment of the link building as it is today.


View of the proton beamline from the synchrotron to Target Station 2 in 2007. This section passes through the reconfigured Nimrod Hall 1.


The east side instruments in Target Station 2 (front to back): SANS2D, PolRef, INTER, OffSpec and WISH can be seen under construction in October 2007.

Di Wright, Tony Kershaw and Peter Barnes in the main control room working towards Target Station 2's first neutrons in August 2008.


Debbie Greenfield, Stuart Ansell, Julian Norris, Steven Wakefield, Erik Schooneveld, Andrew Taylor, John Webster and Steve Bennington watch as the champagne cork flies high after first neutrons arrive at Target Station 2 on 2 August 2008.

> “By 10pm, we couldn’t get any neutrons. So we went home. I remember I had a restless night. We had just spent £140 million. I kept on thinking, “Had I just got it wrong?” I composed all the various excuses you could make, but basically it boiled down to that I needed to resign. Back in the next day and it turned out that the shutter on INTER (the first instrument) was offset from all the others because it had an inclined beam. A small adjustment and neutrons flooded through! Into the bin went my letter!”
>
> **Andrew Taylor**
> former ISIS Director

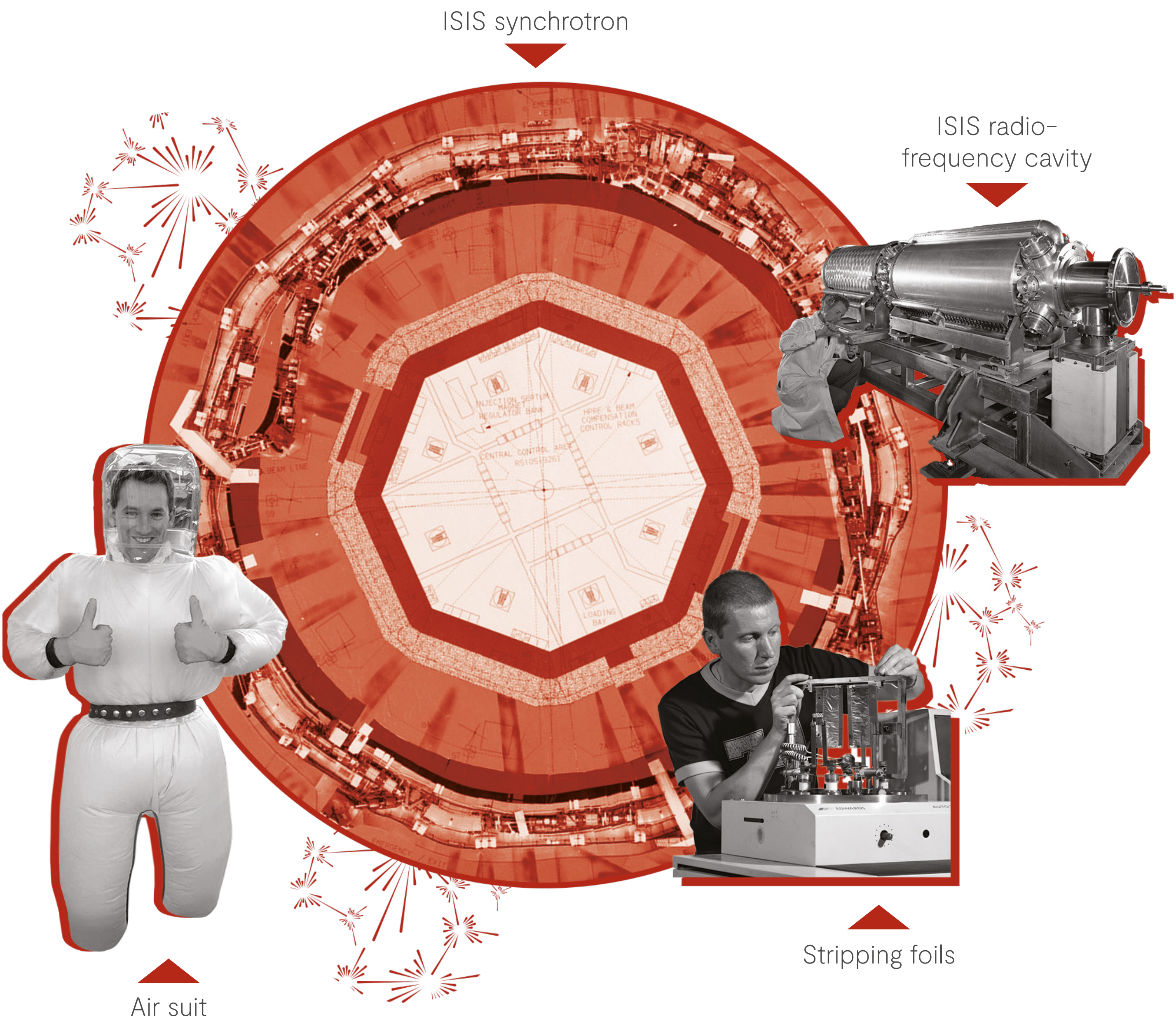
Harry Jones managed the design and build of Target Station 2 and its connection to the ISIS synchrotron. Thanks to his experience and detailed knowledge of ISIS and its infrastructure, he succeeded in completing the design and build of Target Station 2 to within around 1% of budget.

Harry gives a thank you speech to staff at the celebration of Target Station 2 achieving first neutrons, 7 August 2008.


The Vickers building upon completion in June 2018. The building was named after Jane Vickers, who was the Health Physics and Facility Safety Group Leader from 2005 until her untimely death in 2014. During that time, she instituted the Health and Safety Management System that remains the foundation of ISIS safety management today, led an overhaul in health physics and radioactive waste operations management, and influenced safety, health and environment management practices and culture across the Science and Technology Facilities Council (STFC).

ISIS Target Station 2 in October 2021 after solar panels were installed on the roof.

Over the years, ISIS has continually improved efficiency and sustainability in all areas of its operations. This has become increasingly important with the drive towards net zero. Solar panels on the roofs of the target stations now generate 1 GWh of electricity per year, while replacement of the RIKEN solenoid, new air blast coolers and cooling towers, and new radio-frequency systems have saved a further 3 GWh. Additionally, the helium recovery system saves around 53000 litres of liquid helium each year.

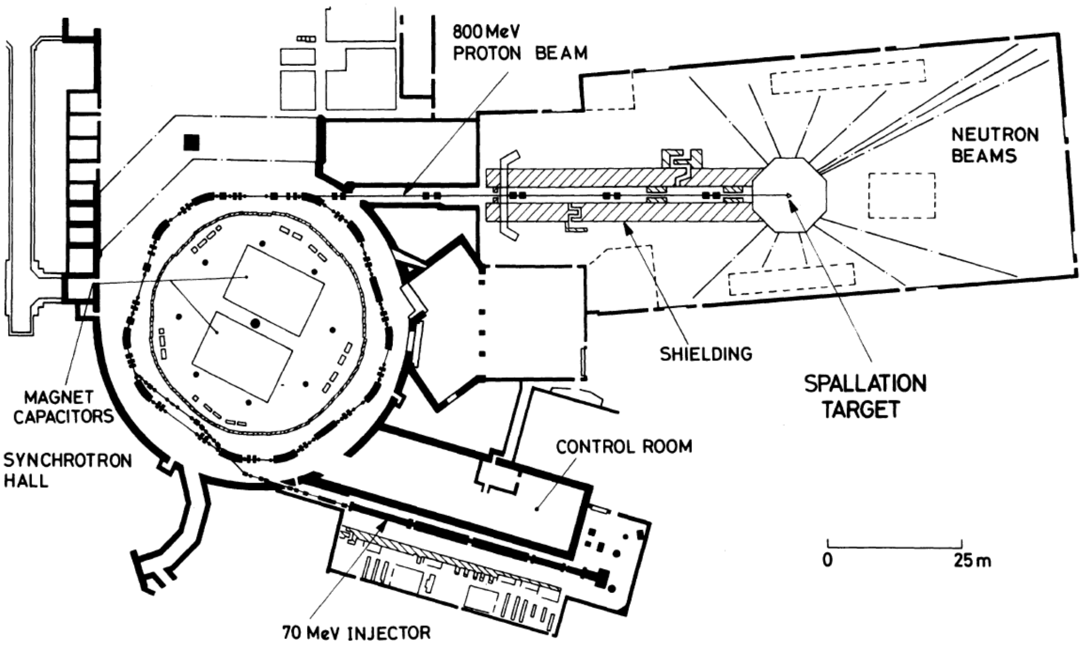

ISIS synchrotron
ISIS radio-
frequency cavity
Stripping foils
Air suit

# Machine and target

**At the heart of ISIS is a high-power 800 MeV rapidly cycling proton synchrotron, producing neutrons from water-cooled tungsten targets in each of the two target stations. The synchrotron is fed by a 70 MeV injector linear accelerator (linac) which in turn is fed by a radio-frequency quadrupole (RFQ) accelerator, which is fed by an ion source. The neutron-producing targets are surrounded by thousands of tons of steel and concrete shielding in assemblies called monoliths, but pipes passing through these monoliths allow neutrons used by the instruments to emerge.**

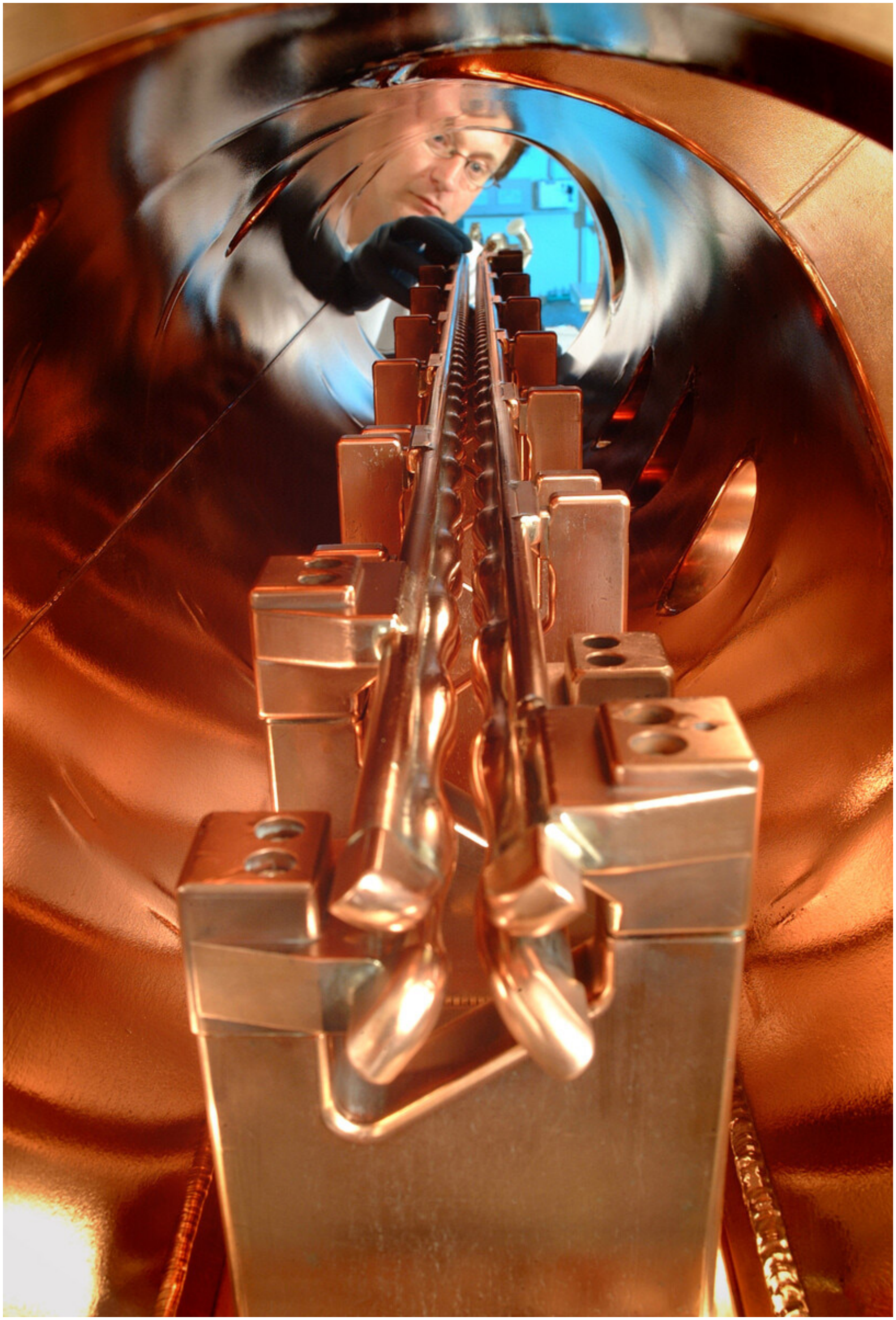
Over the years, significant changes have been made to ISIS hardware, mostly during several months-long shutdowns in 2002, 2004, 2007, 2010, 2014 and 2021–22. During the last of these, the entire heart of Target Station 1 was re-engineered in the most extensive refurbishment job ever undertaken at ISIS.

Programmes to replace old items of plant and equipment and to address issues of optimising lifetimes and reliability have been in place for many years, and these programmes have been structured so that items of plant and equipment posing the greatest risks to the ISIS running programme are accorded the highest priority.

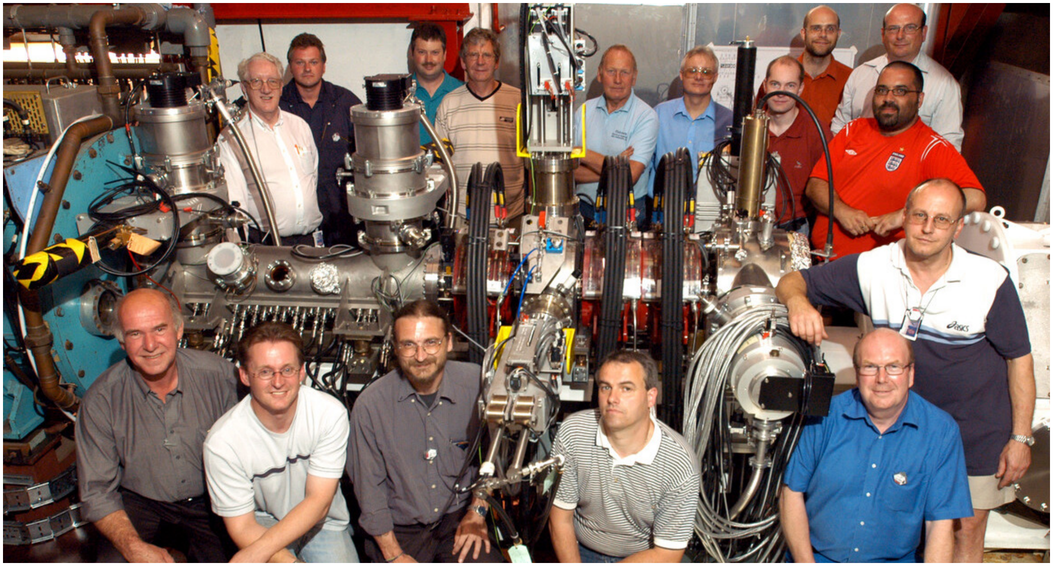



First plans for the Spallation Neutron Source (now ISIS) from the 1977 proposal by LCW Hobbis, GH Rees and GC Stirling.


The item in Dan Faircloth's hands is where it all starts. A stream of hydrogen gas is passed through the ion source and converted into $H^-$ ions. This is the very first process in generating 800 MeV protons.



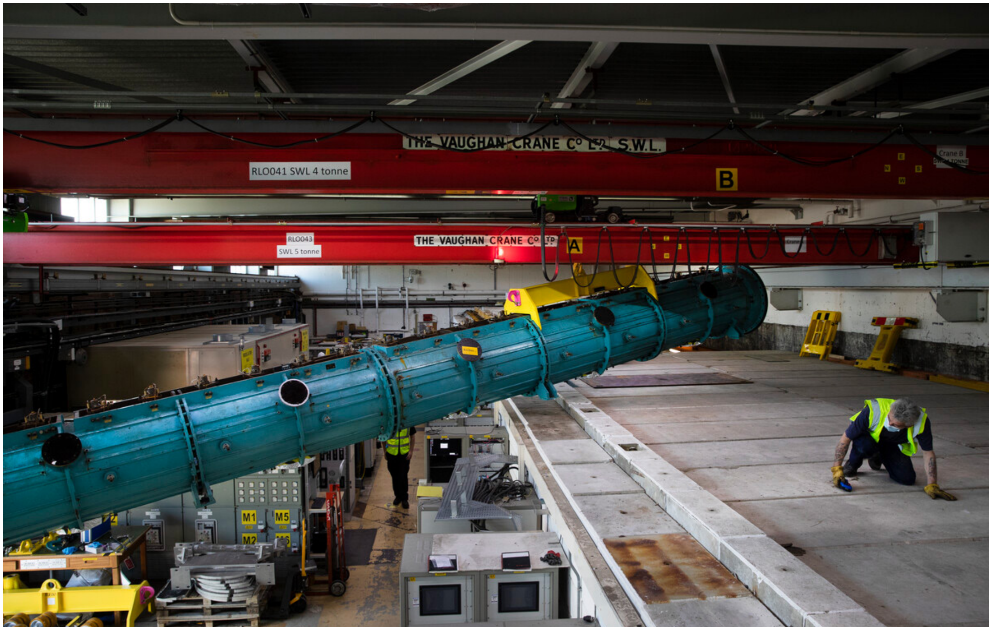
Jim Loughrey inspects the radio-frequency quadrupole with its complex four-rod assembly, which replaced the Cockcroft-Walton pre-injector in 2004. The Cockcroft-Walton pre-injector had a footprint of approximately 200 $m^2$ whereas the radio-frequency quadrupole is just a few square metres.



The radio-frequency quadrupole provides the first acceleration for the beam from the ion source. This was a major development, significantly improving the pre-injection systems. It was installed in 2004 after being tested for a year.

> “My Group Leader, Charles (Chas) Planner, was one of the original designers of ISIS. He suggested that I find out about a new type of accelerator called a radio-frequency quadrupole. At the time, no one at ISIS knew anything about it. It had nothing to do with my role but I fancied the challenge. So off I went to Germany and learnt about accelerator physics, returned two years later and led the project and design. That was a real coup for ISIS at the time and it is still operating 20 years later. I won the Individual Merit Award and I owe it all to Chas, and I wish he was here to hear that.”
>
> **Alan Letchford**
> Head of Linear Accelerator R&D (front row, third from left)

After the radio-frequency quadrupole, the linac accelerates the beam to 70 MeV. The ISIS linac is an assembly of four tanks. This is tank 3 with the lid removed, showing the drift tubes after cleaning and maintenance in September 2010.



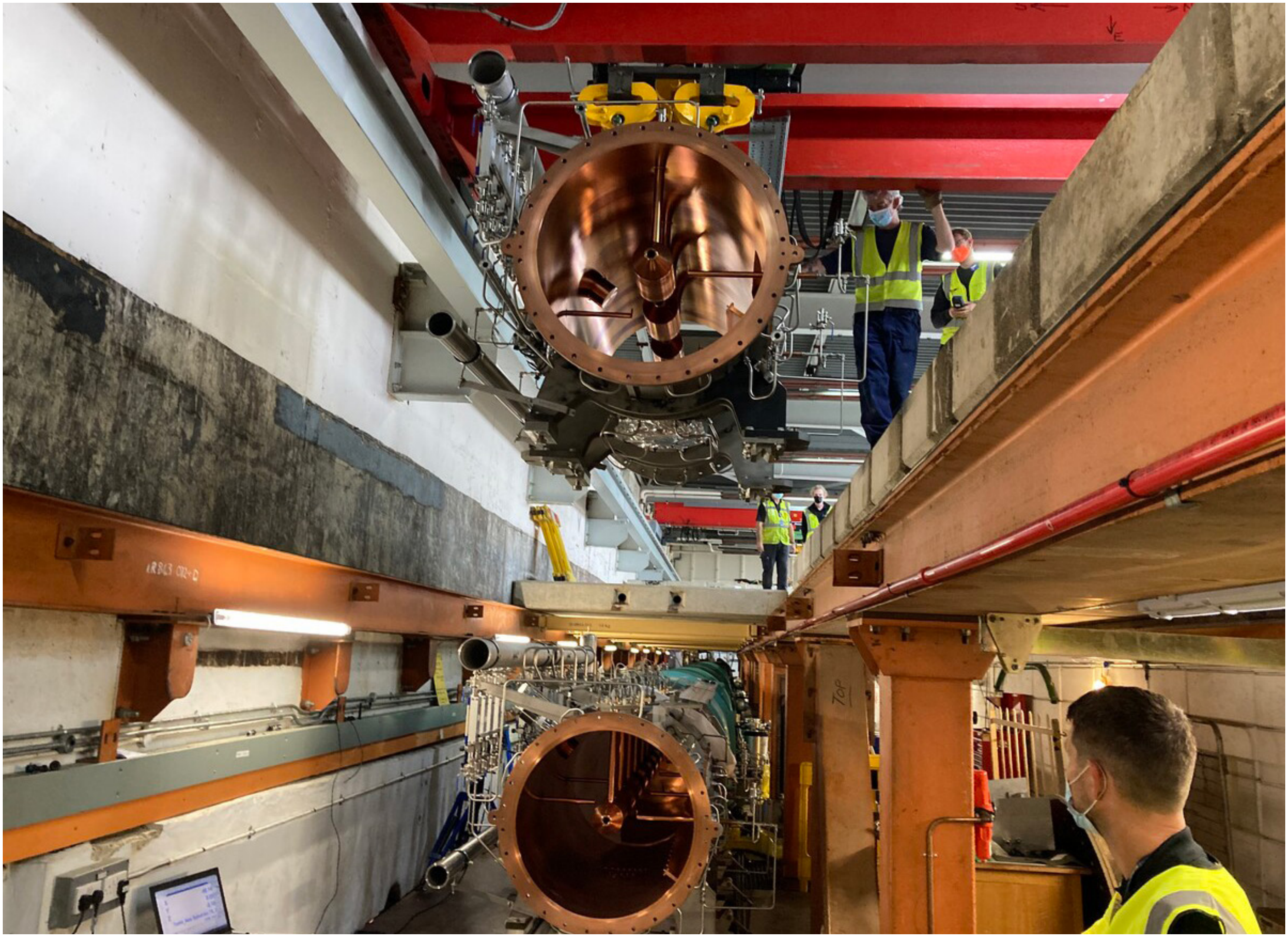

The old tank 4, which suffered increasingly from vacuum problems, being craned out. The tank was welded together and had to be removed in a single piece.

Barry Wilkes checks the clearance as the tank heads towards the door of the linac building.

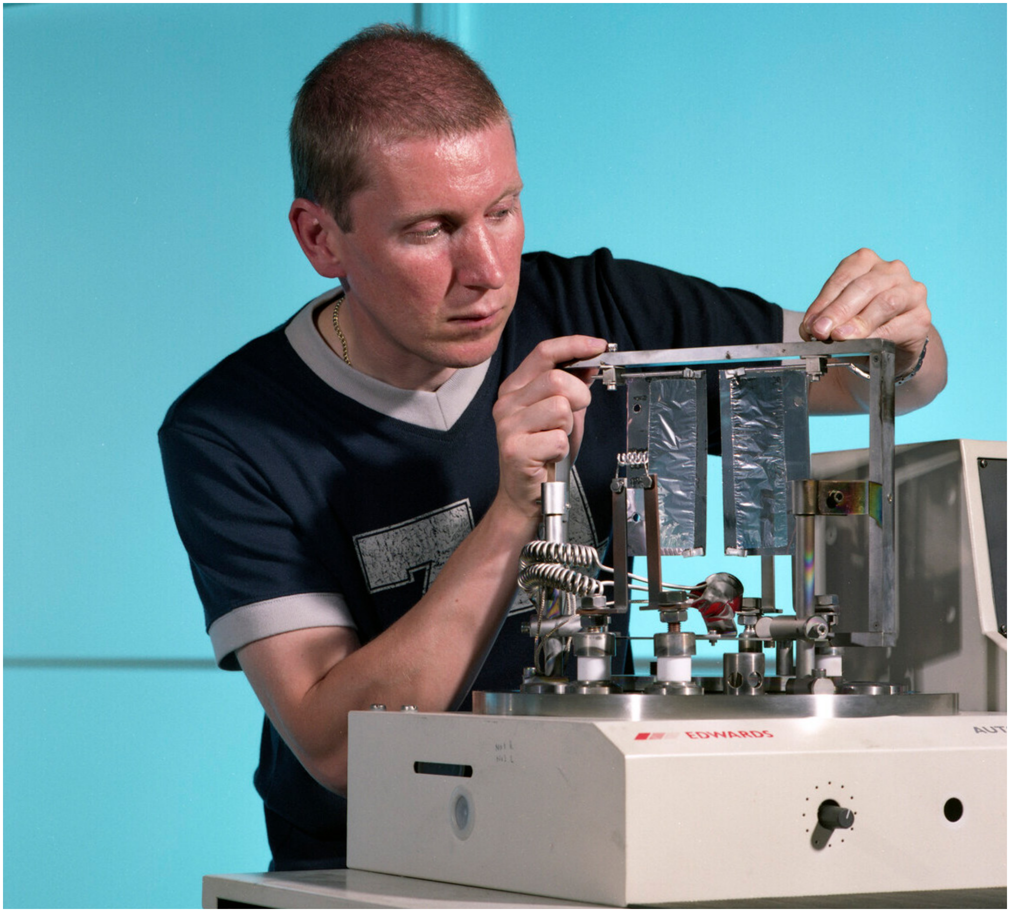
> “After some 20 years working at ISIS, it’s like the tanks and associated radio-frequency systems almost have personalities – their own quirks and tantrums and over time, you get to know and understand them. Keeping a linac working, especially an old one has presented me and the wider teams with a few challenges over the years. Despite those challenges, we always succeeded in repairs and ‘keeping it on the air’. Daftly, maybe weirdly and sentimentally, it felt like some of me was being removed with the upgrade. ‘Goodbye old friend’ was just my mix of feelings in the moment, making way for the new with personal experience quietly saying, ‘look out here comes the next set of challenges’.”

**Mark Keelan**
Radio-frequency Group Leader


Linac tank 4 before it was removed with farewell message from Mark Keelan.



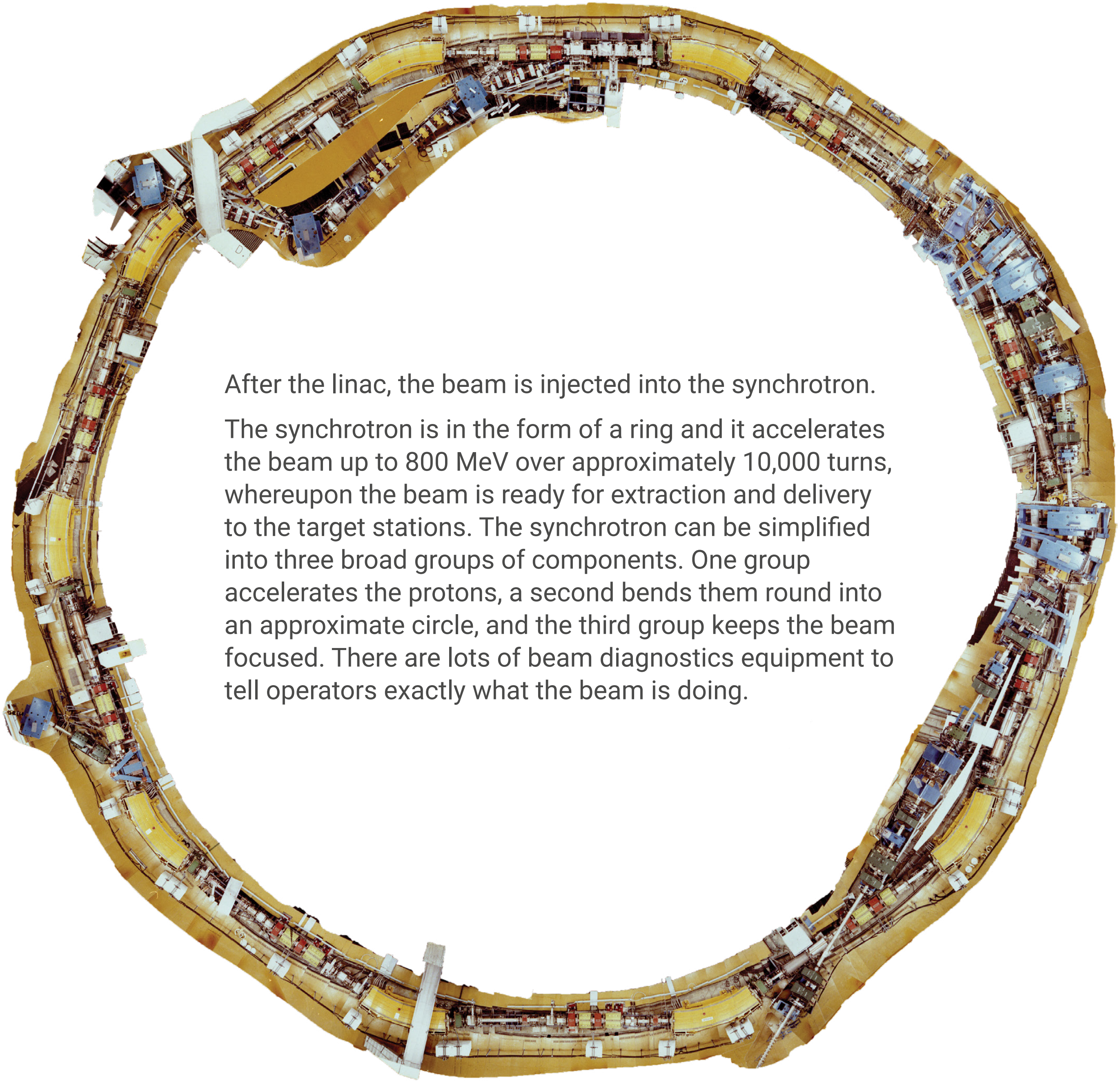
The new tank 4 took more than a decade to design and was installed in sections. The new design is easily maintainable and lessons learned will be applied to the replacement of other linac tanks in the future.




Once accelerated, the $H^-$ ions are passed through a thin stripping foil to remove their electrons and produce protons for further acceleration in the synchrotron.

Geoff Matthews prepares the foils in June 2001.

> "The original ISIS foils were made from aluminium oxide and were very fragile, but a campaign of collaborative research and development has enabled us to evolve the foil design through carbon-based foils to the corrugated nano-crystalline diamond foils used at present, which are much more robust."
>
> **Hayley Cavanagh**
> Machine Physics Operations Leader

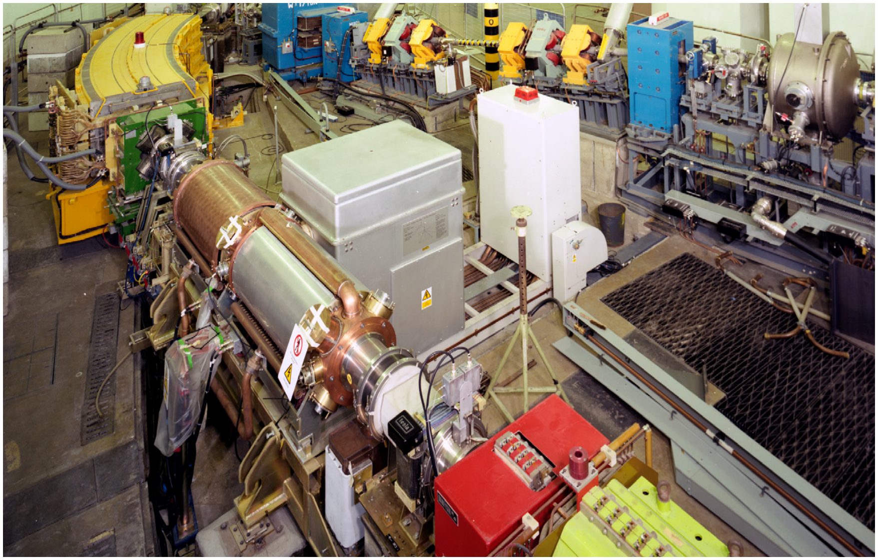


After the linac, the beam is injected into the synchrotron.

The synchrotron is in the form of a ring and it accelerates the beam up to 800 MeV over approximately 10,000 turns, whereupon the beam is ready for extraction and delivery to the target stations. The synchrotron can be simplified into three broad groups of components. One group accelerates the protons, a second bends them round into an approximate circle, and the third group keeps the beam focused. There are lots of beam diagnostics equipment to tell operators exactly what the beam is doing.

> “At the opening, I remember David Gray (then ISIS Director) responding to questions from journalists: “How do you build a machine as complex as this? Did you get industrial partners to do it?” David responded that in reality, we designed it in-house. Where appropriate, we collaborated with industry on some of the tasks, but we had to tackle the most challenging issues ourselves. In the laboratory, we already had the expertise to realise complex projects: the machine, the accelerators, the detectors, the data acquisition, the data handling.”
>
> **Andrew Taylor**
> former ISIS Director

Design engineer John Hirst preparing one of the first ISIS radio-frequency cavities in March 1982. These are the systems that accelerate the protons in the synchrotron.

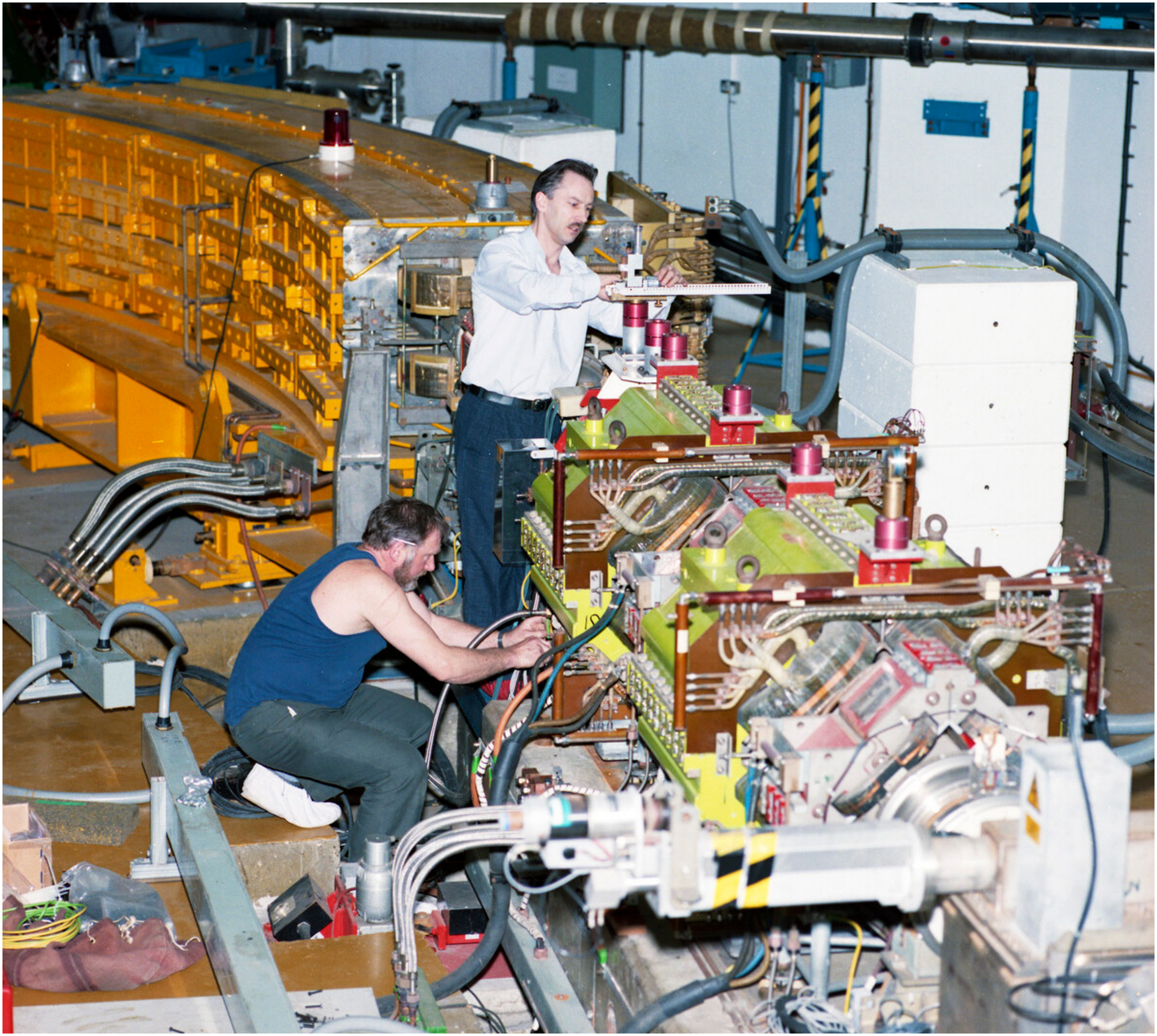


One of the six ‘fundamental’ radio-frequency cavities used for accelerating the proton beam in the synchrotron, 2004.

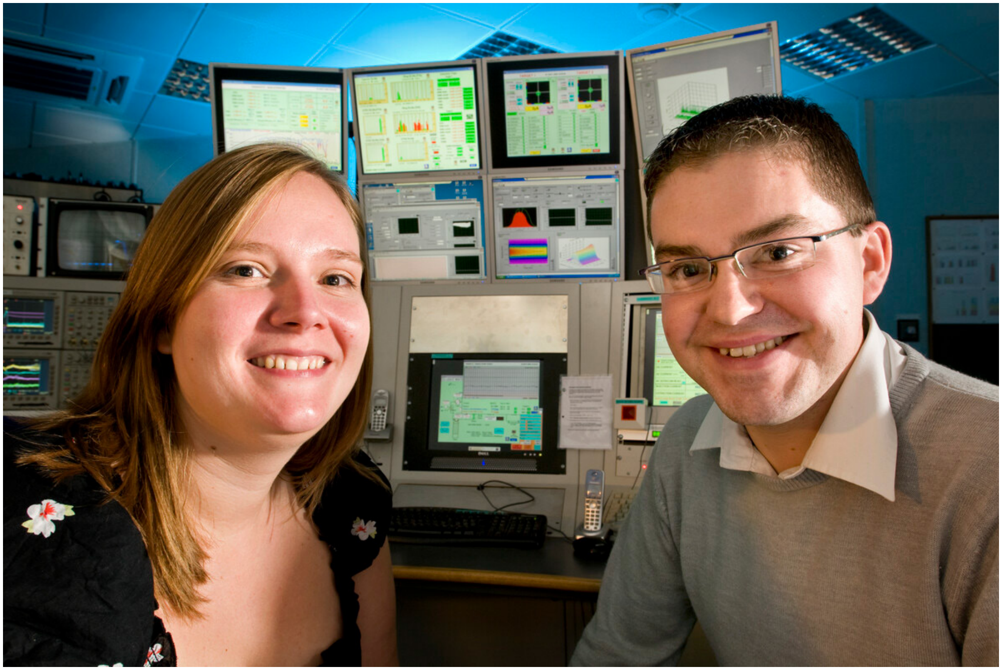
In 2004, ISIS began to install a ‘second harmonic’ system to increase the amount of beam to accelerate. Here, design engineers John Hirst, David Jenkins and technician Terry Western inspect one of the four systems before installation.

The role of the dipole magnets is to bend the proton beam around the ten 'superperiods' that form the ISIS ring. These magnets were made specially for ISIS and the first one is shown here just after its delivery in March 1982. They arrived without the central vacuum chamber and radio-frequency shield, which ISIS fitted before installation.

Left to right: Jamie Searis, Steve Cook, Adrian Hooper and Oliver Newell, of the Accelerator Engineering Group, at work on the lower half of one of ISIS's dipole magnets as it is refurbished in July 2011.



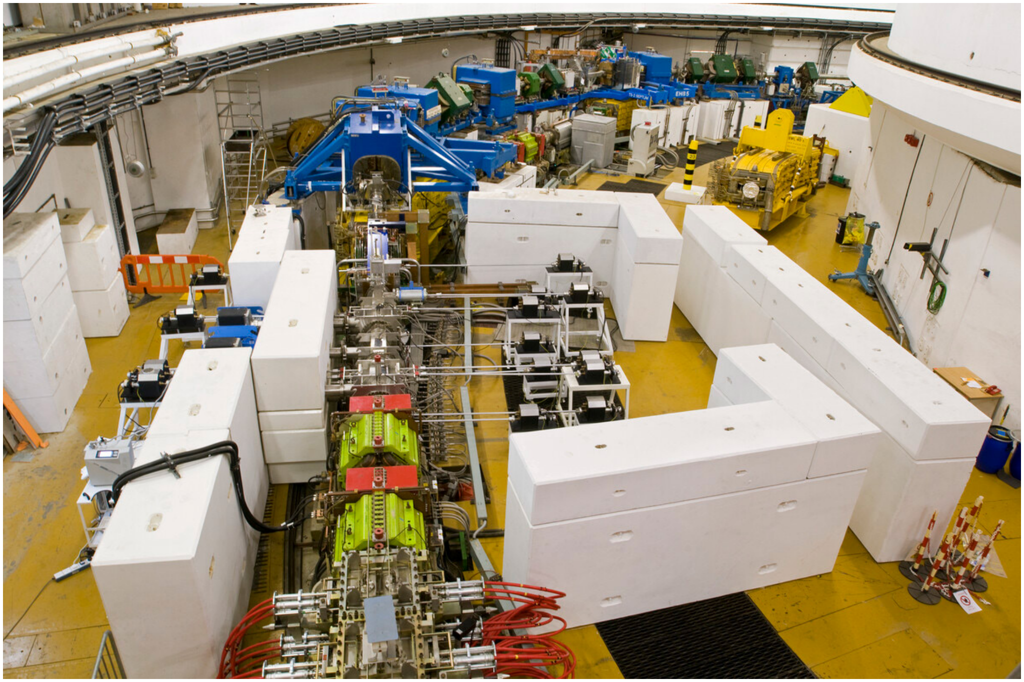
New quadrupole magnets to keep the beam focused are being installed in the ISIS synchrotron by Mike Krendler and Bob Blowfield in May 1992.



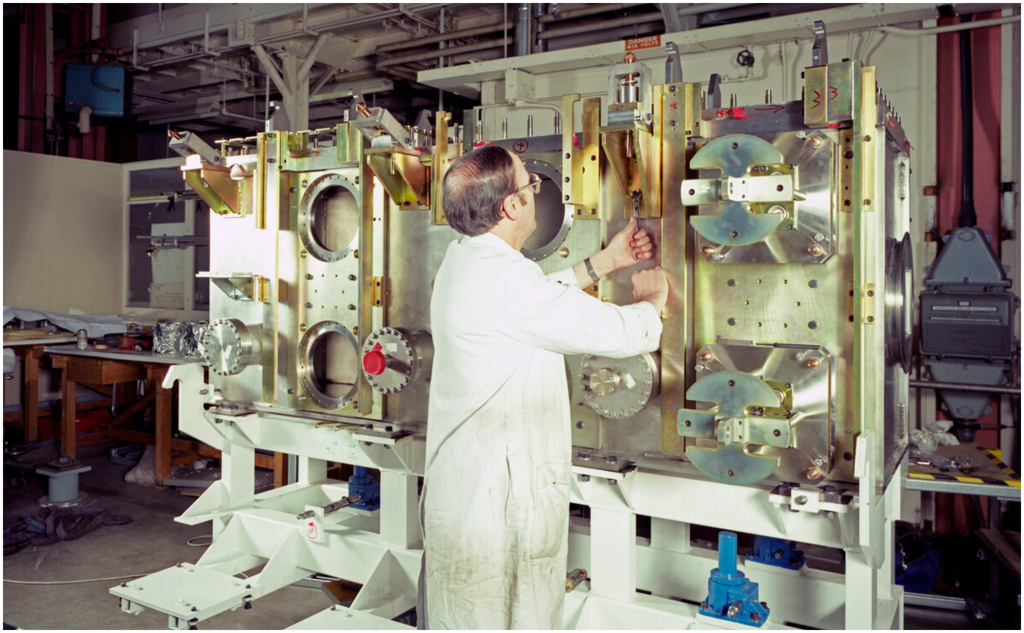
Sarah Fisher and Bryan Jones, commissioning new beam diagnostic systems in the main control room (MCR) in 2009. The accelerator systems are constantly developed and upgraded with new technology and the MCR itself is now in its fourth incarnation.

> “Seeing a graphical user interface you’ve dedicated a lot of development time to come to life, empowering the crew and physicists to optimise the beam performance, is an incredibly rewarding experience.”
>
> **Sarah Fisher**
> Diagnostics Software Section Leader

> “It’s been an honour to work with and learn from the people who originally built ISIS and hugely satisfying to play a part in continuing to upgrade and improve ISIS for the future.”
>
> **Bryan Jones**
> Head of Accelerator Performance Improvement



After acceleration to 800 MeV, the beam is kicked up and out of the synchrotron and into the large blue magnets which steer the beam to Target Station 1 or 2.



The magnet that kicks the beam out from the synchrotron ring is naturally called the kicker magnet. Here, a new magnet is being assembled in May 1990, ready for installation the following year.

Oliver Newell inspects a newly-manufactured kicker magnet section in March 2013.

The magnet power supplies are bespoke components require renewal and replacement.

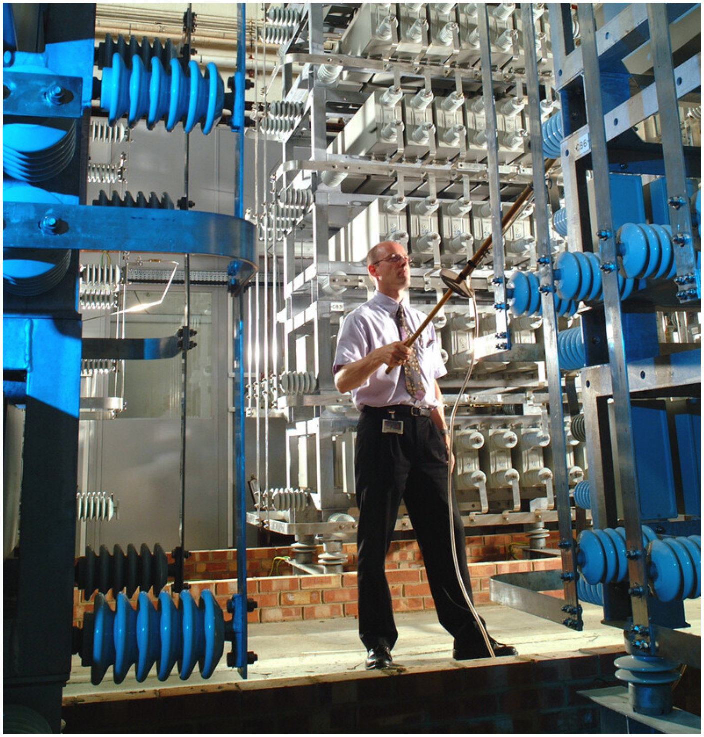
Adrian McFarland installs the last cables on the refurbished kicker power supply in July 2007.

A major part of ISIS's sustainability programme has been the removal of as many single point failures as possible. The main magnet power systems were one such problem. However, replacing these systems for modular ones is akin to open heart surgery while the patient is awake and functioning.

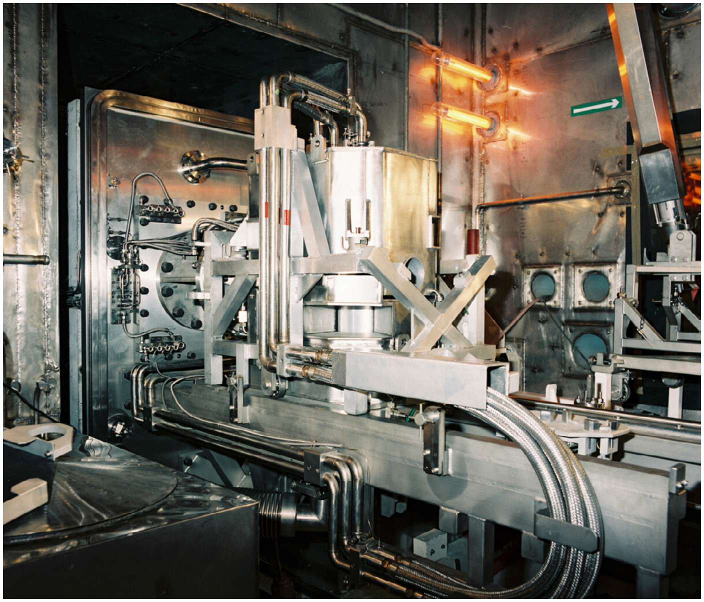
Steve West inspects the new ten-choke system in May 2009. This will eventually replace the NINA choke – now one of the oldest components still operating at ISIS.

"My most rewarding experience was working with Adrian Morris, Jim Gray and Steve West to design, build and commission the replacement for the synchrotron main magnet power supply – a really complex electrical system known as the White circuit. The existing power supply was the original and used a choke that had previously seen service as part of the NINA accelerator at Daresbury. To replace all the various components probably took ten years, but to see the new, next generation DC power supply, AC power supplies, the new capacitor bank, replacement separate chokes for the NINA choke and the system's new control system all working together for the first time was extremely professionally rewarding."

**Mike Glover**
Head of Electrical Systems Division



Neil Meadowcroft inspects the new main magnet power supply capacitor bank, which is in circuit with the choke system, in August 2002.



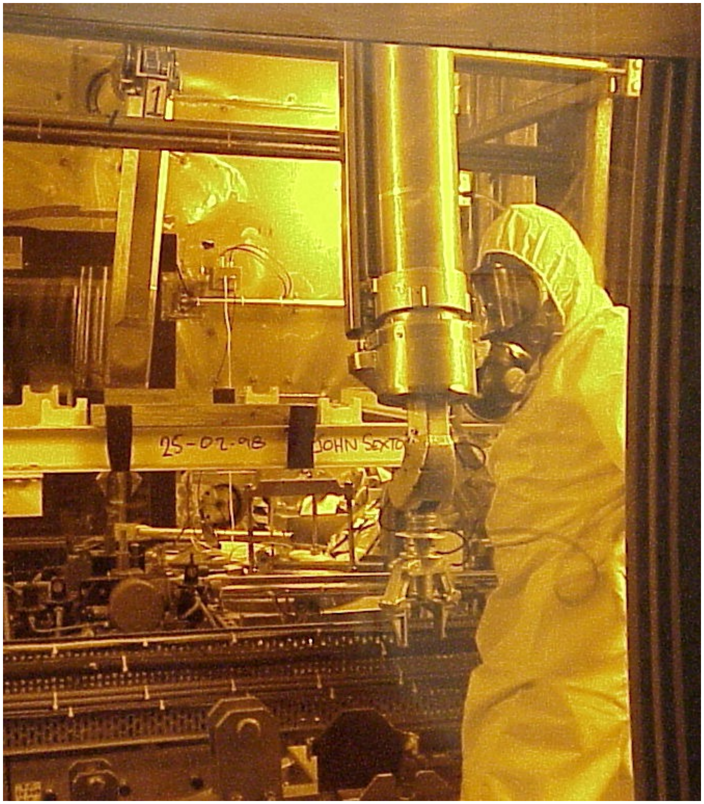
The image shows the target moderator system in Target Station 1, where the protons are used to generate neutrons. Initially, these neutrons are travelling very quickly, so the moderators slow them down to more useful speeds. The entire assembly, which includes the target, reflector and moderators, is a compact block measuring about 2 m³. It is mounted on a trolley system, allowing it to be moved into position for maintenance.

As ISIS was the highest-powered spallation neutron source in the world, there was no experience of how the target and moderators would cope with the high proton and neutron fluxes. Over the years, it became necessary to replace the original depleted uranium targets by tantalum and later to tantalum-clad tungsten. Additionally, the original methane moderator became blocked due to a build-up of tar generated by the radiation damage to the methane. The solution was to allow frequent changes of the liquid methane and the whole moderator to be changed much more frequently than expected.

The new reflector before installation in Target Station 1 in 2004.
Left to right: Jonathan Chapman, Andy Coombs, Mike Ruddle and Andy Robinson.

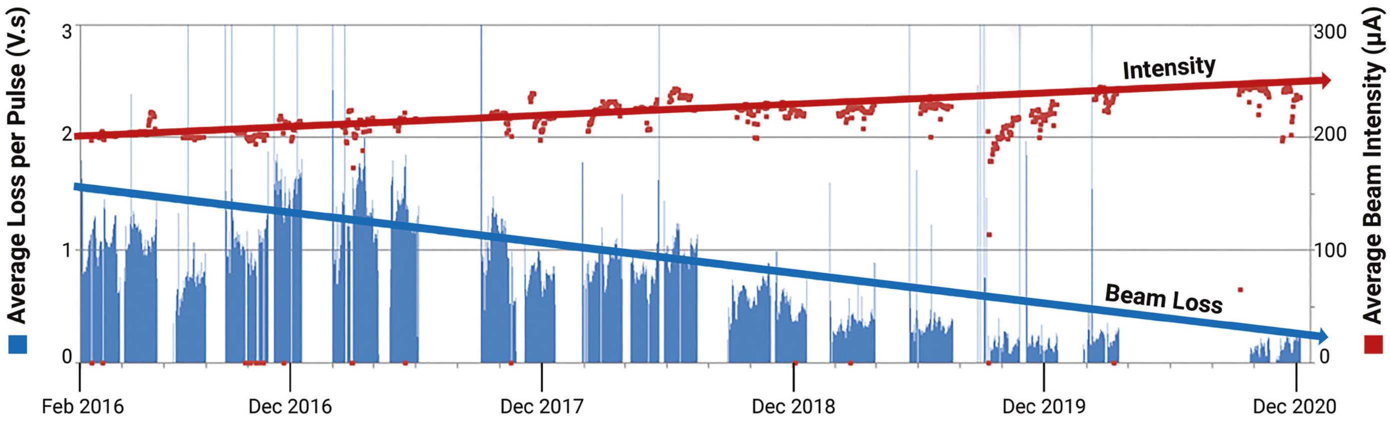
Although many small changes were made over the decades to the target moderator assembly, the basic design had to remain the same until the whole system was replaced in 2022. The design from Target Station 2 was used to simplify moderator changes and maximise the neutron fluxes by designing the target and moderator modules specifically for tantalum clad tungsten. The changing of the target, reflector and moderators also required the whole of the services system to be replaced. Dave Haynes, Rob Buckel and Andy Robinson install the new methane and hydrogen cold boxes in April 2022.

Andy Robinson and Chris Russell check dimensions on Target Station 2's mock up target, reflector and moderator system. The reflector is open to reveal the target in the centre and the moderators above and below.




Working in Target Station 1's remote handling cell requires an air suit to protect against residual contamination, 2002. This is highly skilled work, and both hot and uncomfortable. The yellow colour of the image is because the photo is taken through a zinc bromide shielding window.


Stephen Gallimore in an air suit in Target Station 1, 2010.




One of the main reasons that ISIS is still so successful is the ability to maintain and repair the accelerator in-house. To achieve this, it is important to keep the beam losses during the acceleration of the protons to a minimum. These ‘lost’ protons make the components radioactive and therefore difficult to work on. A major achievement over a number of years has been the result of the efforts of numerous teams, which have resulted in significant reduction in losses. This includes more stable power supplies, more accurate beam controls and improved radio-frequency systems, which have all played their part.

This graph of beam losses and current from 2016 shows an 80% reduction in beam loss. Simultaneously, there has been an increase in beam intensity of 25%.

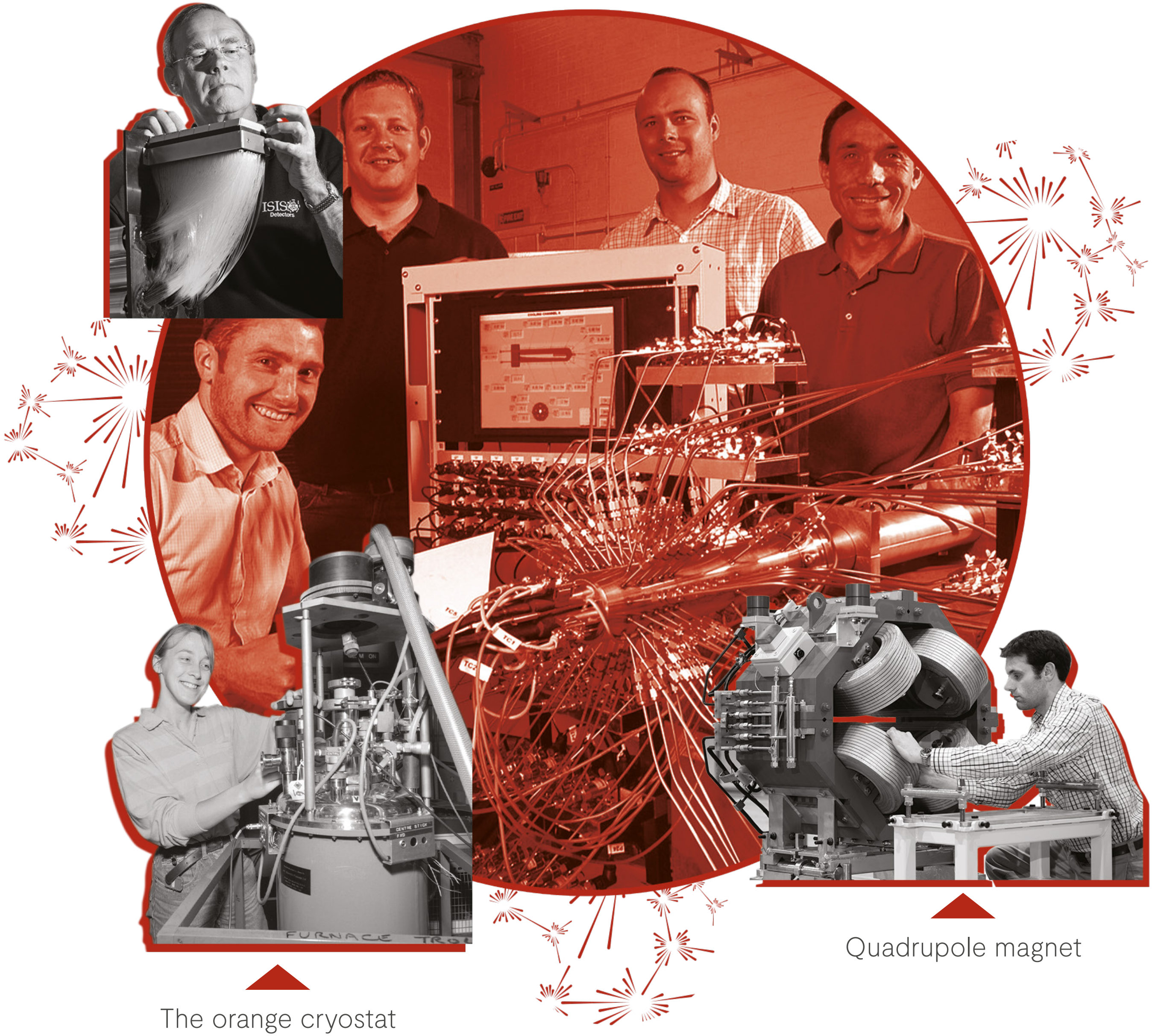
Grahame Rees played a key role in the design of the ISIS synchrotron. The design was very challenging, as the synchrotron had to fit into the space vacated by the old Nimrod synchrotron. Moreover, the routes of the input and output beamlines were already defined by the replacement Nimrod injector linac and the existing hall that would become Target Station 1. However, Grahame did his job so well that the ISIS synchrotron now routinely runs at beam currents well in excess of its design beam current.

Former ISIS Director David Gray (left) and Grahame Rees (right) at the ISIS 20th anniversary, December 2004.

> “The success of ISIS and its appearance in the Guinness Book of Records as the world’s most intense source of pulsed neutrons was, to a large extent, a consequence of Grahame’s flair for innovation and his attention to detail.”
>
> **Chris Prior**
> former Leader of the Intense Beams Group


In 2004, ISIS was presented with the Guinness World Record for the most powerful pulsed neutron spallation source in the world. David Hawksett presents the Guinness World Record certificate to Ian Gardner in April 2004.

> "It was fantastic when we won—a real honour for everyone at ISIS. We were all hoping there would be a good few crates of Guinness to go with it, but no such luck!"
>
> **Ian Gardner**
> former Head of the Accelerator Division



ZnS detector elements

Target design

Quadrupole magnet

The orange cryostat

# Technical excellence

**Critical to the success of ISIS has been the developments made in every corner of the facility. Without the drive to improve and enhance systems to replace old and obsolete equipment, ISIS would not be the world leading facility it is today. ISIS has always exploited new technologies, as well as keenly collaborating with others to solve the technical problems of the day. Detectors, sample environment, polarised neutron techniques and target manufacturing are some examples where ISIS has made important contributions to the knowledge base. All have played an essential role in keeping ISIS at the very forefront of scientific research.**

> "One of the reasons I enjoyed working at ISIS so much was due to the no-nonsense, generous and can-do attitude I received from the technical services. There are lots of things that can go wrong. I would be invariably calling people, asking for help. It was the can-do attitude I got back that made all the difference. Whenever I said what I thought the problem was, I was taken seriously. The way people work together at ISIS is constructive and very professional. At my leaving do, I found out they had a nickname for me. Last Minute Andersen! I admit I did ask last minute!"
>
> Ken Andersen
> former Osiris Instrument Scientist, now Director of the Institut Laue-Langevin

## Detectors

**Instruments are designed to deliver a particular set of data parameters, resolution, flux, or sample dynamics. Neutron detectors with the right signal-to-noise, sensitivity and coverage are essential to enable instruments to deliver the required science.**

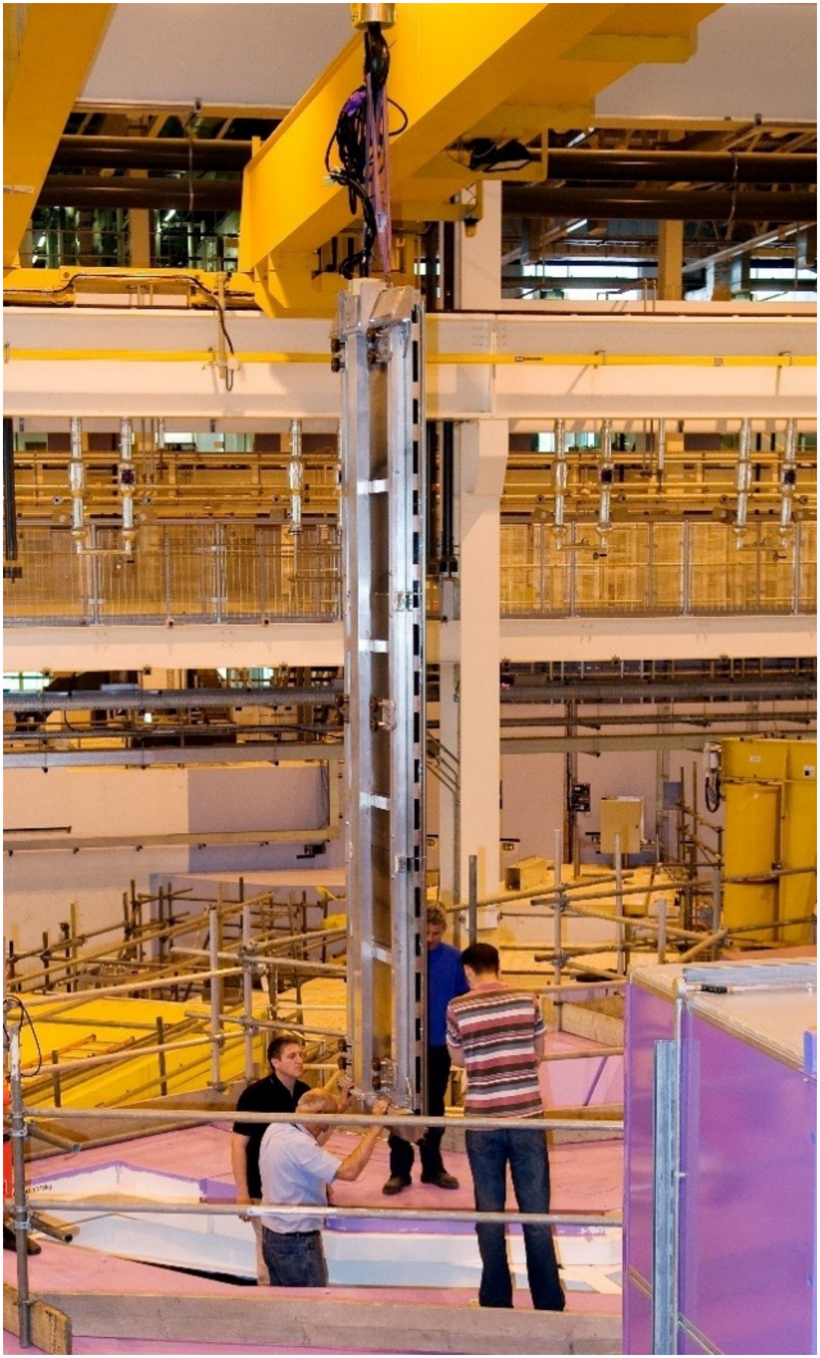
At the start of the ISIS detector journey, there was an extremely tight budget and scintillator detectors, built in house, were the presumed solution. Here Zoë Bowden is preparing the HET 2.5 m bank for the installation of lithium glass scintillator detectors.

As soon as the first experiments took data, it was clear that these detectors were too noisy and too sensitive to the gamma rays which are also present in neutron beams. Even more problematic, they also self-generated additional background. Helium-3 detectors, which had a much lower signal-to-noise ratio, replaced the original detector bank in February 1988.


Andrew Taylor with the representative of the detector manufacturer, Pierre Lecuyer, checking the near completion of the detectors.

With the scientific need to reduce the dead area between detectors, the third iteration of helium detectors built for Maps saw the installation of 1.3-metre-long position-sensitive detectors. These were the first gas tube detectors that could be used as a 2D detector, rather than each tube being an individual counter. Each tube was divided electronically into 128 unique detectors. At the time, they were the longest helium-3 detectors in the world and made especially for ISIS by Reuter Stokes.

Chris Frost, then Maps Instrument Scientist, stands in front of the Maps detector bank, September 2004.



Larger and larger detector banks with fewer gaps required longer and longer helium-3 tubes. This culminated in LET where 384 4-metre-long detectors were used to generate over 100,000 individual pixels.

The production of these tubes proved to be very difficult with many technical issues to overcome. These detectors have not been installed anywhere else.

John Dryer and Matt North assemble a LET detector pack in August 2009.

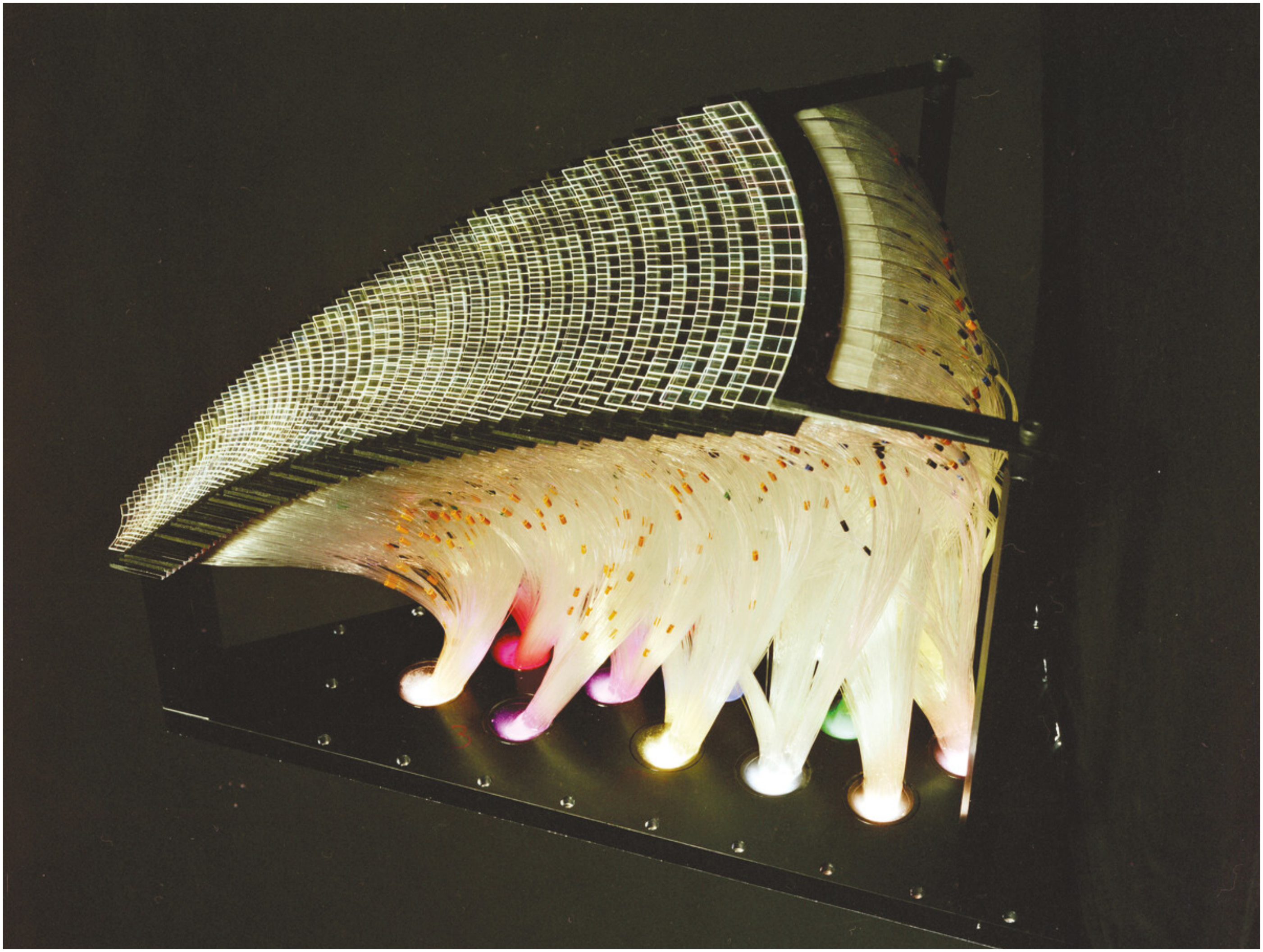
Rob Bewley in front of the detector packs before installation in LET, showing the scale of the detector bank.

LET was the last massive helium-3 detector array as, within a few years, the price of helium-3 had risen to such an extent that the cost of such an array became out of reach.

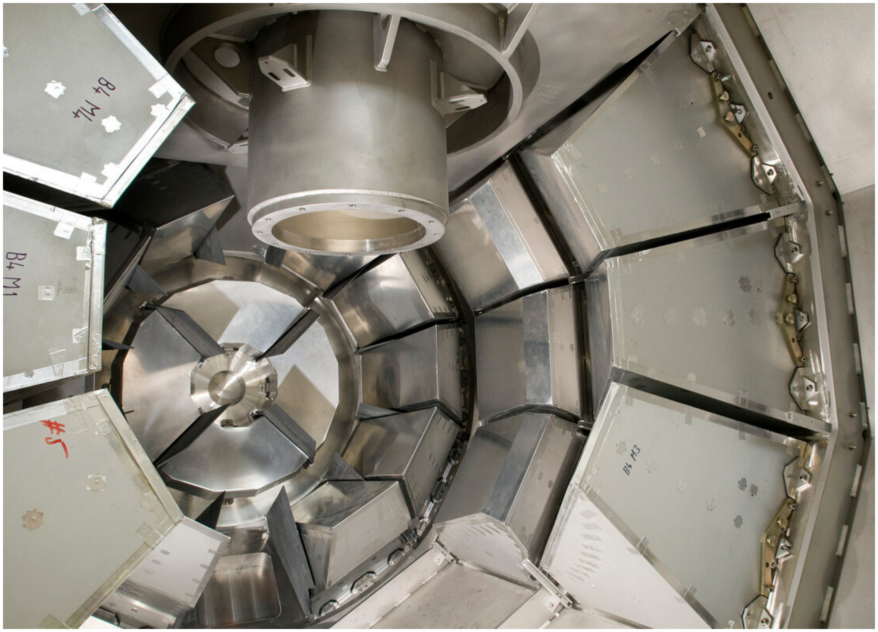
The spectrometers at ISIS transformed the way instruments were designed and changed the way the science was executed across all facilities around the world.

Zoë Bowden and Roger Eccleston inspect the HET detector bank in 1994. The detector's coverage was only 10% of the coverage later achieved in LET.

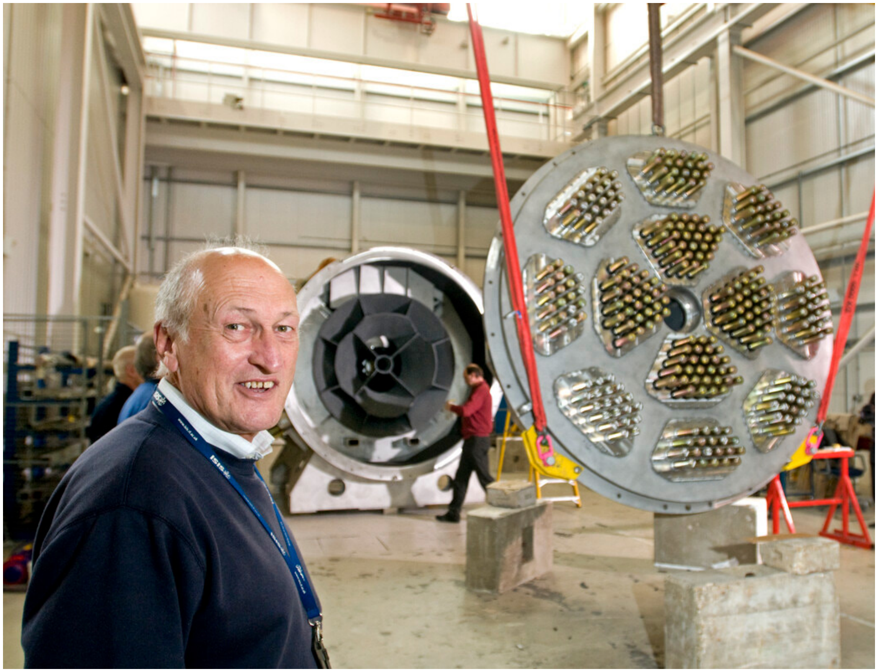
Nigel Rhodes has been the Group Leader and powerhouse of the detector team for many years. He is seen here with the SANS2D detector array. The highest resolution helium-3 tube configuration is used on many instruments.



ISIS has always been at the forefront of scintillator detector development. Instruments that can measure the structure of matter have higher count rates, so more challenging detector shapes are needed to match the data. These have driven the continued development of this type of detector from first neutrons to now. Here, an early module installed on LoQ, shows the coding system that allowed many detector elements to be individually identified, using only a small number of photomultiplier tubes.

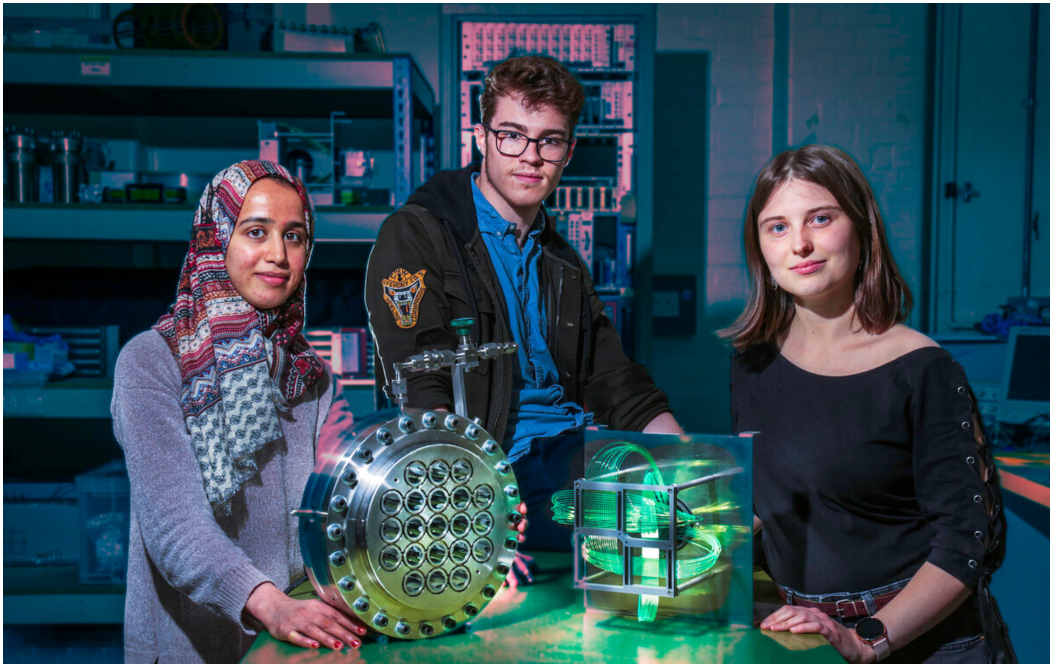



The same drive to maximise the detector coverage and minimise the background resulted in the design of sample vacuum tanks changing dramatically – from thin windows in front of the detectors (acting as the barrier between the vacuum and the air) to detectors being embedded within the vacuum, eliminating the windows. Here is Polaris from the inside.



John Randall supervises the installation of the Polaris end plate in August 2011.

Students Raheema Hafeji, Sam Franklin and Sarah Mann helped in the development of some of the most advanced detector technologies. Wavelength shifting fibre detectors are now the gold standard in scintillation detectors and extensive development led to these detectors being introduced to SXD and the reflectometers. These systems provide microscopic resolution down to 3 mm and on the reflectometers down to 0.5 mm.



Work completed by Raheema also enabled the first detection of neutrons with a µRWELL type of detector. This is a technology from particle physics, adapted for neutron detection.

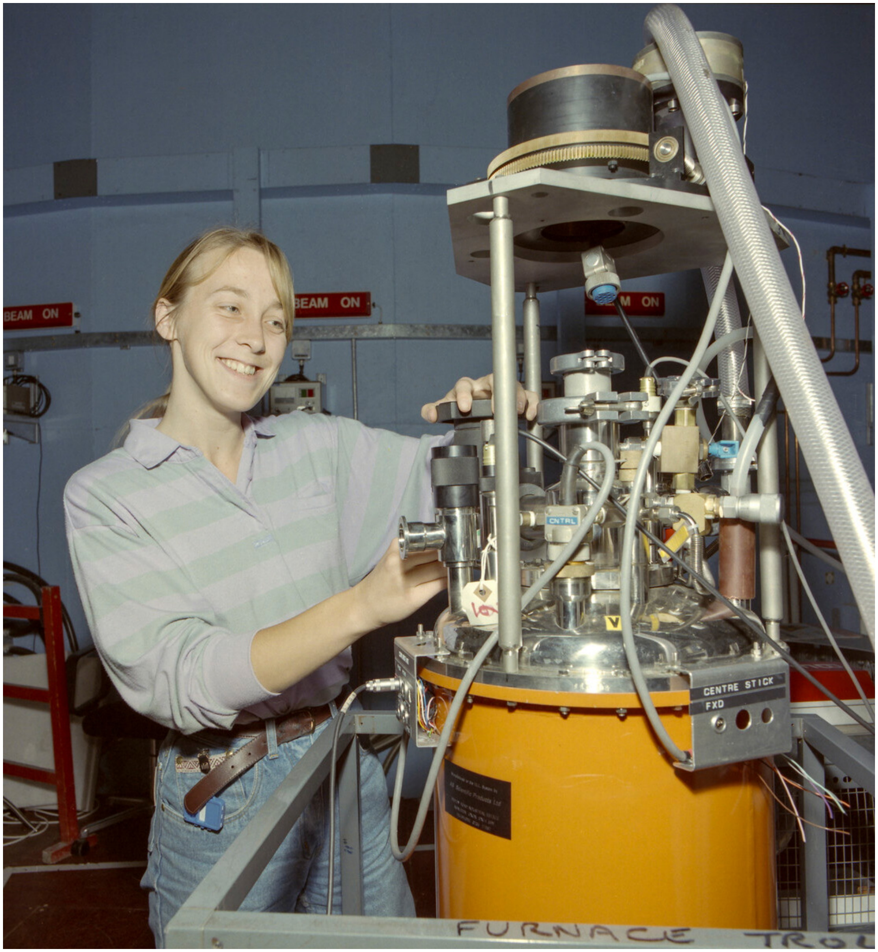
> "One thing that left a lasting impression on me from my time at ISIS was the purposeful environment – each day there was that strong drive towards progress. No doubt, the people are what make ISIS the remarkable facility that it is, and they were part of my inspiration to continue working with detector technologies to this day!"
>
> **Raheema Hafeji**
> former Industrial Placement Student in the Detector Group


With both gas and scintillator systems, the analogue and digital signal processing has been instrumental in delivering state-of-the-art detectors. Erik Schooneveld has been the bedrock of that development,
here testing a field programmable gate array system.

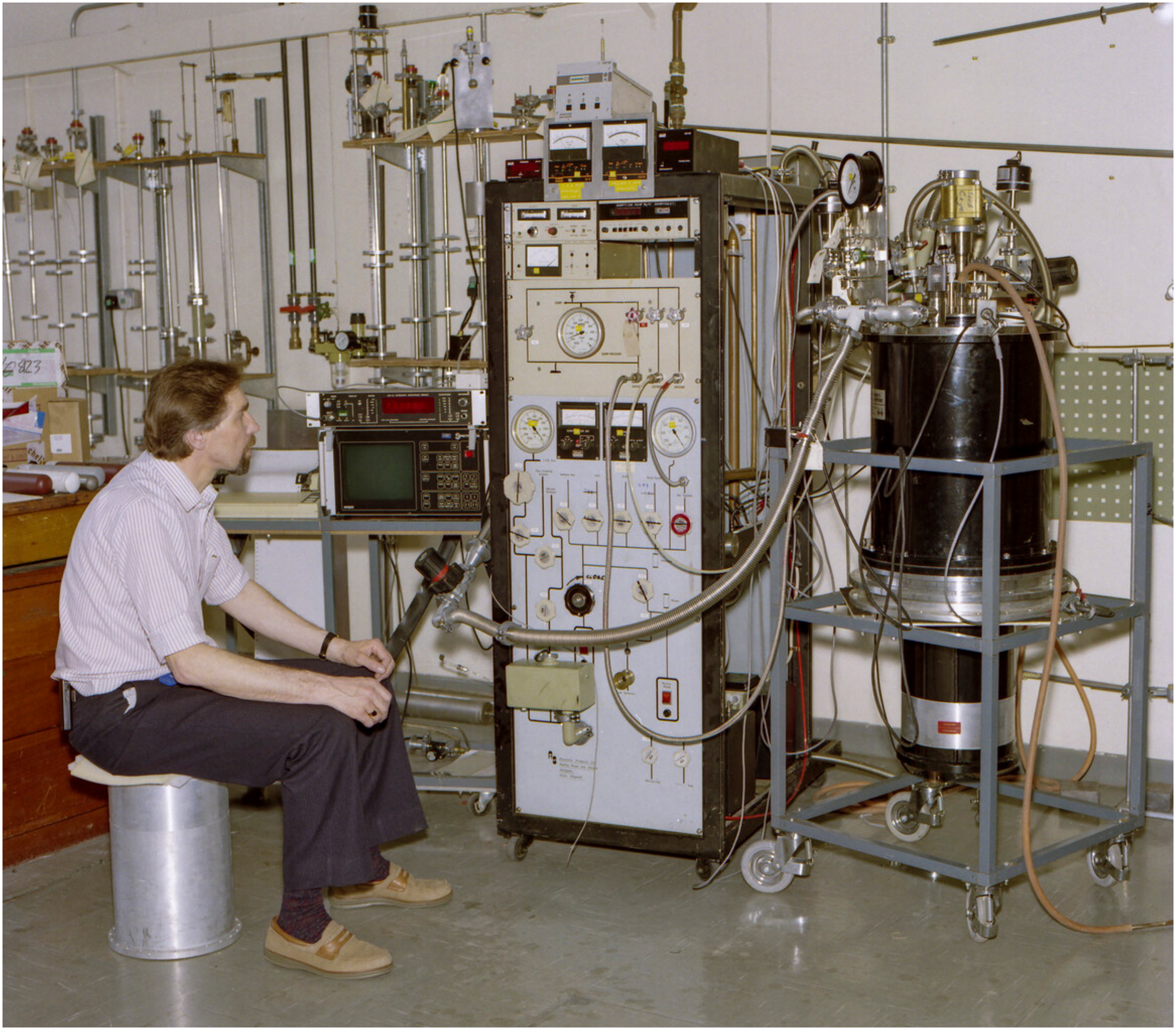
> “ISIS is a great place to work with passionate people who value my work and are very supportive of innovation.”
>
> **Erik Schooneveld**
> Detector Research and Development Section Leader

## Sample environment

**The first experiments at ISIS did not use advanced sample environments and room temperature experiments were common. Although closed-cycle refrigeration aimed to reach 10 K, 20 K was more achievable with helium cryostats. Basic furnaces provided elevated temperatures, and combining pressure, temperature, magnetic or electrical fields was still a future goal. Users mostly supplied their own soft condensed matter environments, although water baths were available. There was no characterisation equipment, and chemistry facilities were very limited.**

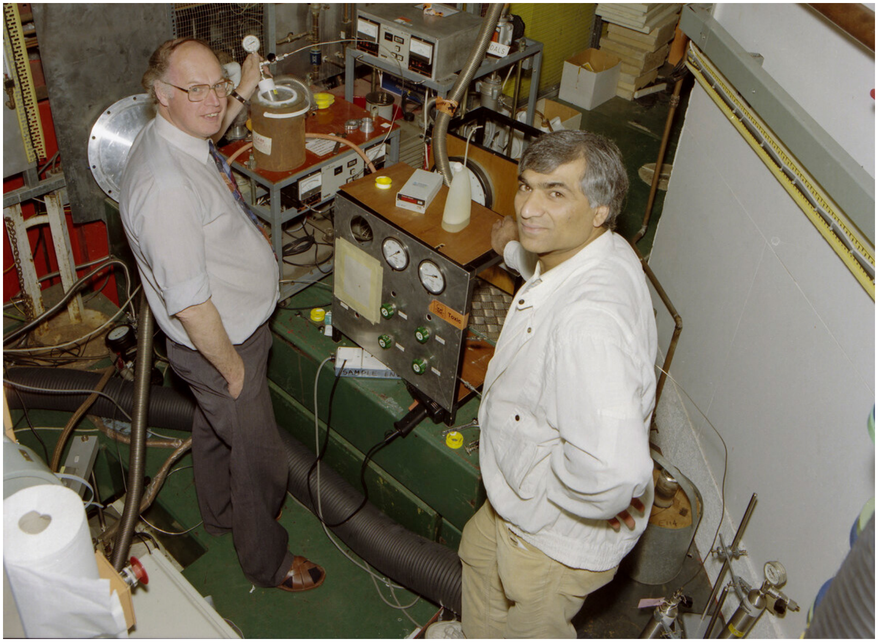



The orange cryostat, designed at the Institut Laue-Langevin, has been the stalwart for cold temperatures. Over the years, it has been improved but the basic design remains the same. SXD user Vicky Nield adjusts the cryostat in 1990.

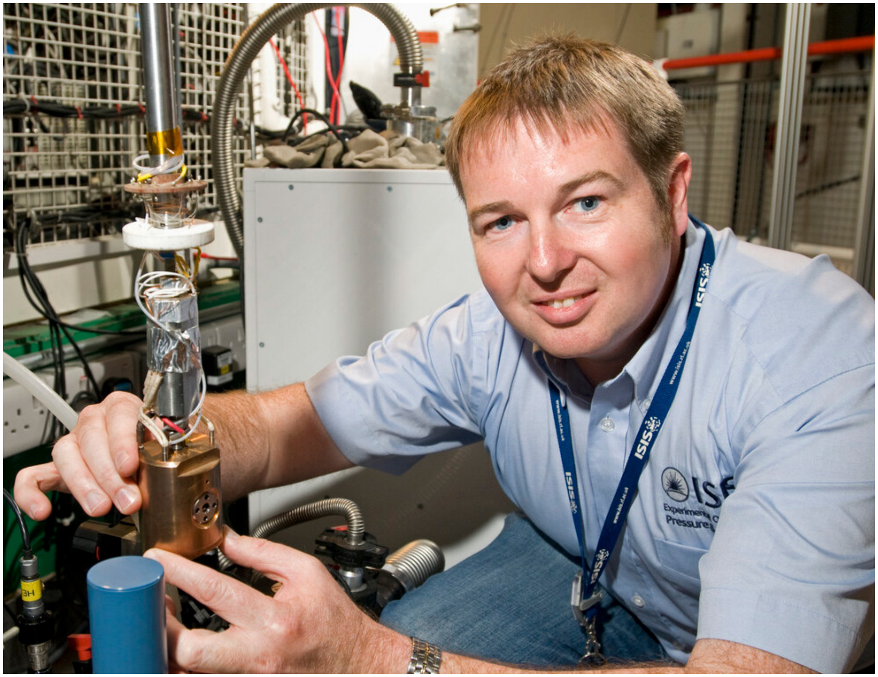


Ian Bailey, who led the Sample Environment team until he retired in 2005, tests the sorption cryostat, a system that could provide temperatures colder than outer space.


Alex Jones and placement student Lucy Bain from the Cryogenics Team work together to lift a liquid helium tank in Target Station 1.



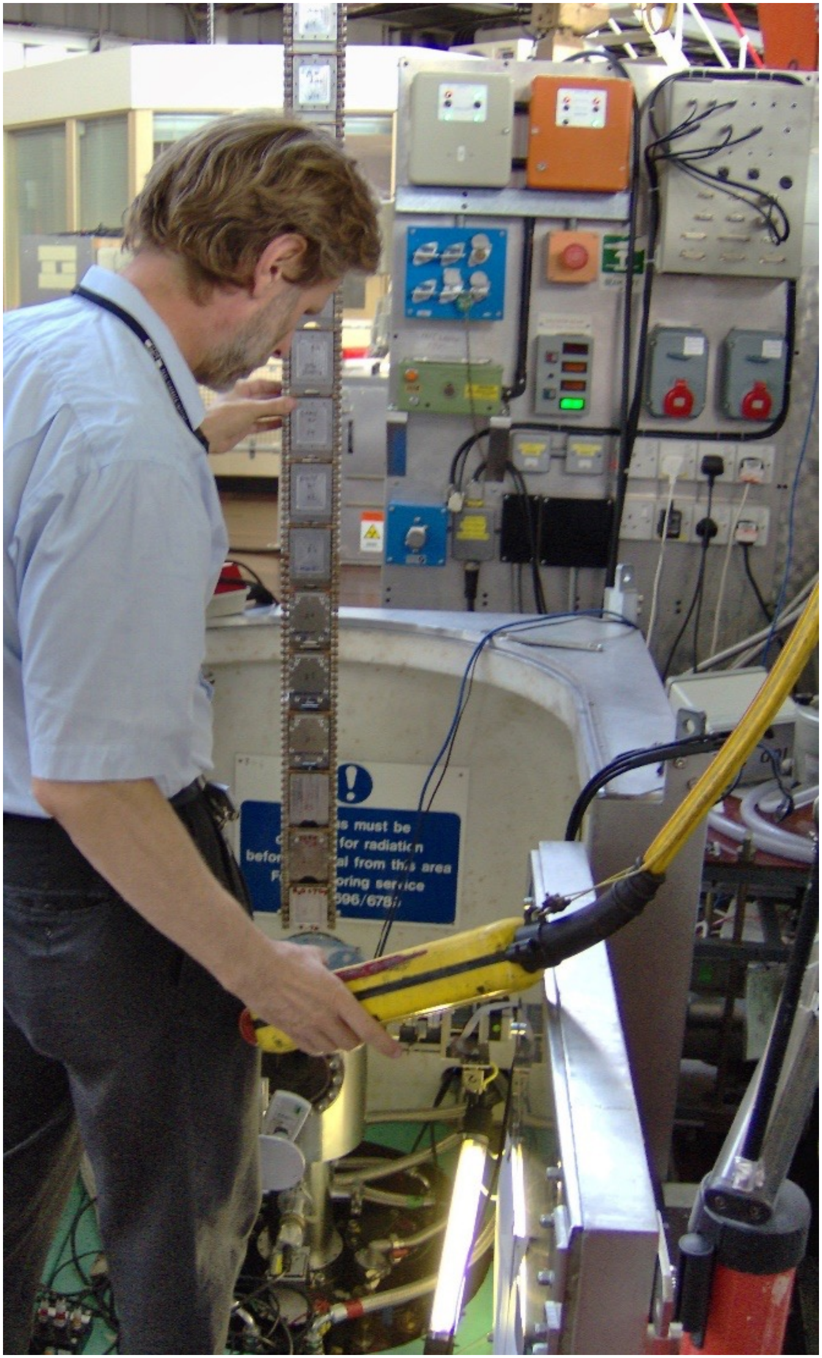
Other areas of sample environment have also become more complex. Here, an early gas-handling system is being used by Chris Wormald, University of Bristol, and Ashok Adya, University of Abertay, to condense carbon and nitrogen monoxide mixtures into a pressure cell on SANDALS.




Today, the combination of extreme temperatures, high pressures and magnetic field is the norm. Chris Goodway loads a pressure cell on to a cryostat centre stick on RIKEN in 2008.

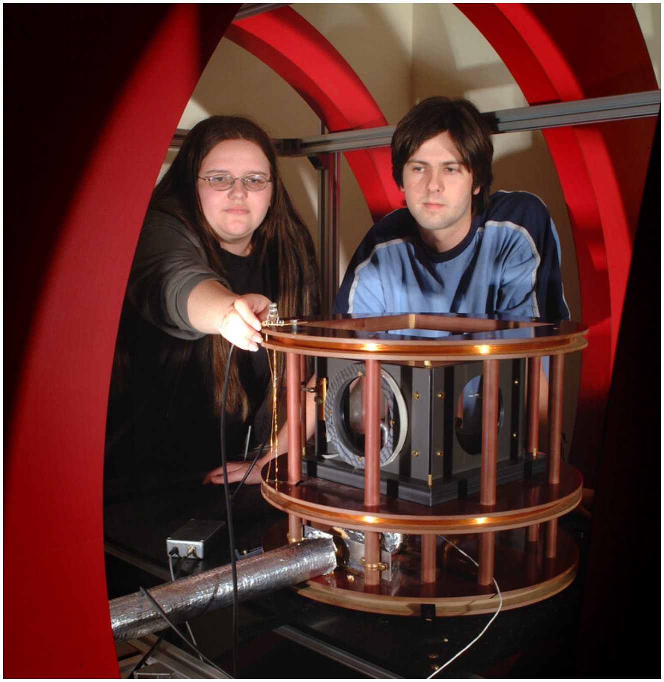

Neutrons are particularly good at investigating magnetic materials. The provision of strong magnetic fields is a key requirement at a neutron source. ISIS went from a single high-field magnet to five systems designed for dedicated areas of science.

Dave Bunce checks two new magnets, one for spectroscopy and one for diffraction, both delivering 10 T fields, in 2009.



As instruments became more powerful, the sample environment had to be adapted. One way to increase efficiency is to have an automatic sample changer to reduce the time taken to swap samples.

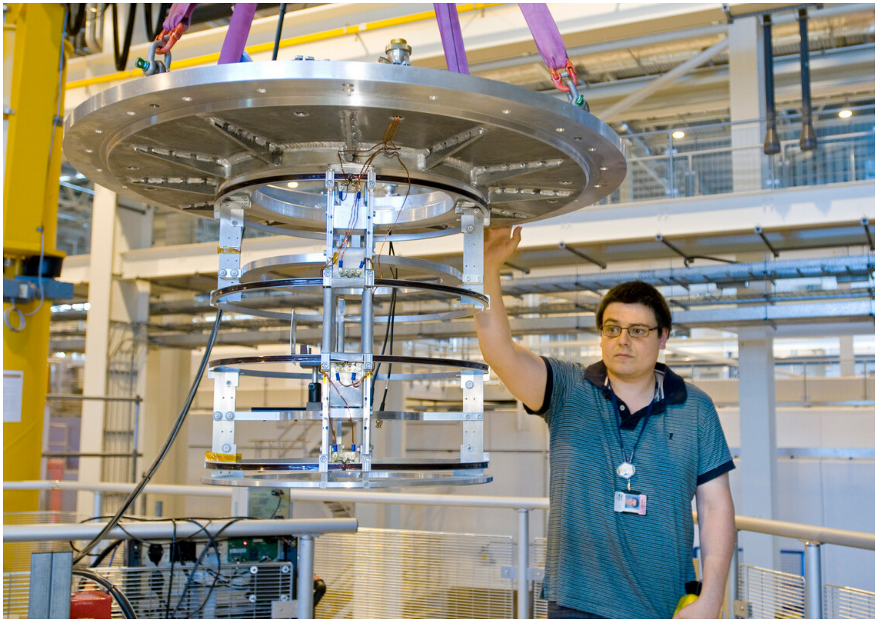
Stewart Parker installs the fully-loaded sample changer into the Tosca cryostat in September 2006.



## Polarised neutron techniques

**A key attribute of neutrons is a property called spin, which enables insights into a material's magnetic properties that other techniques cannot achieve. The process begins by aligning neutrons to have a single direction of spin, which can be achieved using a polarising filter.**

Steve Parnell and Kathryn Baker developing ISIS's first helium-3 filter systems in August 2002.



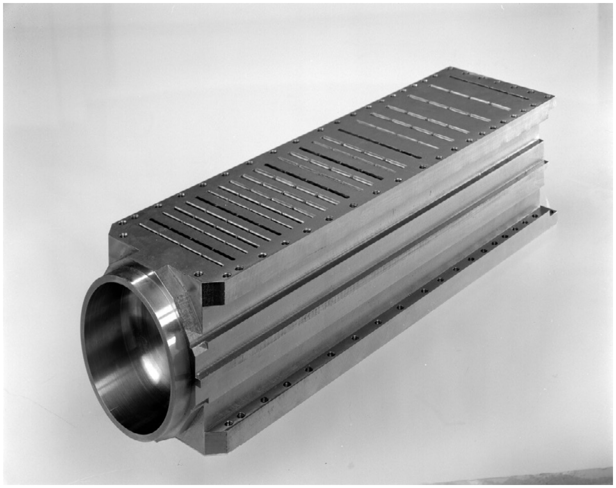
Pascal Manuel removing the polarised neutron insert device after its first use on WISH in August 2011.

In 2012, a joint project with the Institut Laue-Langevin saw the delivery of a helium-3 filling station for filters. The team is assembled with the newly installed FLYNN system in March 2012. Left to right: Ross Stewart, Jon Taylor and Joe Donaldson, ISIS; and David Jullien, Steve Boag and Pascal Mouveau, Institut Laue-Langevin. ISIS now regularly uses polarisation techniques on a growing number of instruments.

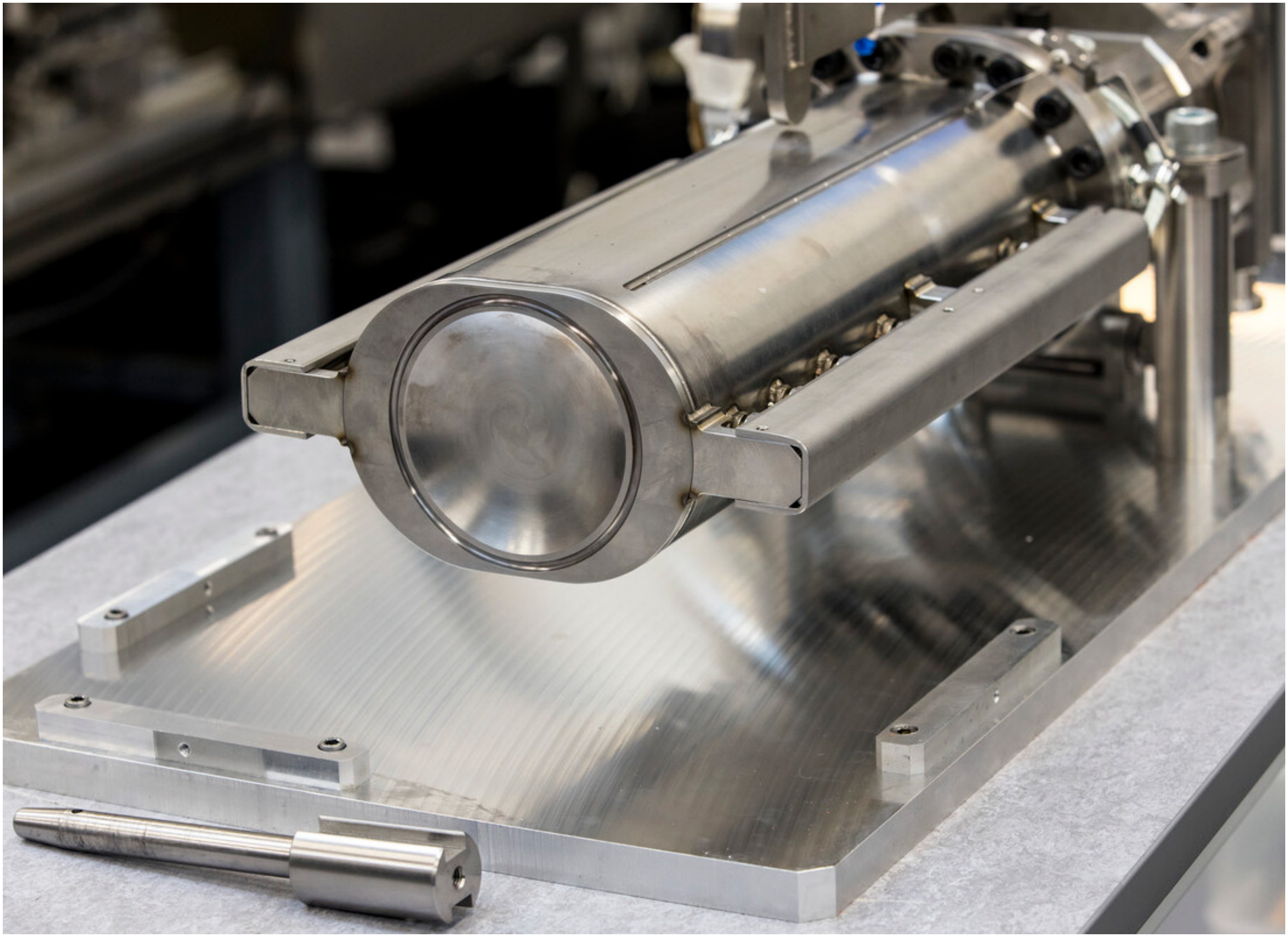
## Target manufacturing

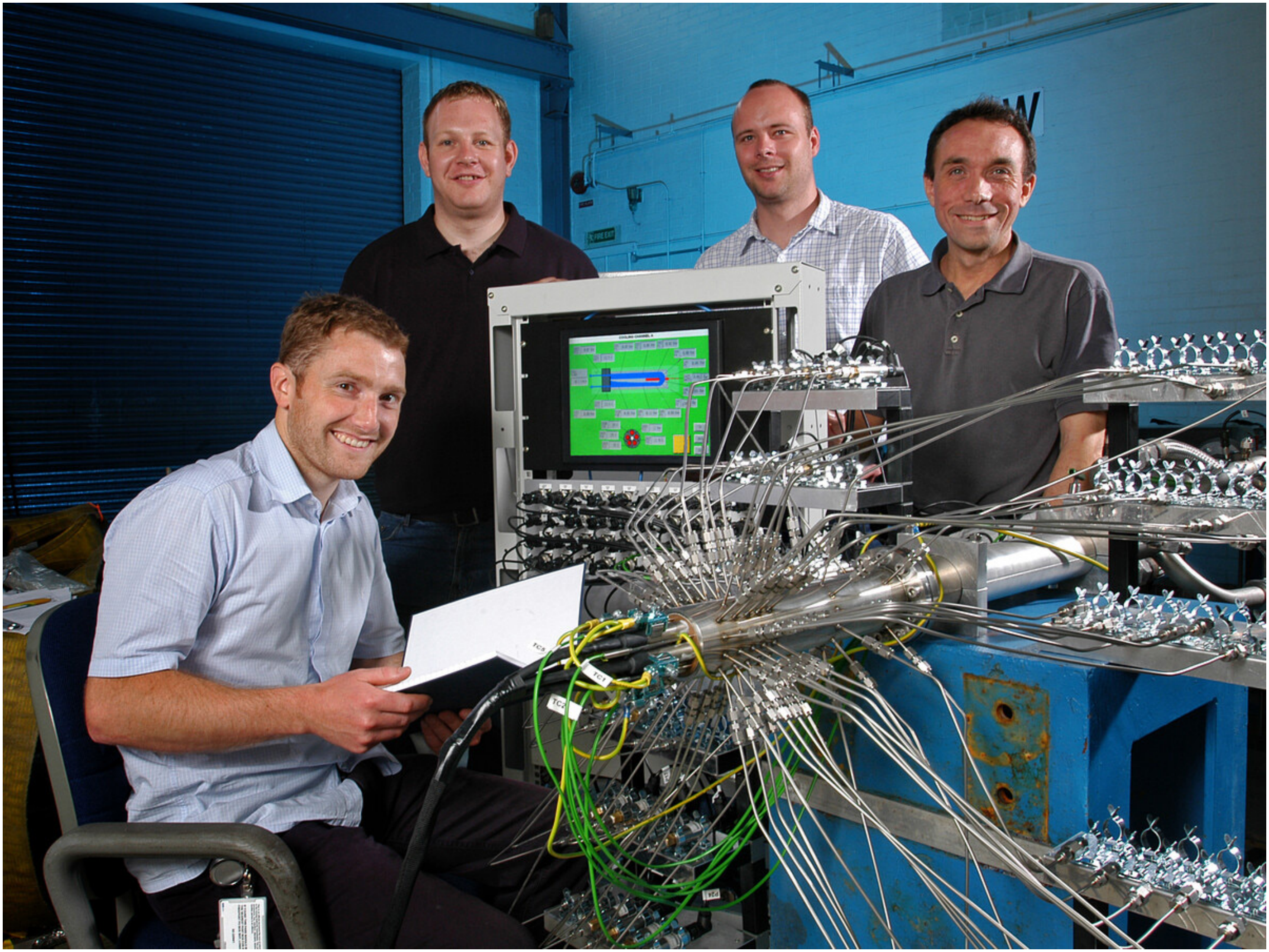
**As the power on Target Station 1 is four times greater than for Target Station 2, each has a very different target. The targets are made of tungsten protected by a tantalum outer coating.**

The internal part of the first ISIS target is shown on the left, and the assembled Target Station 2 target is shown on the right. The new Target Station 1 assembly is shown on the next page.



In 2012, the manufacturer who had supplied ISIS's targets since the 1990s gave notice that they were withdrawing from the business. This presented a major challenge, leading ISIS to bring target manufacturing in-house.





Much work on the processes and materials for target manufacture was needed. The new target designs had to be fully tested for flow, temperatures and pressures. Jon Chapman, Dan Coates and Dave Jenkins are seen receiving the results from Robbie Scott.


Jeremy Moor was tasked with the project of building a manufacturing facility at ISIS.

Working on the target manufacture in the new facility are left to right: Harry Moore, Rowland Maxwell and Peter Webb. In the foreground, Jeremy Moor, Leslie Jones and Dave Haynes discuss the design.

> "Initially it was exciting to be given the opportunity to develop a new facility and learn new processes but then after plenty of Google searches, the depth of the task hit home! I was always well supported and luckily never felt daunted during training or running the project. From the first day, I could see the opportunities to improve the equipment used by the previous manufacturer. Everyone, from the design team through to the whole manufacturing team, had a good grasp of the complexities of using tantalum and tungsten for targets and of exploiting the great facility that we have built. I think the production of ISIS targets is now assured long into the future."
>
> **Jeremy Moor**
> Target Operations Group Leader

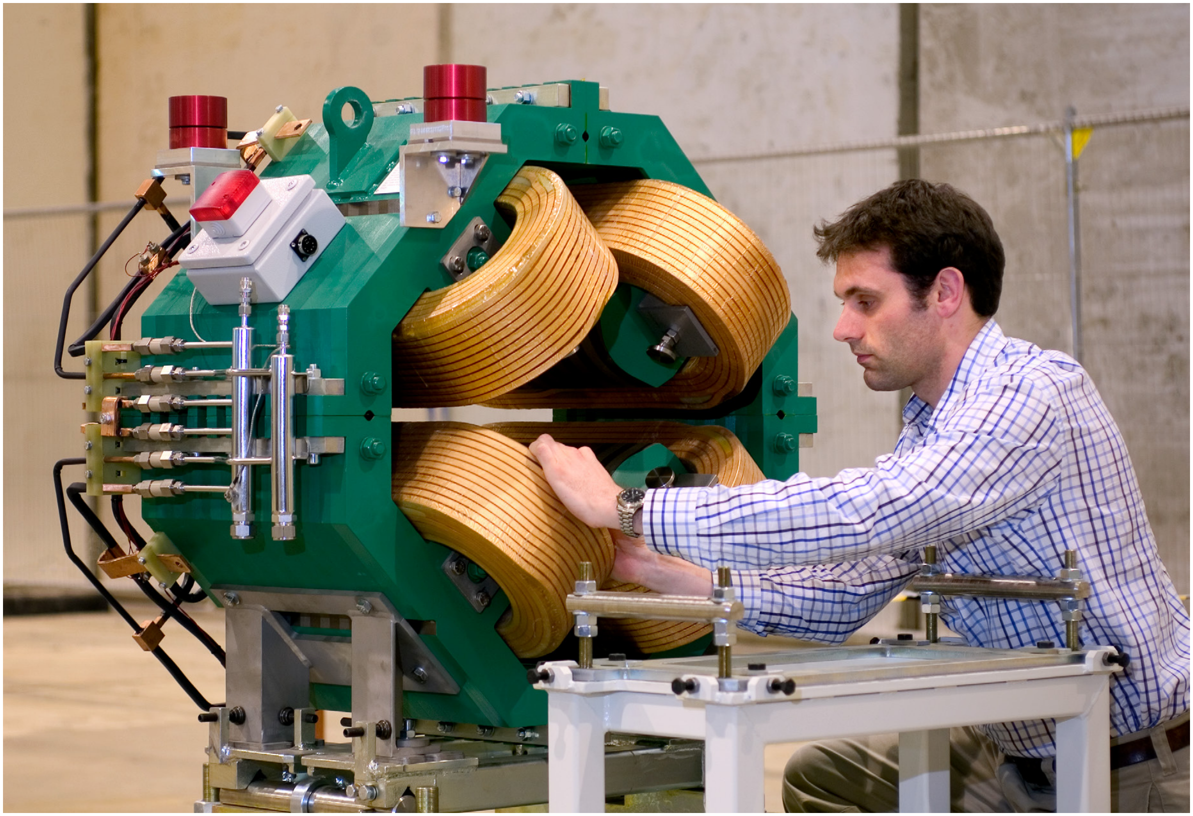
## Design, engineering and technical staff

The training of apprentices and graduates into highly skilled technical experts has been and remains vital to the continued success of ISIS. These home-grown designers, engineers and technicians provide essential expertise across the facility.


Scott Lawrie, ISIS Ion Source Scientist, won I'm A Scientist, Get Me Out Of Here! in April 2016. It is a student-led, online enrichment activity, connecting school students with people working in a diverse range of roles in STEM.

Graduate electrical engineer Stephen Turner testing super conducting materials on Engin-X in February 2016. Stephen joined Target Controls in 2017 and became a STEM ambassador, promoting the STFC graduate scheme, and was also UKRI Prospect Union Branch Secretary. He sadly passed away in spring 2022.


> “Stephen took a meticulous approach to his work, making sure he understood every detail. He was a kind and thoughtful man with a ready smile and good sense of humour.”
>
> **Robin Burridge**
> Target Controls Section Leader



Stephen Jago inspects a quadrupole magnet in May 2006.

> "I came to ISIS as a graduate engineer in 2002. I've been lucky enough to have been involved in some really significant moments in the history of ISIS - from working on the Target Station 2 project, to helping bring on the new Target Station 1 target and moderator systems – all meant a lot of hard work and some late nights, but it has been a real privilege to be part of the team that got them done!"
>
> **Stephen Jago**
> Design Division Head

Len Pearce receiving his apprenticeship deeds from then Rutherford Appleton Laboratory Director, Paul Williams, in 1990.

> “I have particularly enjoyed my involvement with the apprenticeship scheme. It is nice to give a bit back to the scheme which set me on my way back in 1996!”
>
> **Len Pearce**
> Access Control and Instrumentation Section Leader

The opening of the Helium Recovery Facility in June 2016 was a significant milestone for ISIS. The system has been a huge success. Despite the increase in helium needed for experiments at ISIS over the last few years, the amount of helium recovered at ISIS has increased and is now around 95%.

Left to right: Rajesh Kumar Gupta, Richard Down and Jeff Keeping celebrate the opening of the Helium Recovery Facility.

> "My journey at ISIS began in 2006 as a Senior Controls Engineer, and joining the organisation felt like a dream come true. My work here has been both enjoyable and deeply rewarding, offering the chance to engage with cutting-edge technologies and collaborate with experts from various fields. One of my most fulfilling projects was designing, installing and commissioning the control systems for Target Station 2, the Helium Recovery system and more recently, Target Station 1. These experiences have greatly contributed to my professional growth and enabled me to support groundbreaking scientific advancements."

**Rajesh Gupta**
Target Controls Section Leader

Katherine Mordecai started her apprenticeship in 2015, working with different groups around ISIS until eventually joining the Experimental Operations Team in 2019. Katherine maintains and installs new instruments across ISIS and is here checking the bellows of the transmission monitor for the European Spallation Source (ESS) instrument, LoKI, in February 2022.

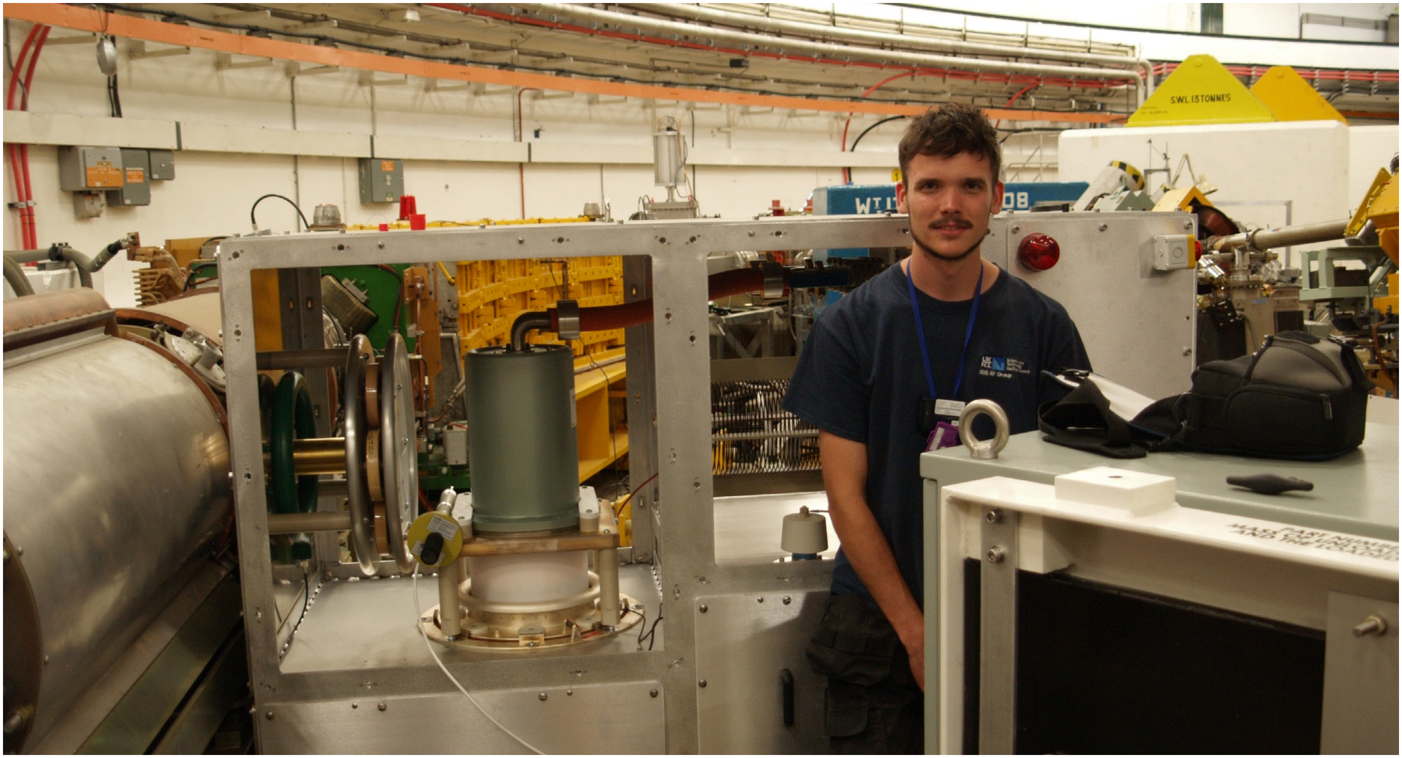
> “I enjoy the range of work a technician can get involved with from supporting experiments to installing new instruments. I feel grateful that I get to work on such exciting projects and instruments. One of my best memories is assembling and testing the sample snout for European Spallation Source (ESS) instrument LoKI.”
>
> **Katherine Mordecai**
> Senior Mechanical Technician

2023 was a ground-breaking year for Tara Allinson. Not only did she win STFC Apprentice of the Year but also ‘Highly Commended’ for both the Impact and Peer Support Awards and the ‘Regional Highly Commended’ at the National Apprentice Awards and ‘Best Project HNV Electrical and Electronic Engineering’ at UCN Expo. During her apprenticeship, which she completed five months early, she designed an electronic circuit to prevent the inefficient filling of cryostats.

Tara Allinson accepting her award for STFC Apprentice of the Year in November 2023.

> “Becoming an apprentice at ISIS is a really good opportunity to be introduced into the workplace, whilst simultaneously gaining an education and also receiving a salary. A-levels isn’t necessarily the preferable route. I started at ISIS when I was 17 and I can’t tell you how much it’s helped me with my confidence.”
>
> **Tara Allinson**
> Electronics Engineer

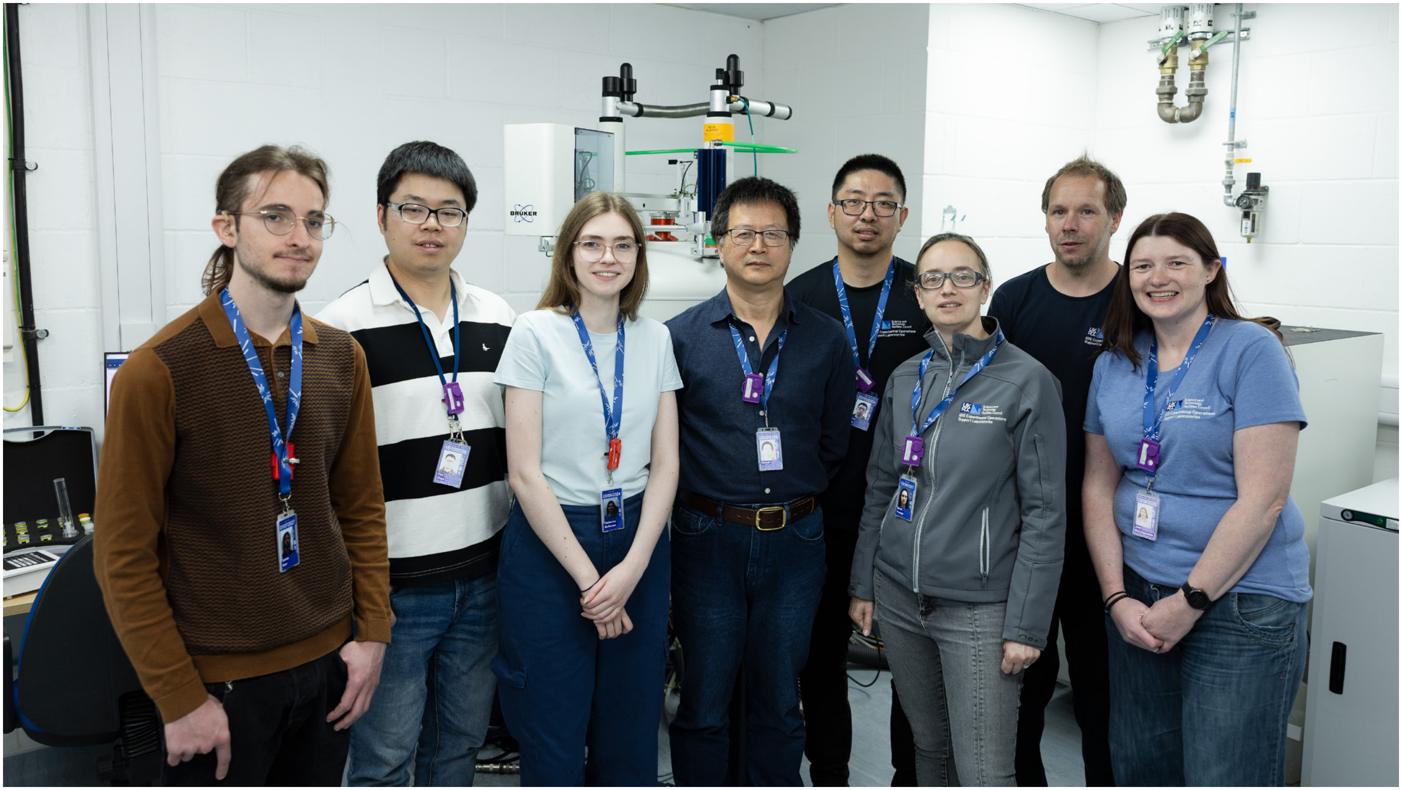
During the same year, having encouraged her to apply, Tara's brother Ryan Allinson, formerly an Electronics Technician with the Radio Frequency Group, obtained a first for a BEng in Electrical and Electronic Engineering and joined the Diagnostics Group.



> "I find ISIS a rewarding place to work as there is flexibility to take a project from concept to commissioning. I find the entire process hugely motivating seeing how I can change an idea to an operational piece of equipment supporting world leading science!"
>
> **Ryan Allinson**
> Diagnostics Electronics Engineer

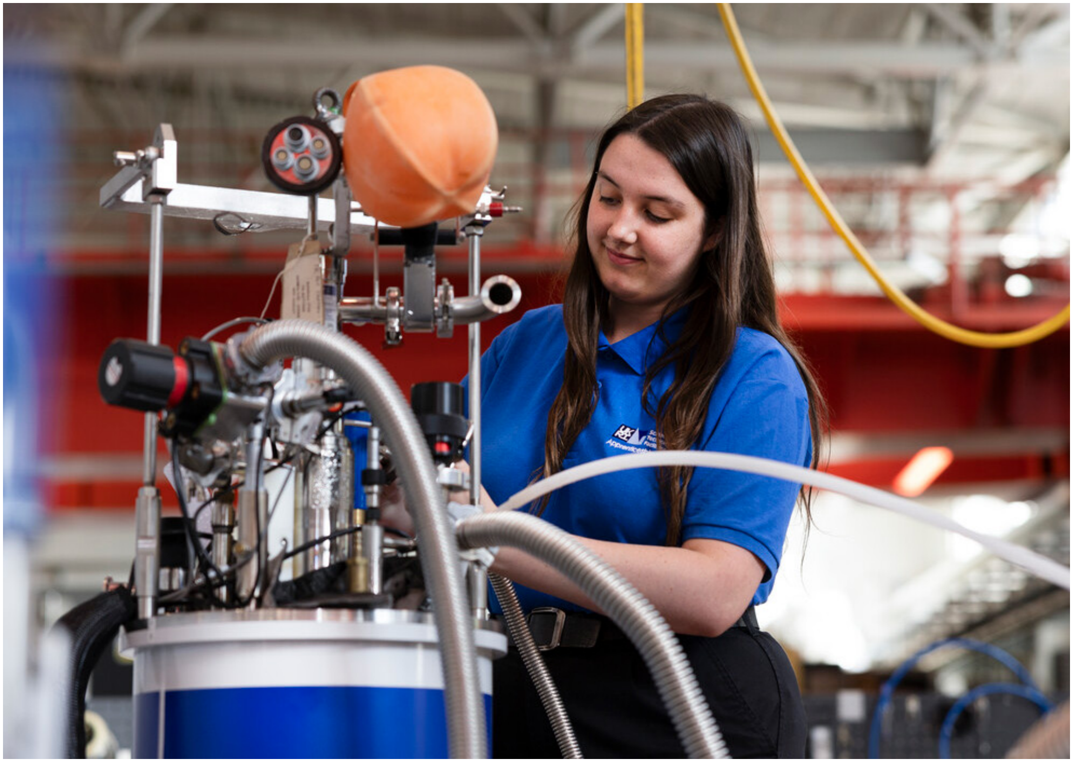
Madi Woollard joined ISIS as an apprentice in 2020. She now works on dipoles and tanks, as well as machining parts, and is shown here inspecting them to ensure all requirements are met.

> "My time here so far has been amazing. No day is the same and it's one of the many things I love about working here."
>
> **Madi Woollard**
> Mechanical Support Technician



The Deuteration Laboratory team in July 2024. Left to right: James Keer, Yao Chen, Catherine McKeown, Peixun Li, Kun Ma, Sarah Youngs, James Tellam and June McCorquodale.

> “A standout memory has been witnessing the evolution of the ISIS Deuteration Laboratory. It began with a single postdoctoral researcher and has since grown into a dedicated team of five permanent staff, regularly joined by summer students, placement students, visiting scholars and additional postdoctoral researchers.”
>
> **Peixun Li**
> ISIS Deuteration Scientist Lead



Ella Ward began her apprentice training in 2021, here gaining hands-on experience by managing the ultra-low cryostat, ensuring the mixture is returned safely to the dilution fridge.

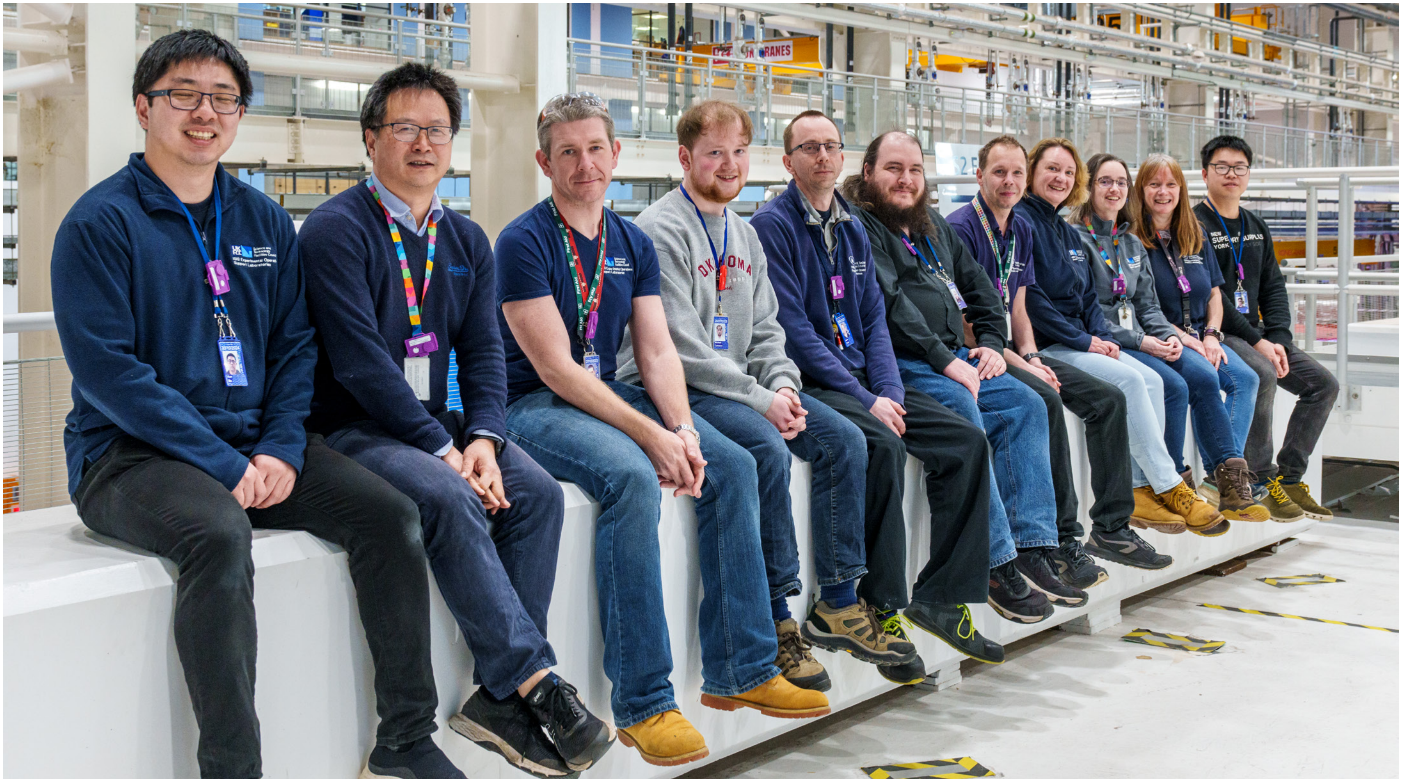
> "I've had the opportunity to learn from several teams, including Cryogenics, Soft Matter, Target Operations, Target Manufacture and the Sample Environment Design Group. This experience has been incredibly rewarding, allowing me to gain a diverse set of skills and knowledge. I am thoroughly enjoying my time at ISIS and feel that I have grown into a more well-rounded technician because of the work I have been exposed to."
>
> **Ella Ward**
> Mechanical Apprentice

# Supporting user research

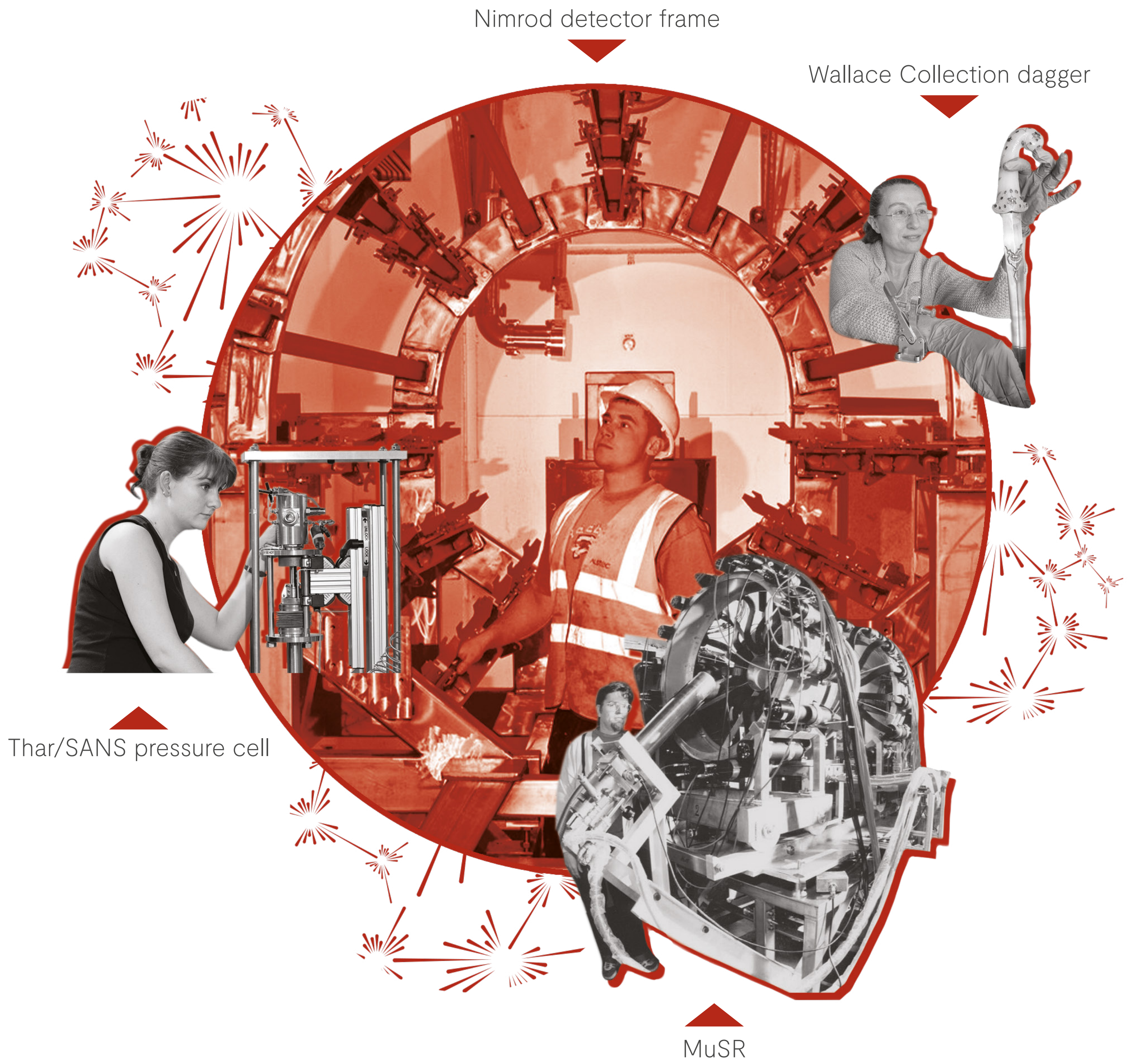
**There are many dedicated teams and individuals across ISIS provide essential assistance to researchers before, during, and after their experiments, helping them to maximise the outcomes of their work at ISIS.**

## Support Laboratories

The ISIS Support Laboratories team assists users in preparing and analysing samples for beamline experiments and provide advice and support to ensure health and safety. The laboratories cover a wide range of areas, including biology, chemistry, deuteration, hydrogen and catalysis and materials characterisation.



Left to right: Kun Ma, Peixun Li, Gavin Stenning, Michael Cameron, James Taylor, Daniel Nye, James Tellam, Ludmila Mee, Sarah Youngs, Sarah Langham and Yao Chen, 2023.


Nimrod detector frame
Wallace Collection dagger
Thar/SANS pressure cell
MuSR

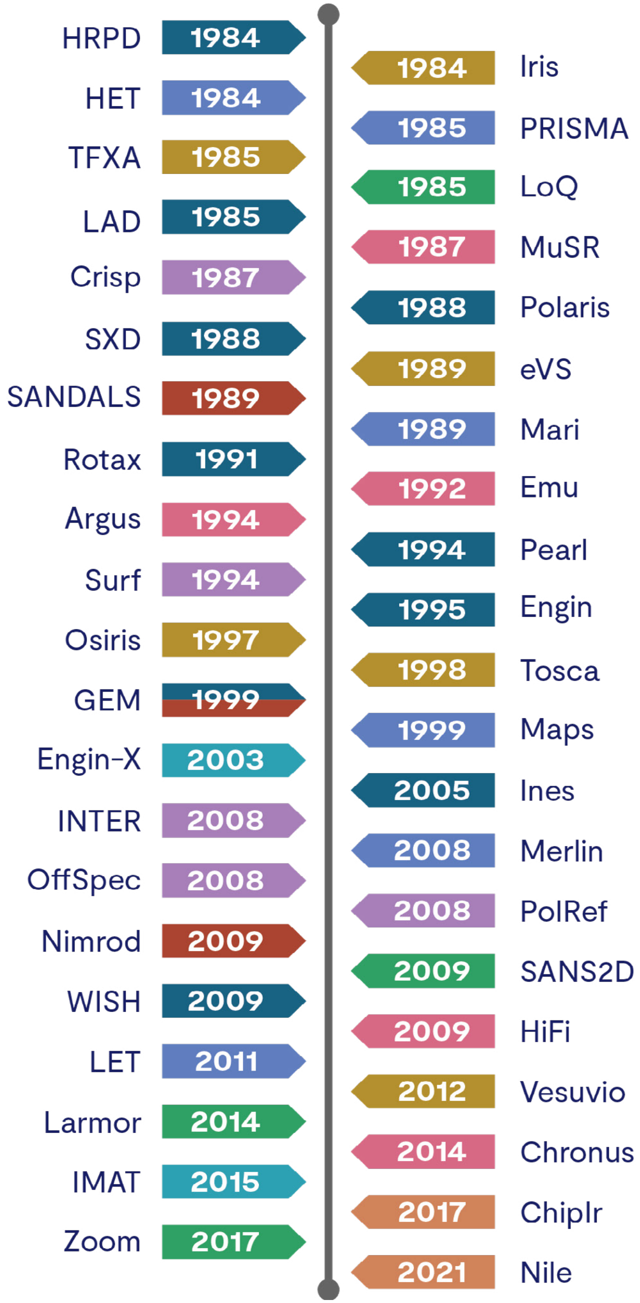
# Instruments

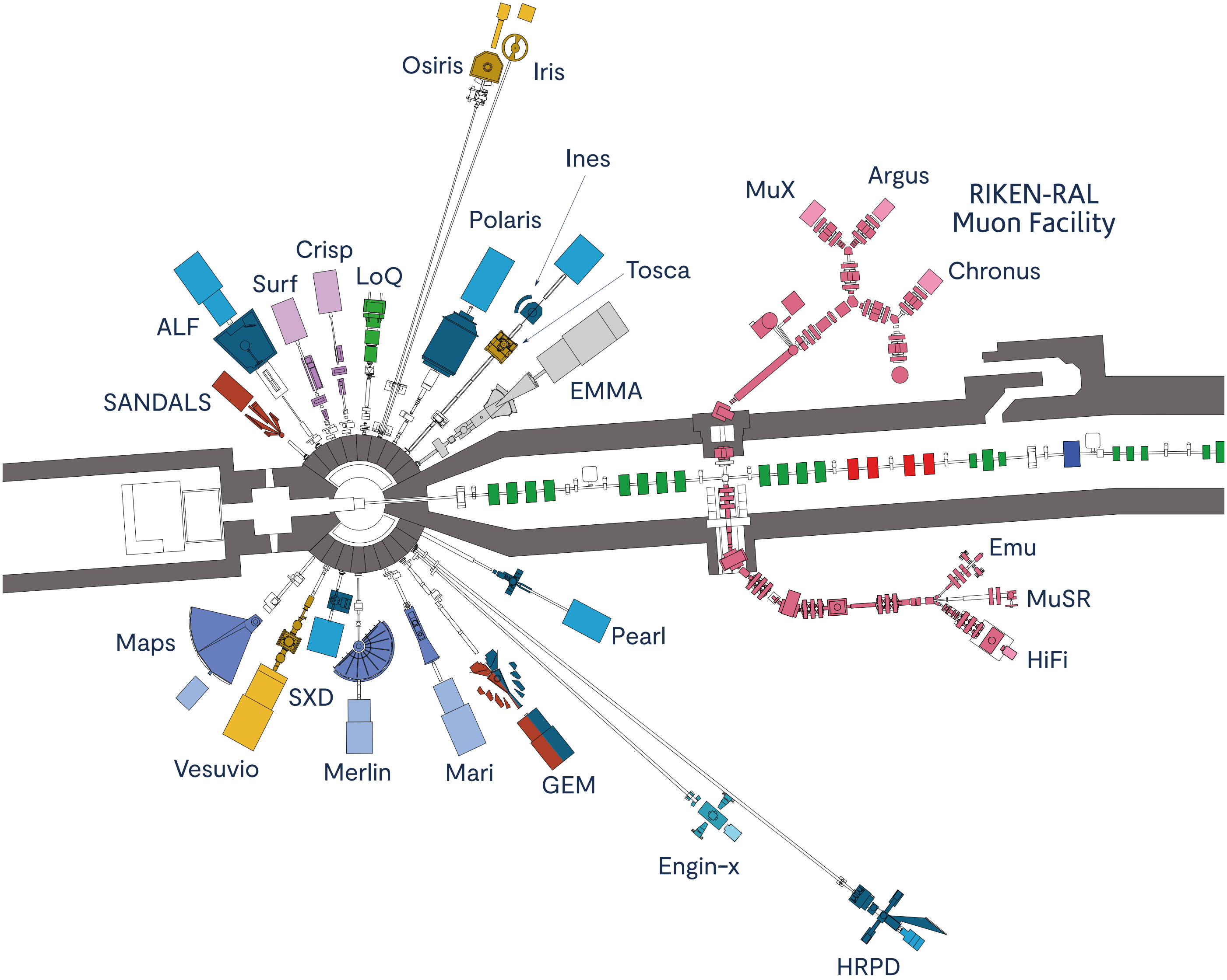
**Over the course of 40 years, the suite of neutron and muon instruments at ISIS has provided unique insights into the properties of materials on the atomic and molecular scales. From imaging to spectroscopy and diffraction to irradiation, capability and capacity have grown and developed such that we now offer an outstanding set of over 30 experimental stations, with more planned through the Endeavour programme.**

Led by the science needs of the user community, the ISIS instrument suite has evolved dynamically throughout the facility's lifetime and at each step in this journey, has delivered enhanced performance. The ability of our instruments to investigate the structure and dynamics of materials in unprecedented detail ensures that the UK remains at the forefront of global materials research.

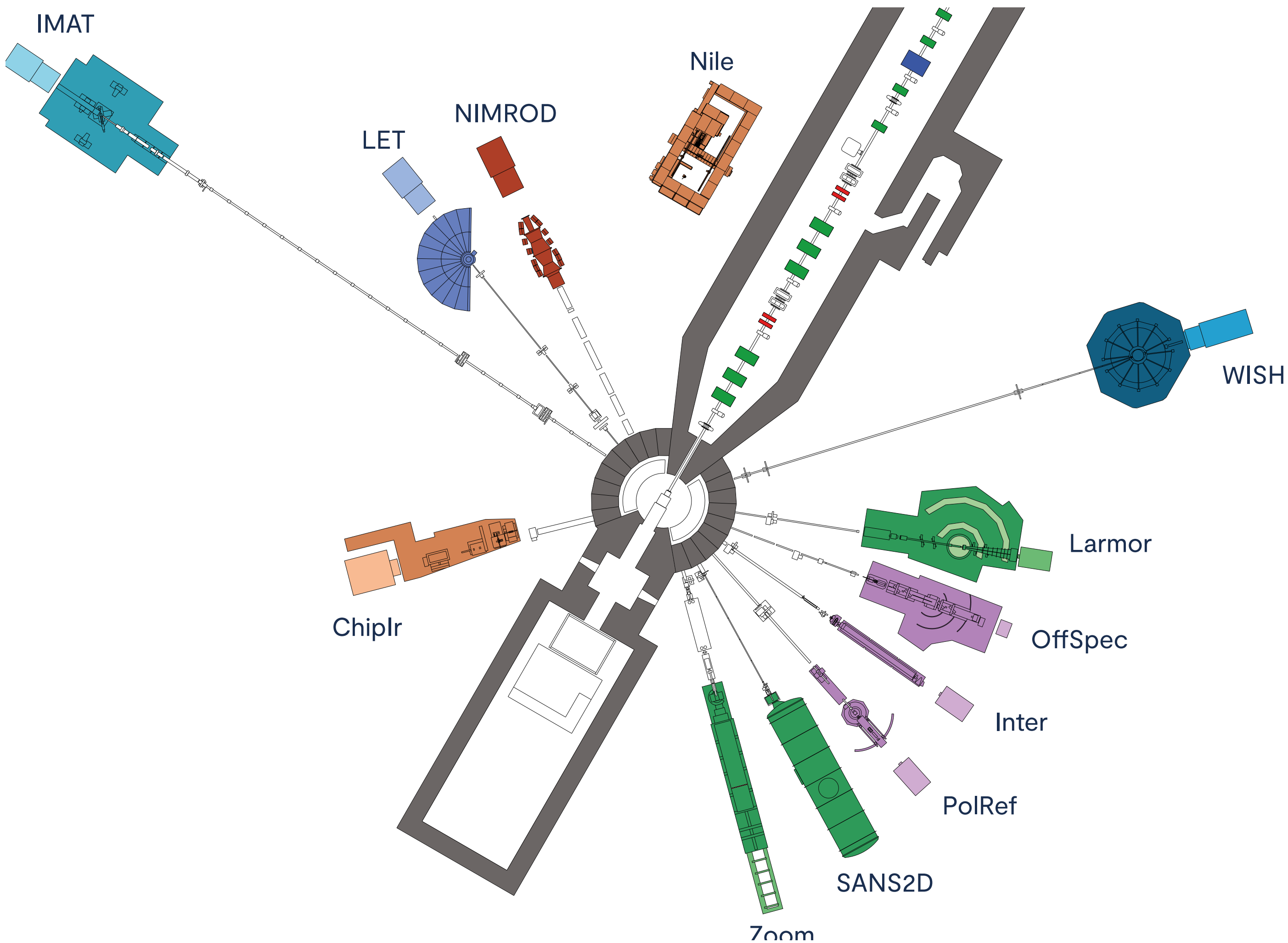
## Types of instruments at ISIS

- Diffractometry
- Reflectometry
- Small-angle scattering
- Molecular spectroscopy
- Excitations
- Muon spin relaxation, rotation and resonance
- Neutron irradiation
- Imaging and diffraction
- Disordered materials






Schematics showing the layout of the instruments in Target Station 1 (above) and Target Station 2 (next page).

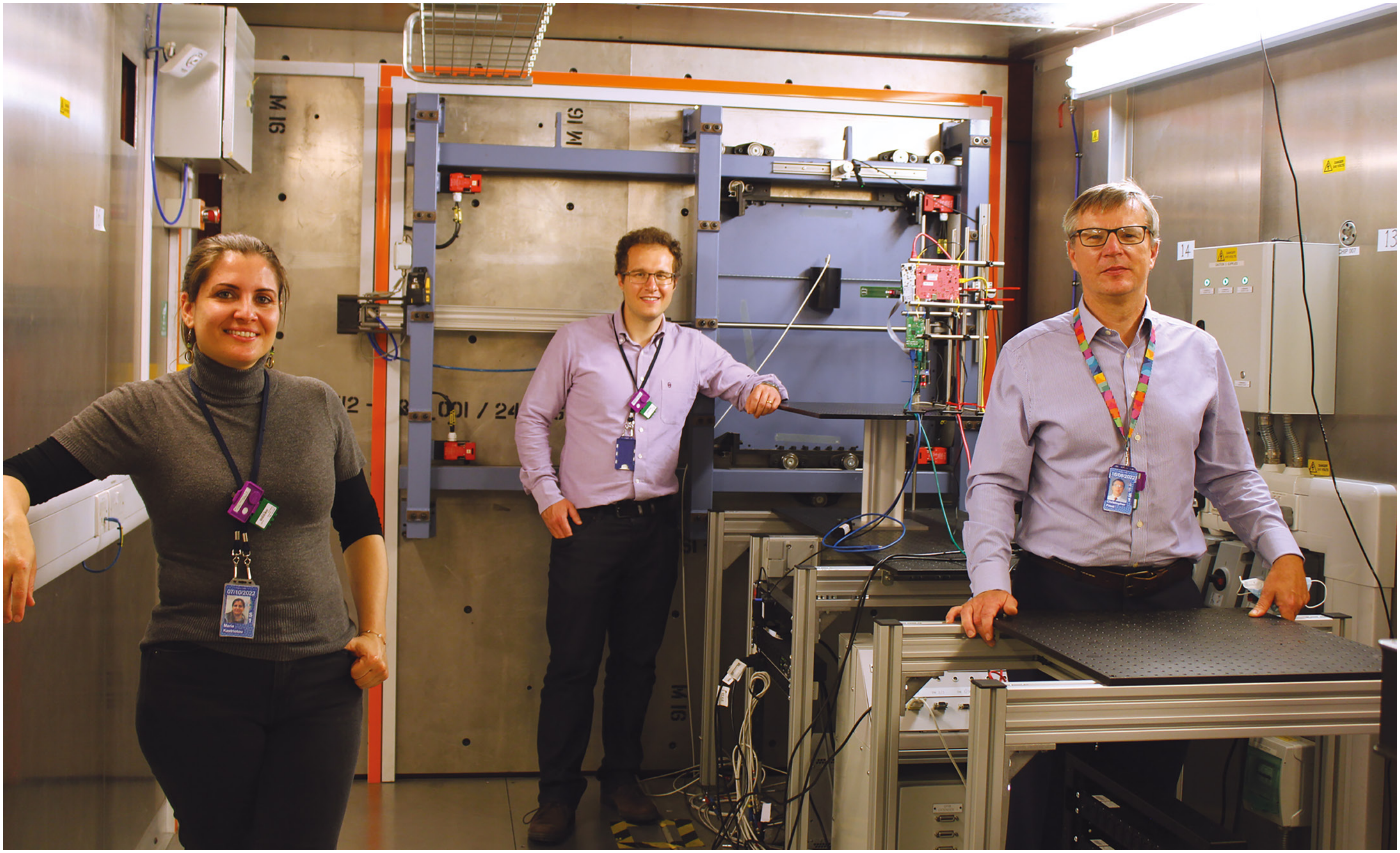

IMAT
LET
NIMROD
Nile
WISH
Larmor
ChipIr
OffSpec
Inter
PolRef
SANS2D
Zoom

# Neutron irradiation

**Mimicking the interaction between high-energy cosmic rays and electronics through microelectronic irradiation.**

## ChipIr

ChipIr uses the very highest energy neutrons produced by ISIS to mimic those produced by cosmic rays - but a billion times brighter. This allows companies to test the disruption of the electronics that lie behind the internet, electric vehicles, AI technology and more.

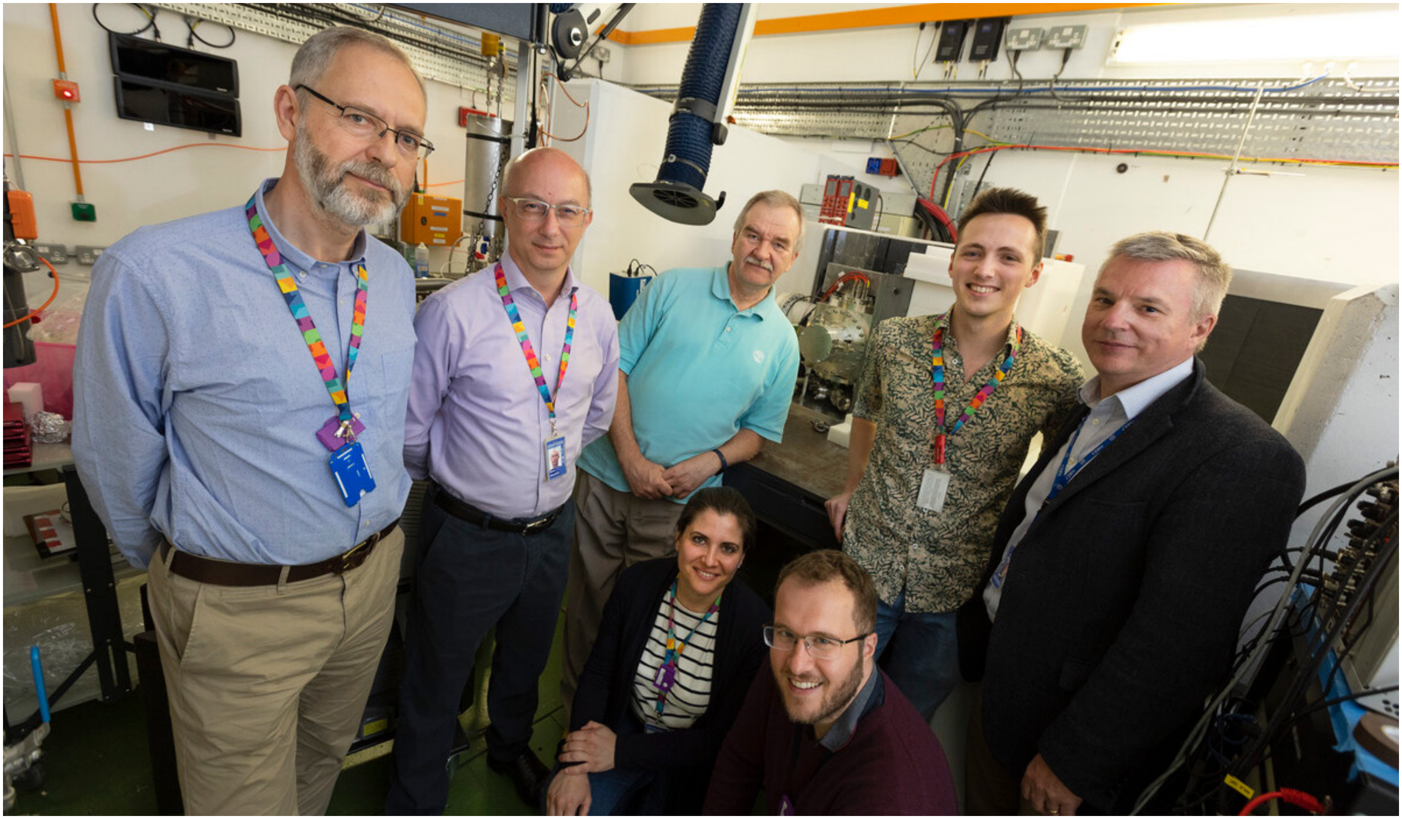



Instrument Scientists Maria Kastriotou, Carlo Cazzaniga and Chris Frost at ChipIr.

## Nile

Operational since 2021, Nile is the only instrument that does not use the ISIS accelerator. Instead, it employs two small fusion-based neutron sources to provide fast-neutron irradiation capability for electronic and detector testing, training and neutron activation studies.

In 2023, a team led by STFC's Particle Physics Department and Imperial College London proposed an experiment on Nile to help search for the so-called 'Migdal' effect – a rare phenomenon key in the hunt for dark matter.



Left to right, top: Pawel Majewski, Dave Newbold, Sergey Balashov, Timothy Marley and Chris Frost. Left to right, bottom: Maria Kastriotou and Carlo Cazzaniga.

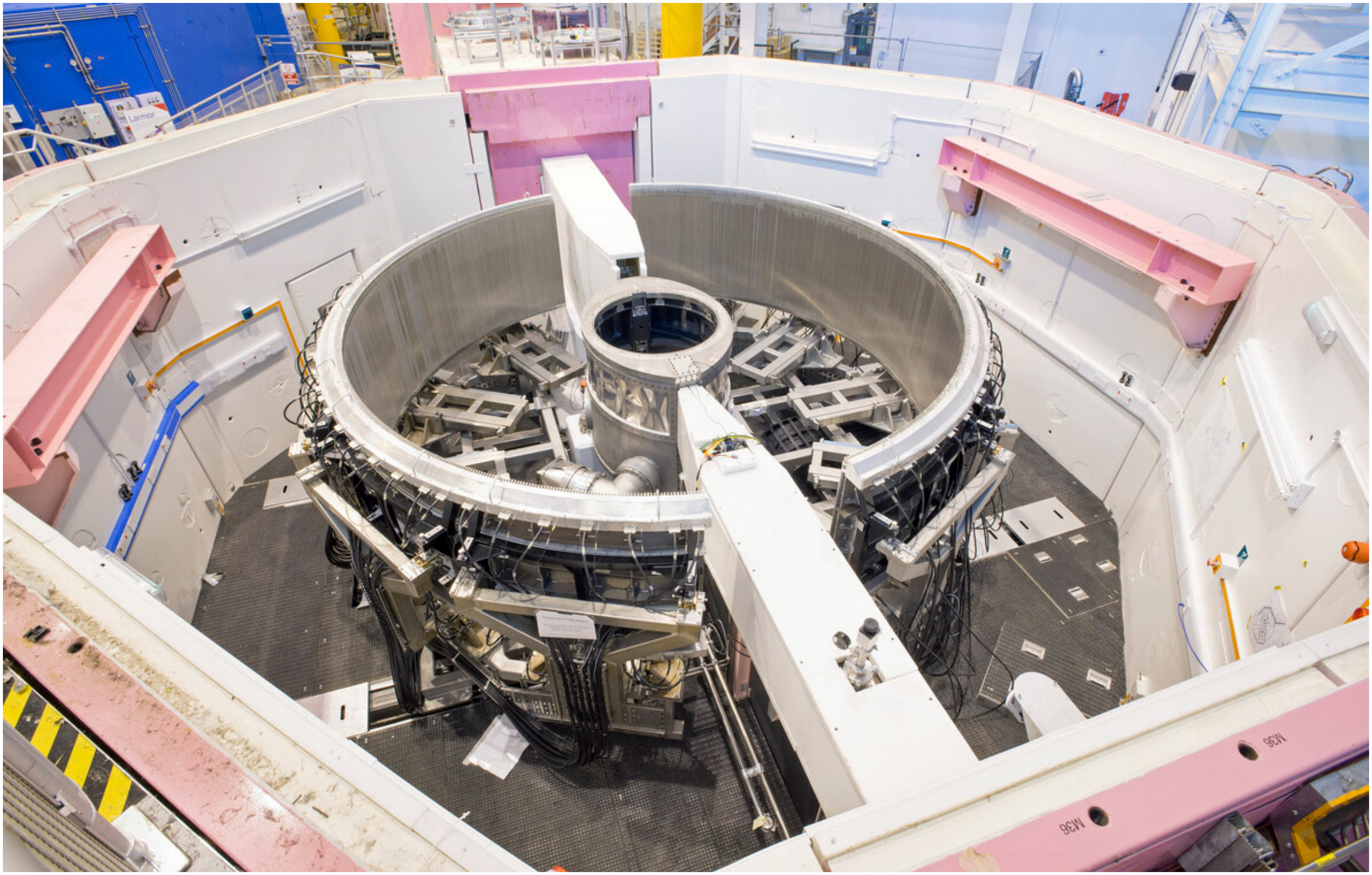
# Crystallography

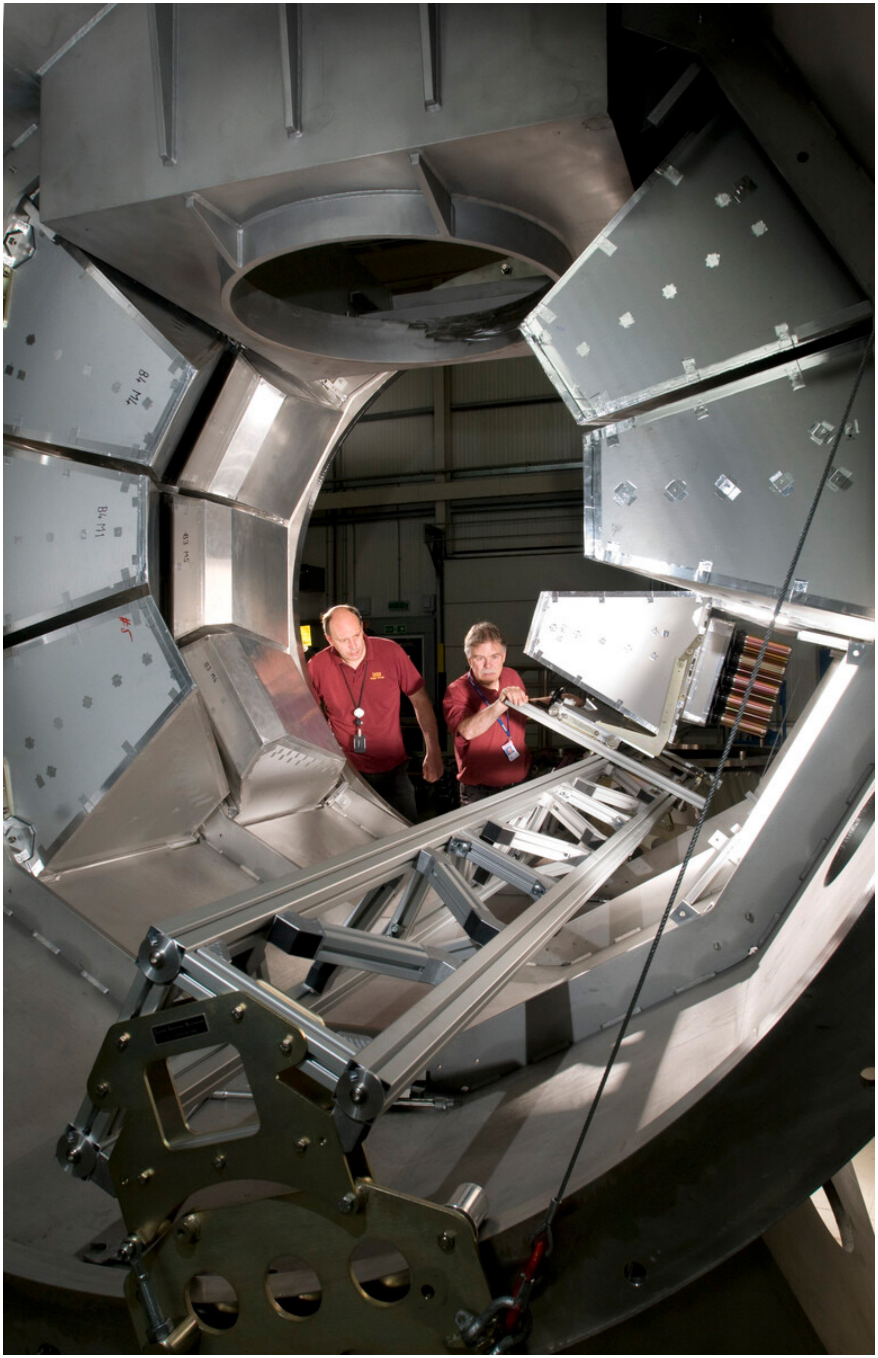
**Characterising the composition and arrangement of atoms in materials.**

## WISH

WISH uses long-wavelength neutrons to reveal structural details in functional materials with large cells, such as complex magnetic materials and porous framework materials.

Here, we have a unique look at the WISH instrument inside its block house. The detector array (outer grey circle), neutron guide housing (lower white inserts) and sample environment space (centre) are all visible, September 2014.





## Polaris

Originally a very early attempt to use polarised neutrons at a spallation source, Polaris has operated as a powder diffractometer since the late 1980s, occupying two different beam ports and undergoing four separate builds. It is used to study atomic positions in crystalline materials, with recent experiments investigating charging and discharging of lithium batteries, and the synthesis of thermoelectric materials used to generate power from waste heat.

During the upgrade of Polaris in July 2011, Geoff Eacott and Ashley Lester install detector modules into the new instrument vacuum vessel. The upgrade provided a factor four increase in count rate, an improvement in sensitivity and an increase in neutron detection efficiency.

## SXD

Among the instrument suite, SXD was and still is the only single crystal diffractometer. Its detector array has expanded over time from one to eleven detectors to obtain very precise structures of molecular, pharmaceutical, mineralogical, magnetic and engineering single crystals.

In 2024, new detectors were installed on SXD. This upgrade afforded higher neutron detection efficiency and an increase in neutron count rate. As a result, SXD can now measure much smaller single crystals, which is advantageous for materials that can only be made in minute quantities.

> "What I love about working at ISIS is that we can enable the pieces of the jigsaw puzzle to come together. The samples that come to us often have so many properties and the multi-technique approaches available at ISIS help in multi-disciplinary areas."
>
> **Matthias Gutmann**
> SXD Instrument Scientist

## HRPD

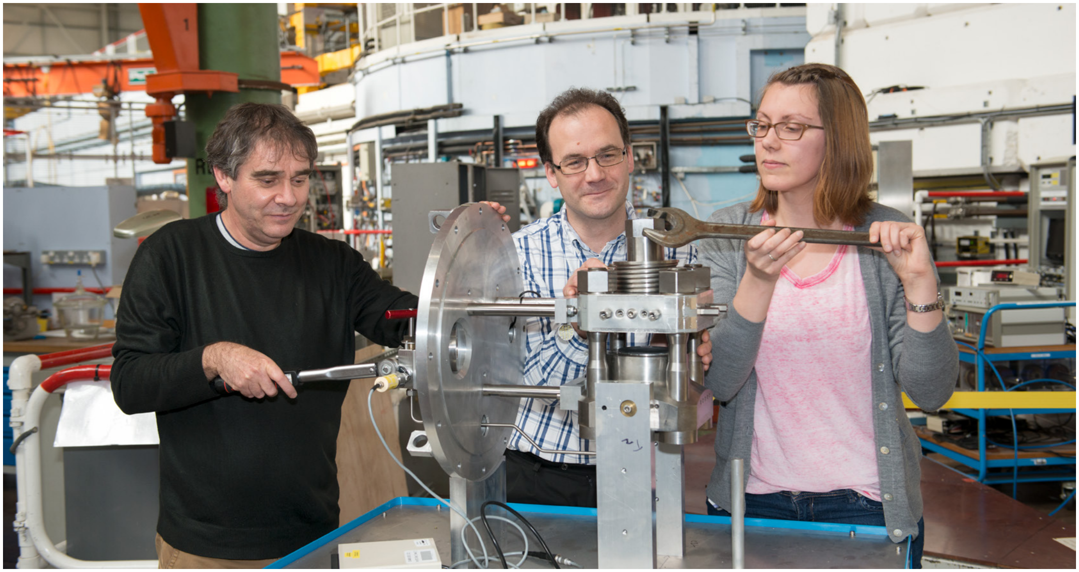
HRPD was one of the first instruments to collect data at ISIS in 1984. Since then, it has been used to precisely determine the position of atoms in a variety of materials, including superconductors, engineering components and planetary materials. HRPD was the highest resolution neutron powder diffractometer in the world for nearly three decades and produced several of the highest cited ISIS papers.

Instrument scientists Dominic Fortes and Christopher Howard monitor a sample stick removed from HRPD.

## Pearl

Pearl is one of the few dedicated high-pressure neutron instruments in the world. When equipped with the hydraulic Paris-Edinburgh press and suitable anvils, 28 GPa of pressure can be generated for neutron diffraction studies of samples at extreme pressures and temperatures. Experiments on Pearl have enabled the understanding of natural and industrial processes experienced by a wide range of substances, including minerals, explosives and pharmaceuticals.

Kevin Knight, Craig Bull and Helen Playford, ISIS, preparing the Paris-Edinburgh press to investigate properties of a perovskite up to 10 GPa.



> The outstanding capabilities of the Pearl beamline have proved invaluable in tackling the fundamental science that underpins real-world, technological challenges.
>
> **Colin Pulham**
> University of Edinburgh

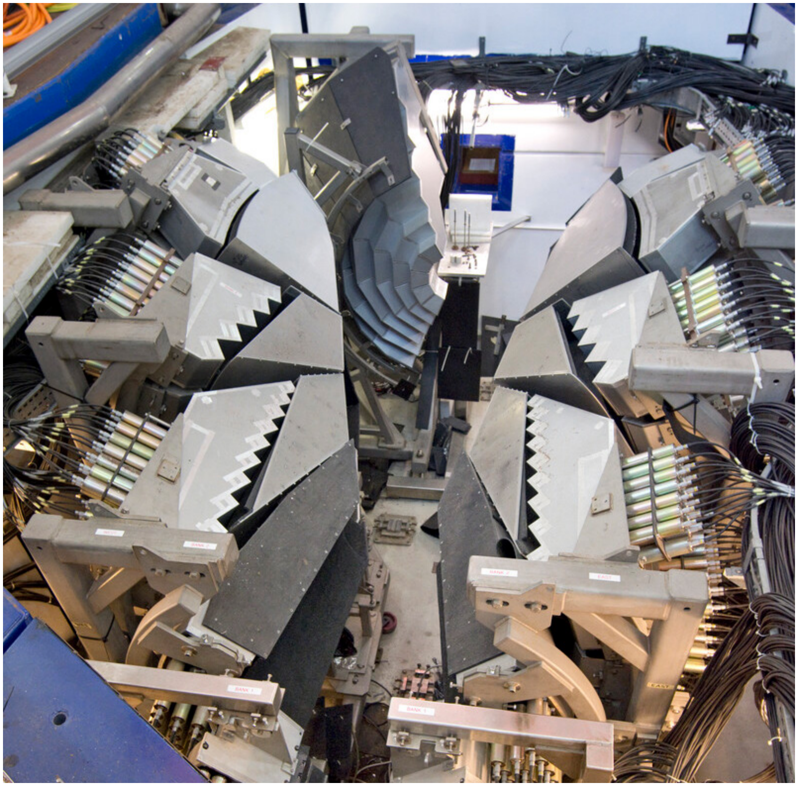
## Ines

Ines is a diffractometer built in partnership with the Italian National Research Council (CNR). Since 2005, it has been used to analyse the structure and composition of numerous priceless cultural heritage objects.

Ines Instrument Scientist Antonella Scherillo examines one of the daggers from the Wallace Collection in November 2015.

> "I treasure my memories of holding in my hands precious and ancient artefacts – the list is endless from nuragic bronzes to the Wallace collection arms and armour – the dagger you see here was beautiful, encrusted with large rubies, but the most interesting part was to re-discover the secret of the manufacturing method."
>
> **Antonella Scherillo**
> Ines Instrument Scientist

# Crystallography and disordered materials



## GEM

GEM was a transformative instrument, replacing LAD, the oldest ISIS instrument that first ran on an early pulsed source at Harwell Laboratory. GEM measures atomic positions in crystalline and amorphous materials with an emphasis on disorder, especially battery components, other energy materials and glasses. The design of GEM would later come to influence Polaris.

As shown in this image from November 2017, GEM has a large and complex instrument detector array. This design really transformed high-rate powder diffraction at accelerator neutron sources.

> “GEM offered me the possibility to non-invasively study unique, over 3,000 year-old bronze swords in order to gain understanding about the manufacture of these swords and secondly, to identify the actual way these swords were used. This is highly important in understanding better the social changes around 1200 BC, and how fighting techniques changed.”
>
> **Marianne Mödlinger**
> University of Bordeaux

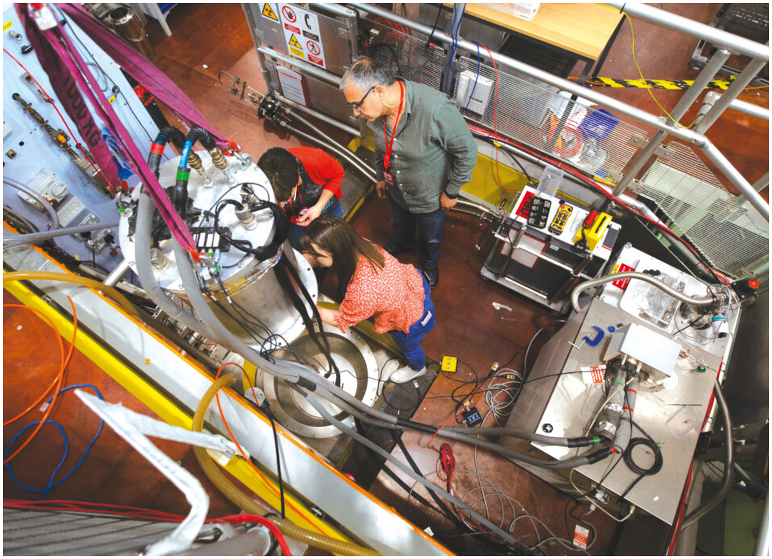
# Disordered materials

**Characterisation of disordered solids and the atomic-scale structure of liquids.**

## Nimrod

Nimrod was built in collaboration with the Italian National Research Council (CNR) and uniquely looks at material structure from individual atoms through to assemblies covering tens of nanometres. It gives vital multi-scale insight for applications as varied as astronomy, batteries and biochemistry.

David Garland, ALSTEC, during construction of the Nimrod instrument detector frame.



Gabriel Cuello, Institut Laue-Langevin, and Christèle Combes, Institut National Polytechnique de Toulouse, work with ISIS Instrument Scientist, Terri-Louise Hughes to load sample environment apparatus into Nimrod in May 2022. The team were interested in understanding the structure of amorphous calcium ortho- and pyro-phosphates materials for bone substitution.

## SANDALS

SANDALS was the world's first neutron diffractometer dedicated to structure determination in hydrogenous liquids and amorphous materials. It is used to study molecular interactions in biologically relevant aqueous solutions, ionic liquids and solvents to support green chemical processes.

Alan Soper and Brian Holesman checking detector panels during the construction of SANDALS in December 1989.

> "The wide Q-range neutron diffraction technique at SANDALS is absolutely invaluable for our studies. No other technique is currently capable of giving such accurate, direct measurements of the structure of a liquid."
>
> **Oliver Hammond**
> Bath University


Users John Holbrey, Kerry-Anne Hughes and Tristan Youngs from Queens University Belfast on SANDALS, May 2006, looking at the structure of phosphorous trichloride solvated in ionic liquids. The chemical is used to manufacture surfactants, gasoline additives, antiseptics and medicinal products. It is a nasty compound but is 'stabilised' in the presence of an ionic liquid allowing chemical studies to be performed.

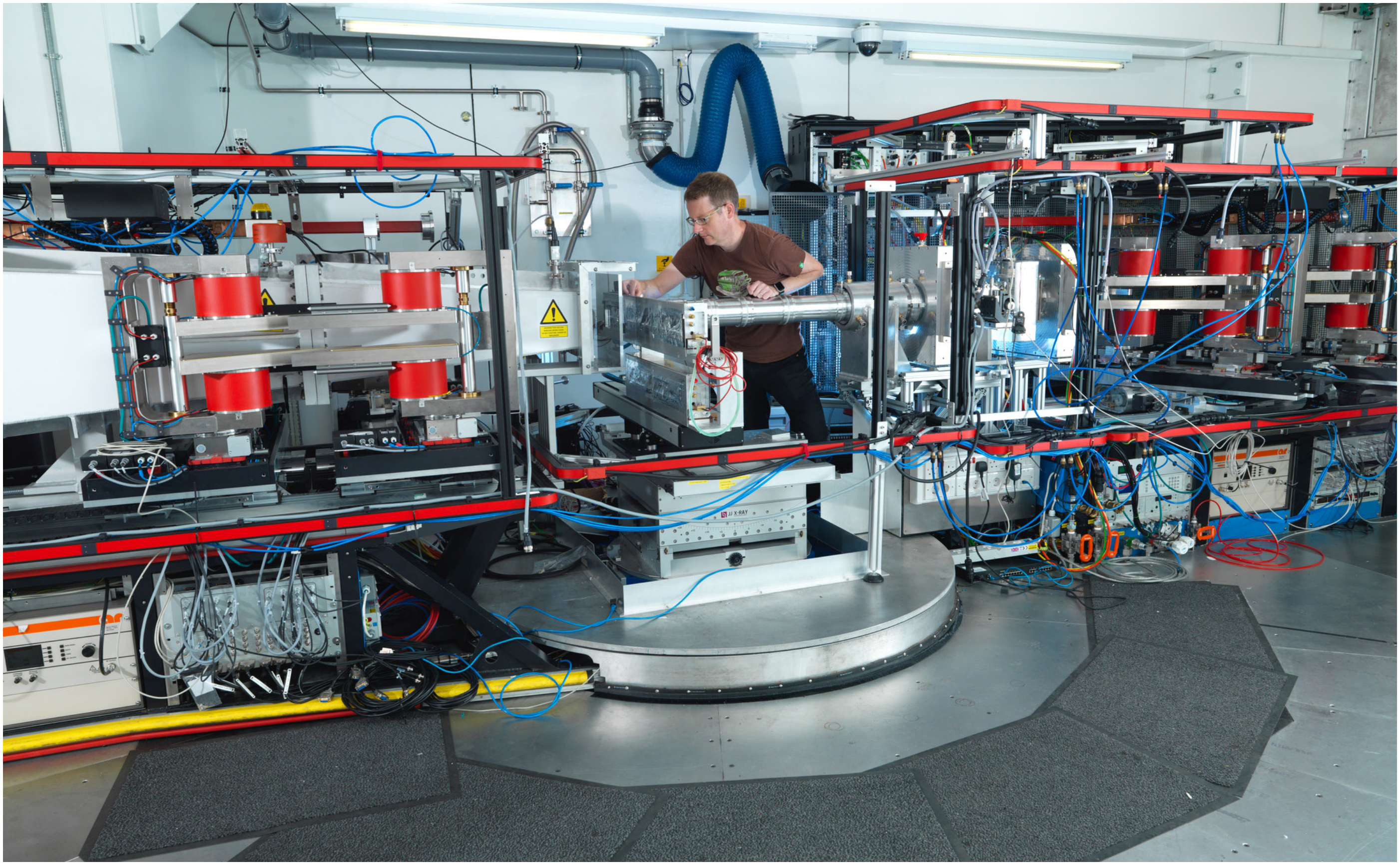
# Small-angle neutron scattering

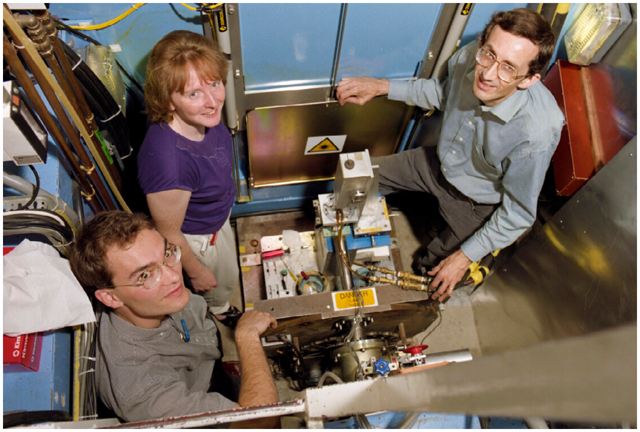
**Determining the size, structure and/or distribution of molecules and assemblies.**

## Larmor

Larmor is the second instrument collaboration between ISIS and Delft University of Technology. It uses the fact that neutrons spin around a magnetic field to encode the path that they take through the instrument. This allows scientists to study materials over a uniquely wide spatial range (approximately 1 nm to 38 µm).

ISIS Instrument Scientist, Robert Dalgliesh, loads a sample on the Larmor instrument in 2017.





## LoQ

LoQ studies the nanoscale shape and size of molecules, particles, or voids in a diverse range of materials of technological interest. It has been in operation since 1985 and is the most prolific instrument of its type in the world.

ISIS users Anne Young and C Brigault, Brunel University, study the formation of polymer gels on LoQ with support from Richard Heenan, ISIS, July 1996.

Sarah Rogers, LoQ Instrument Scientist, prepares the Thar/SANS pressure cell in April 2008. The cell was designed for the study of droplets dispersed in pressurised media such as supercritical fluids, organic solvents and aqueous systems.

> “I first came to ISIS as a student when I was at the University of Bristol. My supervisor, Julian Eastoe, told me I’d be working in a pit on LoQ and he wasn’t wrong! I was hooked from this first visit and carried on using neutrons throughout my PhD and postdoc and actually started my employment at ISIS within the SANS Group as an Instrument Scientist on LoQ.”
>
> **Sarah Rogers**
> Division Head for Materials and Engineering

## SANS2D

SANS2D was the first small-angle neutron scattering instrument in Target Station 2 and is unique in its ability to study very weakly scattering samples. It probes the nanostructure and interactions of a wide variety of systems and can resolve the component distribution within soft matter complexes, such as viruses and drug delivery vehicles, through contrast variation.

Ed Spill inside the long SANS2D instrument vessel, inspecting the detector array after installation, April 2014; the very same vessel that needed to be delivered on the back of a lorry, shown here as Richard Heenan looks on.

## Zoom

Zoom is the most recent addition to ISIS's suite of SANS instruments and is capable of covering a wide range of science areas. It is used for the study of magnetically-active structures and engineering materials, including quantum systems and industrial steels.

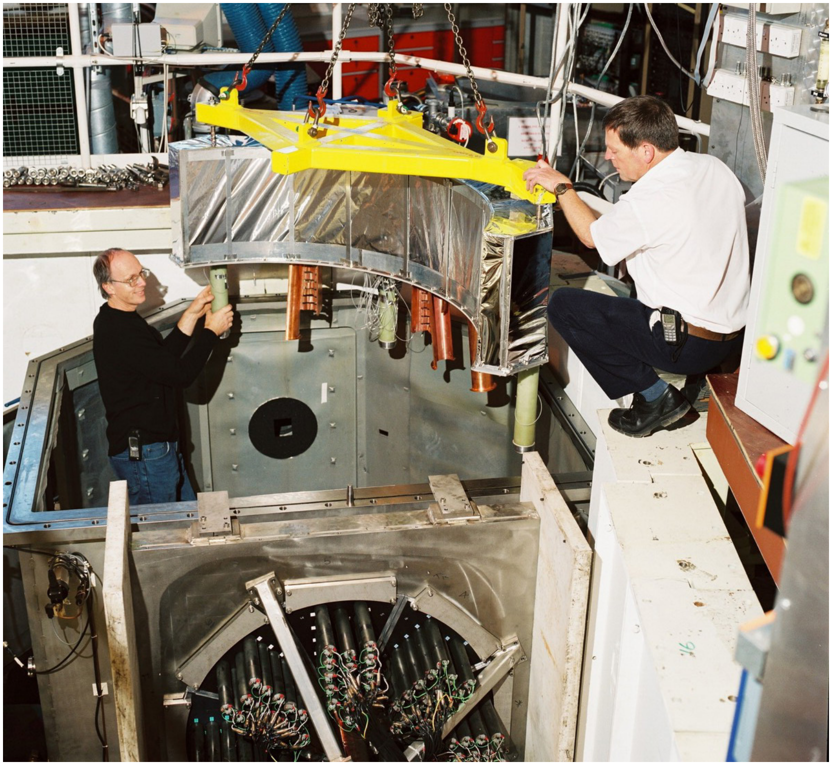
Building progress for Zoom in May 2013 as the vacuum tank is being delivered.

Left to right: Miina Ojansivu, Hanna Barriga, Jelle Penders and Cat Saunders, Imperial College London and Karolinka Institute, with Instrument Scientist James Doutch, who used Zoom to gain structural understanding of lipid-based particles for clinical applications.

> "Our collaboration with James Doutch at Zoom has enabled us to understand the structure of our formulations at the nanoscale in a level of detail that was previously not possible. It's really fascinating to see how we can use this moving forward to design the next generation of lipid nanomedicines."
>
> **Hanna Barriga**
> Imperial College London

# Molecular spectroscopy

**Characterisation of atomic and molecular vibrations and motions.**

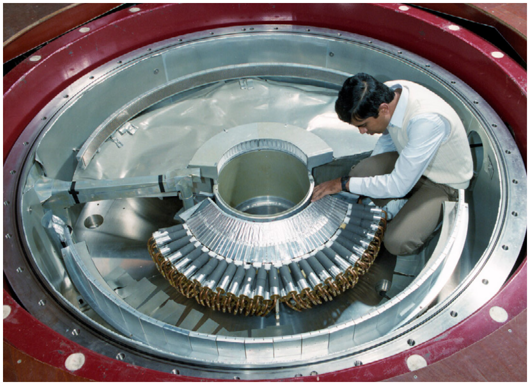


## Osiris

The first neutrons were recorded on Osiris in 1997. Since then, it has established itself as a leading instrument for the study of diffusive and rotational motions of atoms and molecules in materials ranging from novel battery compounds to anti-cancer drugs.

Dennis Abbley and Jeff Vine lower the pyrolytic graphite analyser into position. The analyser filters neutrons based on their energy.

> “Helping to build Osiris was what I enjoyed most when I worked at ISIS. Osiris and Iris were really two outliers in using cold neutrons at Target Station 1. Target Station 2 was then a huge step further in that direction to expand cold neutrons at ISIS. There’s been a real shift worldwide in spallation sources moving towards cold neutrons.”
>
> Ken Andersen
> former Osiris instrument scientist, now Director of Institut Laue-Langevin



## Iris

Iris was the first spectrometer at ISIS, built in partnership with Bhaba Atomic Research Centre, India. Since 1984, it has been used to accurately measure atomic motions in materials, covering liquid, biological and soft matter, catalytic surfaces and quantum materials.

Ramaprasad Mukhopadhyay, part of the ISIS-India collaboration, fixes cadmium shielding to the Iris detector housing in October 1990.

Eighteen years later, the manifold to the graphite detector was upgraded.

> "Carefully designed experiments at Iris combining the unique technique of quasi-elastic neutron scattering with specialised sample environment equipment has allowed us to gain key insights into very complex entities such as bacteria cells. Moreover, it has contributed to further our understanding of intracellular organisation and metabolic rates at extreme conditions, significantly different to ambient."
>
> **Victoria Garcia Sakai**
> former Iris Instrument Scientist, now Division Head for Neutron Spectroscopy

## Vesuvio

Vesuvio is the only instrument worldwide that identifies atoms by mass and shows where they are and what they do. This versatility enables studying diverse phenomena and materials, from the quantum world to cancer therapies.

Left to right: Margherita Simoni, Matteo Castellani and Sara Notari from the University of Rome Tor Vergata prepare to irradiate amino acids with neutrons to better understand the efficacy of radiation protection protocols, July 2023.

> “I had a long career at ISIS, spanning 33 years, working on sample environment, as an instrument scientist on TFXA and finally as Group Leader of the Molecular Spectroscopy Group where I developed the application of computational chemistry programs. I helped organise the installation of Osiris, Tosca and Vesuvio. It really was something to get out of bed for in the morning. Loved every minute of it!”
>
> **John Tomkinson**
> former Group Leader of Molecular Spectroscopy Group and User Relations


## Tosca

Tosca has been developed in collaboration with the Italian National Research Council (CNR) and the University of Kent at Canterbury. It can detect the full range of molecular vibrations in a solid, helping to develop new materials for sustainable fuels, anticancer drugs and next generation solar cells. Tosca is an upgrade of TFXA, the original Molecular Spectroscopy instrument, which was a significant advance in molecular instrumentation.

Instrument Scientist Stewart Parker at Tosca, February 2016.

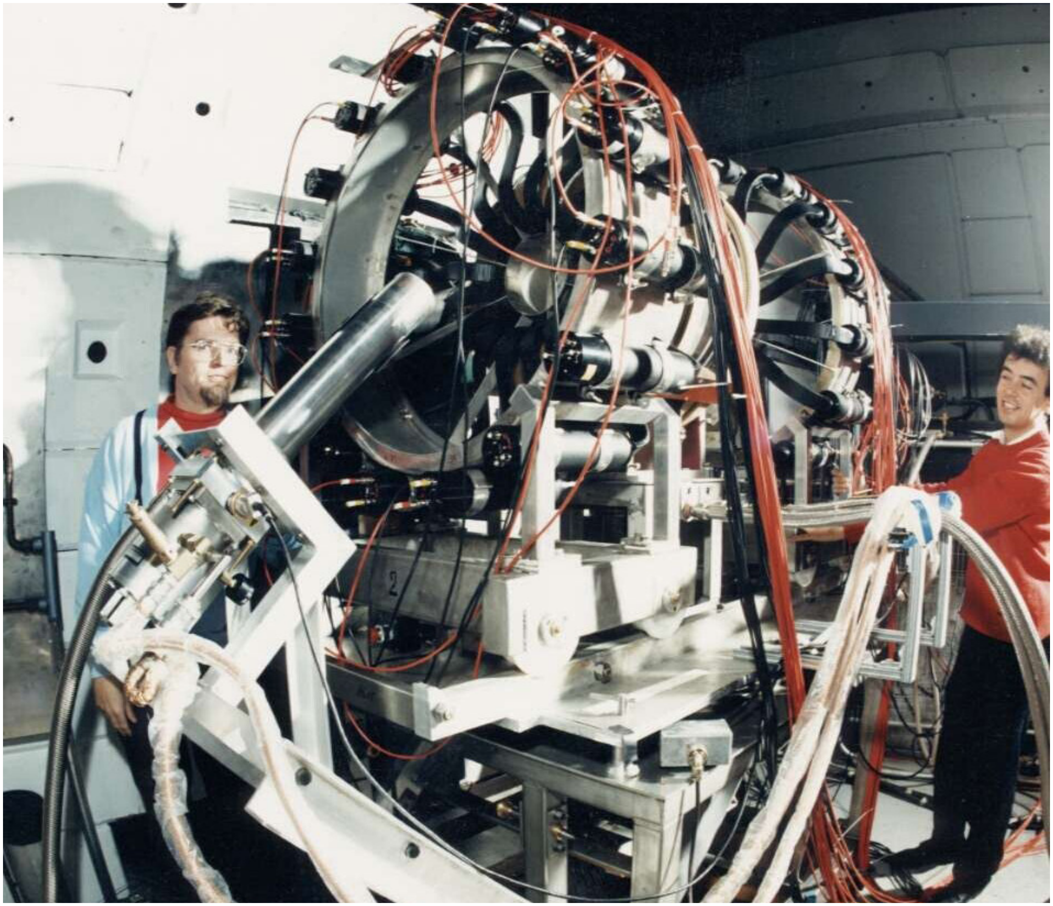
Tosca being craned into position, March 2006.

# Muons

**Local-level understanding of magnetic phenomena, diffusion and molecular processes.**

## MuSR

In 1987, MuSR was the first muon instrument to collect data at ISIS. Built by a collaboration between six nations, it is mainly used to measure the magnetic fields inside magnets and superconductors, finding new quantum states of matter.

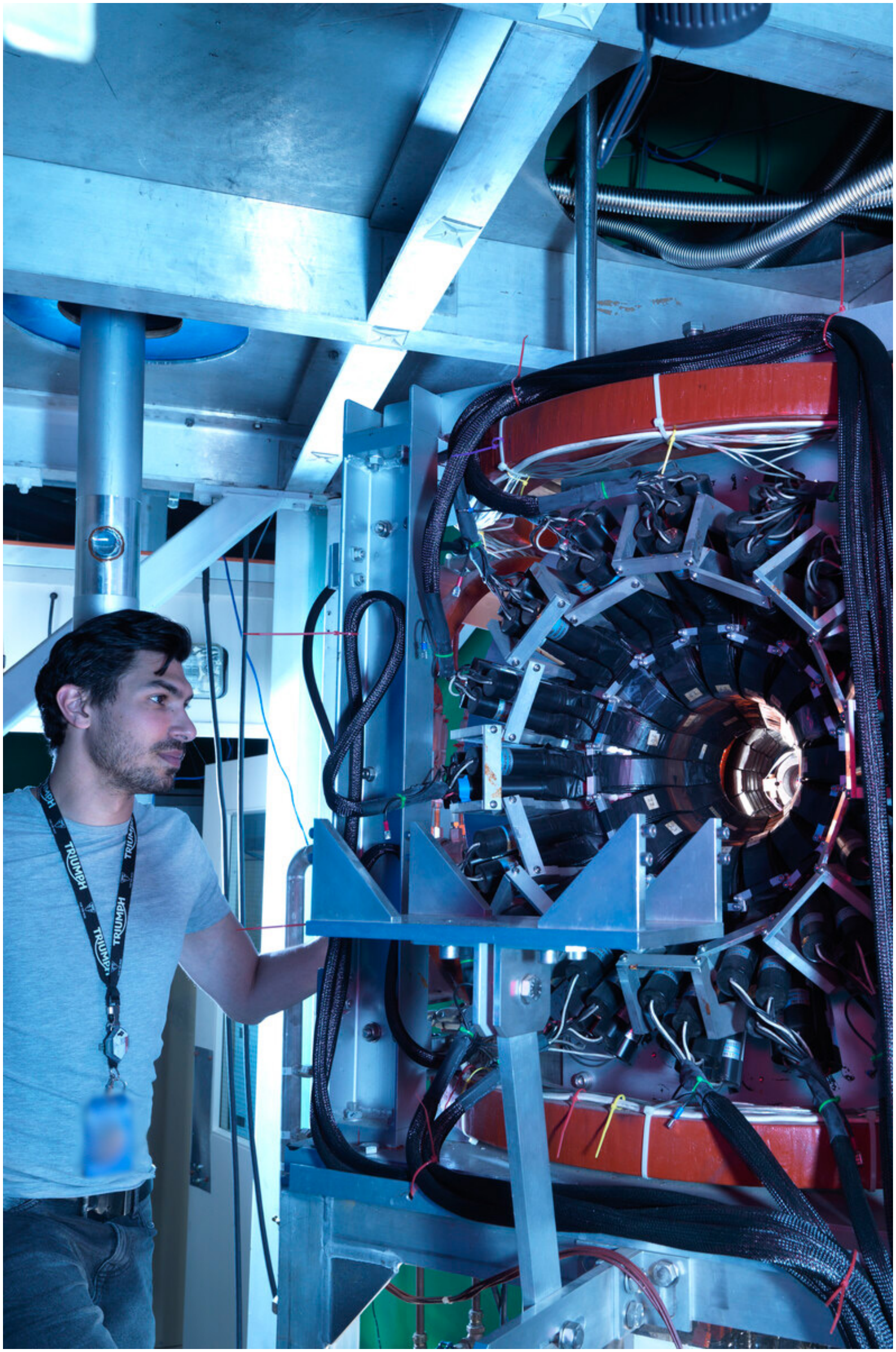


Roberto De Renzi and Ola Hartmann during the initial commissioning of MuSR in 1987.

## HiFi

Occupying the space where the muon development beamline DEVA once stood, HiFi allows magnetic fields greater than 100,000 times the earth's field to be applied to samples. Such capability enables, for example, solar cell materials to be investigated, theories of magnetism to be tested and chemical reactions to be probed. The instrument also offers laser excitation capability, allowing studies of optically-stimulated molecules to be performed.


The first users of the HiFi instrument in December 2009 were a team studying the behaviour of electrons in organic semiconductors. Left to right: Alan Drew, Laura Nuccio, Maureen Willis, Queen Mary University of London, Leander Schulz, University of Fribourg and Iain McKenzie, ISIS.



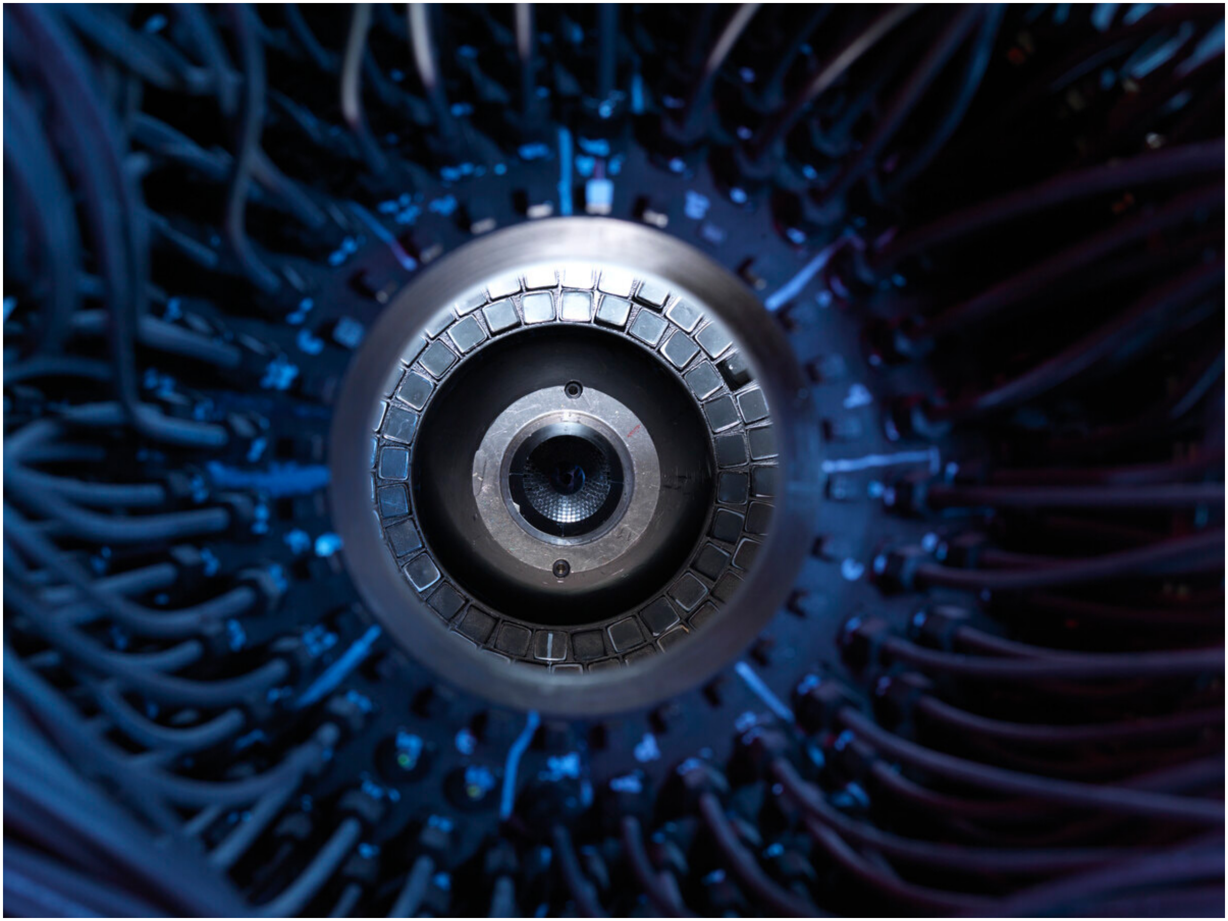

## Argus

Argus was installed in 1994 as the first Japanese collaboration instrument on the RIKEN-RAL muon beamline. Since then, it has been used to measure a variety of materials with custom-tuned beams of muons, including superconductors, battery materials and exotic magnets.

Muon Instrument Scientist, Adam Berlie, checks the Argus detectors.

## Chronus

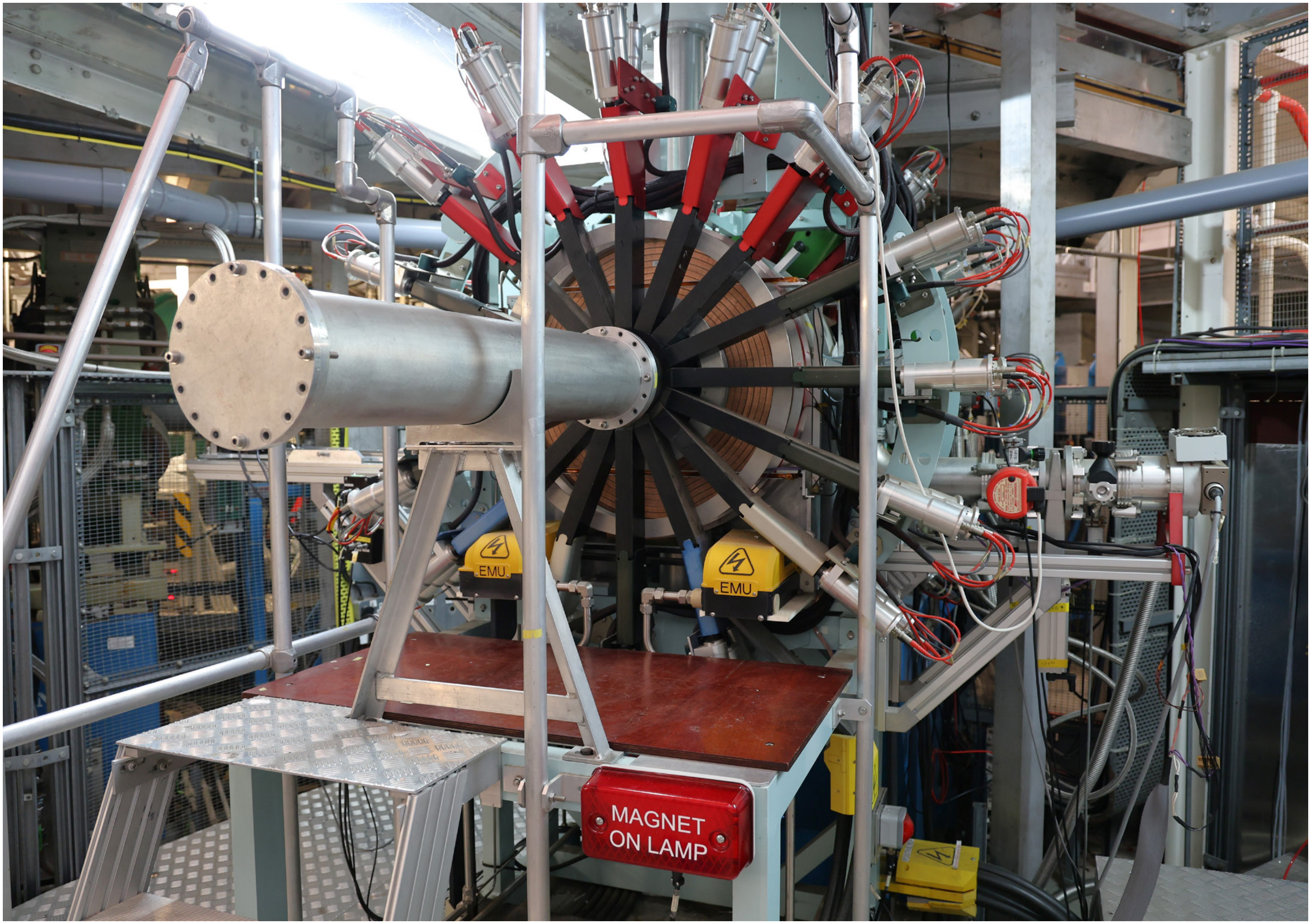
Chronus was installed in 2014 as the second spectrometer in the RIKEN-RAL Facility. Since then, it has been used to study a variety of systems, such as magnetic and quantum materials.



The Chronus detector array is made up of small pieces (or pixels) of scintillator material. Each pixel is attached to a fibre optic cable which sends pulses of light (generated when a positron hits the scintillator) to electronics that convert them into voltages. By time stamping these voltages, the direction and rate of muon decay can be determined and thus the environment in which the muon sits.

## Emu

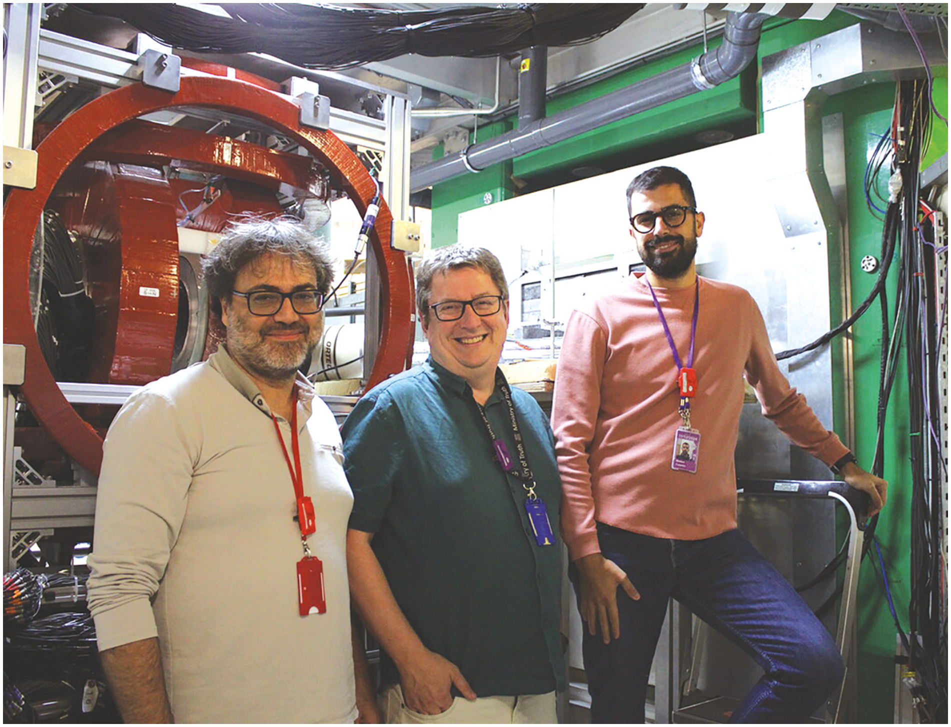
Since 1993, Emu has been used to investigate, at a local level, a variety of systems, including battery materials, magnets and semiconductors.




Emu photographed in 2024.

## MuX

MuX, in collaboration with Japanese colleagues, was installed on the RIKEN-RAL muon beamline in 2014. Since then, it has been used to determine the depth-sensitive elemental composition in a wide variety of materials non-destructively, like precious cultural heritage artefacts, biomaterials, renewable energy and storage devices.



Left to right: Massimiliano Clemenza, Università degli Studi di Milano Bicocca, Adrian Hillier, ISIS Muon Group Leader, and Matteo Cataldo, ISIS and Università degli Studi di Milano Bicocca. The team studied elements from the Baptistry Gates of Florence, gaining insights into the manufacture of one of the most famous depictions of the Old Testament.

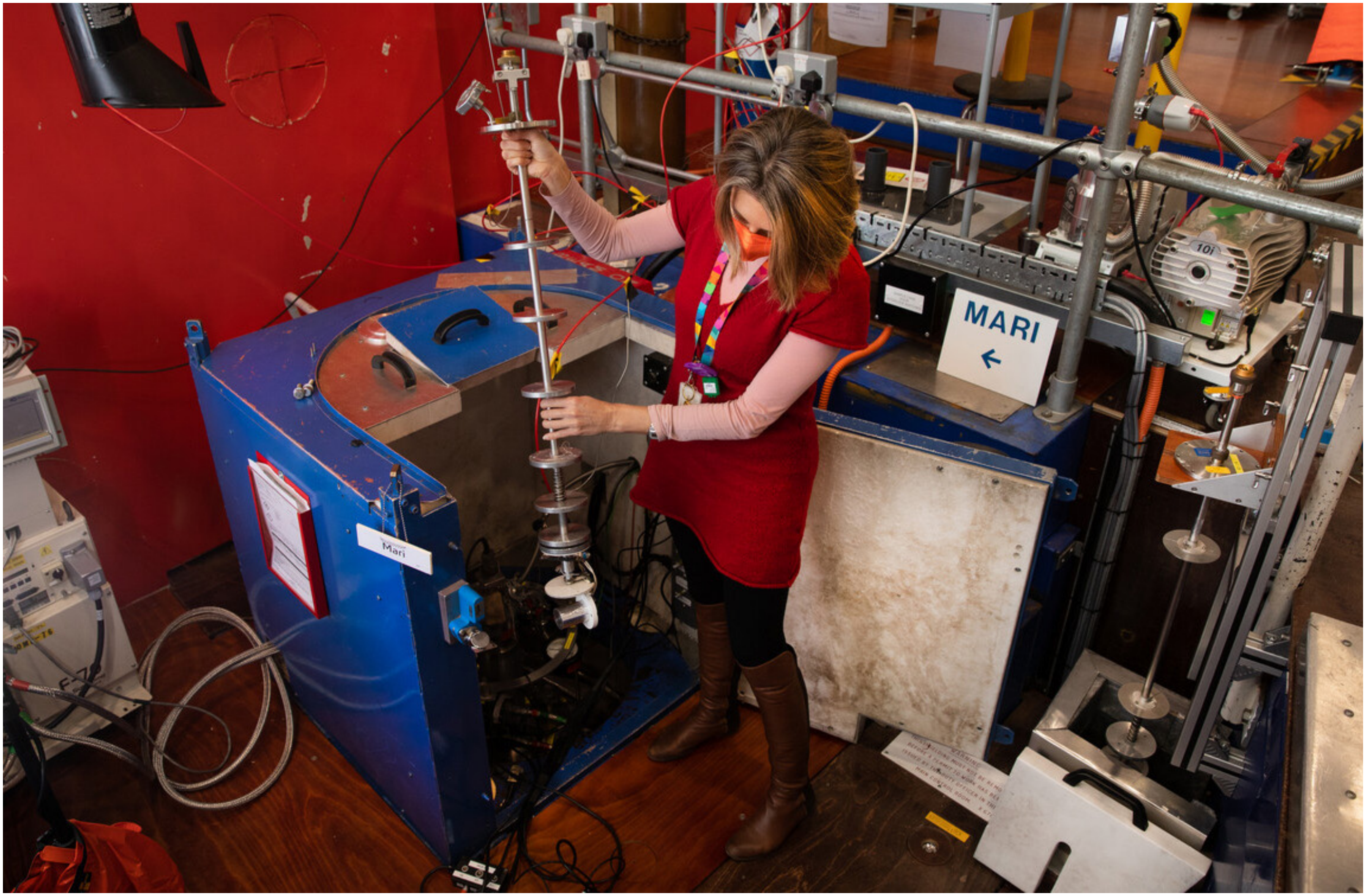
> "This is an interesting project due to the application of muons, because this method is very useful to investigate layered materials. With muons, we can penetrate depending on the material density and size."
>
> Matteo Cataldo

# Excitations

**Characterisation of atomic motions, magnetic interactions and quantum phenomena.**

## Mari

Mari uniquely has detectors below the sample position, giving it an extremely low background. As such, it can measure small signals from magnetic materials, superconductors, energy materials and liquids, ultimately allowing scientists to understand how atoms move in these materials.




Tatiana Guidi, former beamline scientist on the Mari instrument, December 2020, preparing to cool a sample using a closed-cycle refrigerator.

> My English was not good, but people listened to me, Andrew especially. I said 'no' two times to Andrew about the design of Mari. But he said to me that those 'no's made the instrument successful with single crystals.
>
> **Masa Arai**
> former Mari Instrument Scientist and, later, Director of J-PARC MLF


Masa Arai and Andrew Taylor preparing for the opening of Mari in 1989.

> My favourite memories are of working on Mari and its design with Masa. He was always so polite that I never got him to say 'no' to a suggestion. But on two occasions, he did say 'maybe', which I understood meant "never in a million years". And he was right both times!
>
> **Andrew Taylor**
> former ISIS Director

## Merlin

Since 2008, Merlin has provided insights into the magnetic properties and atomic-level dynamics of a wide range of materials. This has been particularly useful for studying materials that exhibit unusual properties, including unconventional superconductors, magnetic materials and thermoelectrics that convert heat into electricity.

Merlin's huge vacuum tank was installed in January 2006. Merlin was the first spectrometer to house the detectors inside the vacuum vessel, removing the need for thin windows which were both technically challenging and added additional background signal to the data.

> "ISIS is a pioneer and world-leading in inventing and developing novel instrumentation. This is especially true for time-of-flight spectroscopy on single crystal samples with the game-changing Maps, Merlin and LET spectrometers. ISIS has revolutionised neutron spectroscopy by building complex machines and providing and improving the entire technology and know-how chain: from high-quality low-background data to their analysis using every byte… or better GB now. Absolutely stunning performance over decades."
>
> **Christian Ruegg**
> Paul Scherrer Institute Director

## LET

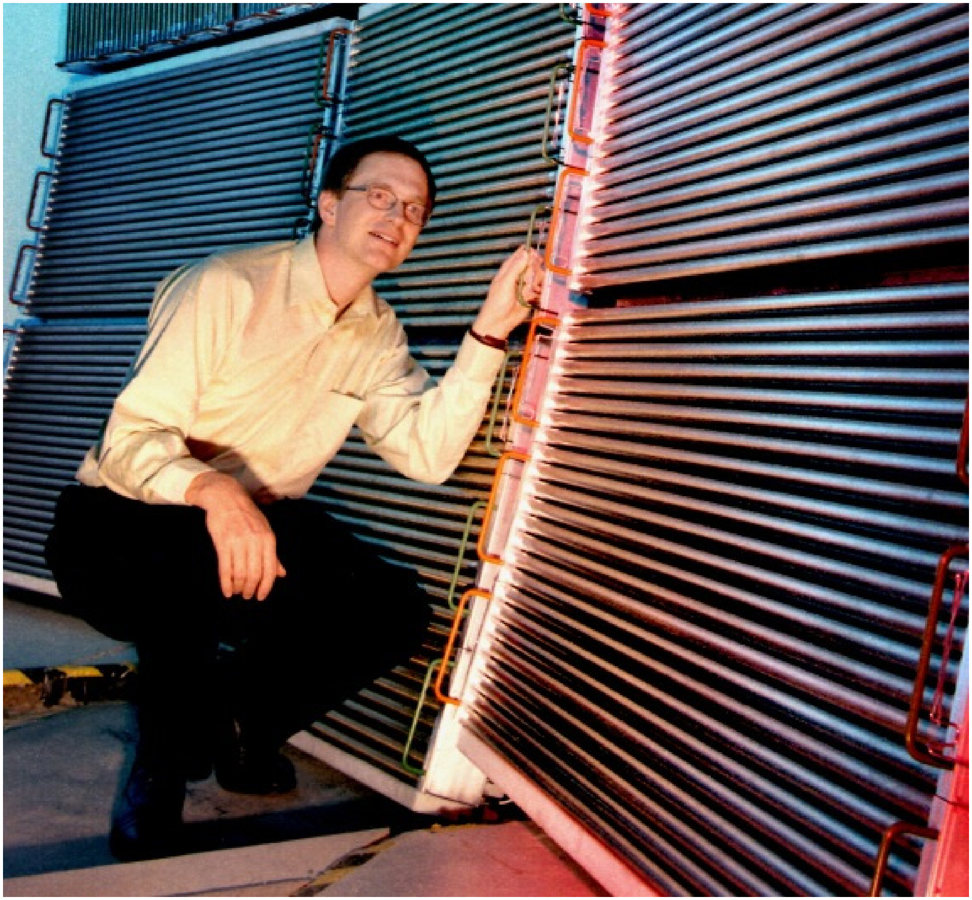
LET is used to measure the dynamical properties of atoms and magnetic fields inside materials often at temperatures only 0.04 degrees above absolute zero. Measurements of quantum materials, where the properties of the material are dominated by puzzling quantum effects, make up most of the science programme on LET.

John Hogg from ALSTEC lines the inside of the LET vacuum tank with cadmium during construction in October 2008. Cadmium is a very strong absorber of neutrons, reducing the possibility that stray, or background, neutrons are detected.

## Maps

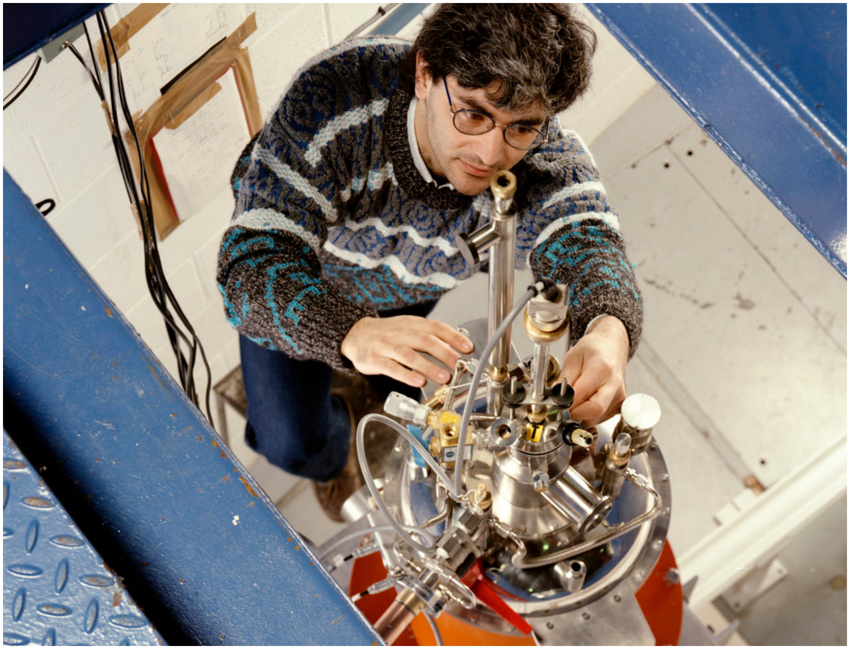
Maps started operations in 1999 and was the first international spectrometer to pioneer the use of position-sensitive neutron detectors to map the 3D arrangement and interaction of magnetic atoms. Today, it focusses on the study of atomic motions in fundamental and applied materials, from magnetism to catalysis.

Former Maps Instrument Scientist, Toby Perring, checks a panel of position sensitive detectors in May 2000. The use of such detector technology is now a standard on similar instruments worldwide.



# Reflectometry

**Characterising the structure of thin films.**



## Crisp

Crisp is the original neutron reflectometer at ISIS and was designed for high resolution studies of a wide range of phenomena, including spintronics and complex polymer films, and can perform polarised neutron reflectivity measurements with full analysis.

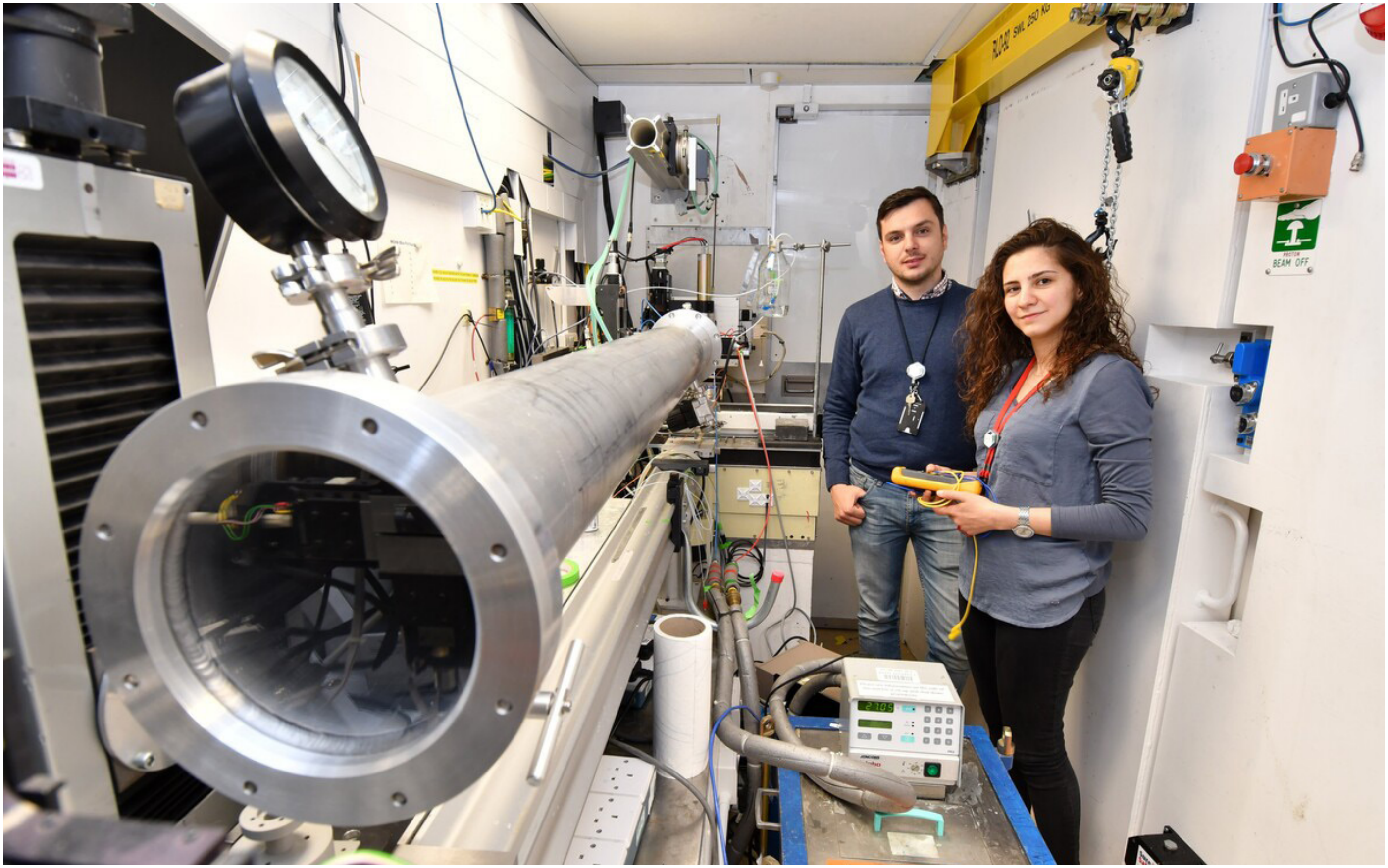
ISIS Scientist, Roberto Felici, adjusts a cryostat for a high-temperature superconductor experiment on Crisp in May 1987.

> "After almost 10 years of trying to get people interested in neutron reflectivity, one day out of the blue, around 1985, the then ISIS Director Alan Leadbetter asked at coffee why we weren't building a reflectometer. I was given the job to build one and named it Crisp after a racehorse that narrowly missed winning the Grand National. The next couple of years were a real rollercoaster of excitement as we developed a world-leading programme in soft matter which contributed substantially to the ISIS programme and reputation."

**Jeff Penfold**
former ISIS Instrument Scientist

## Surf

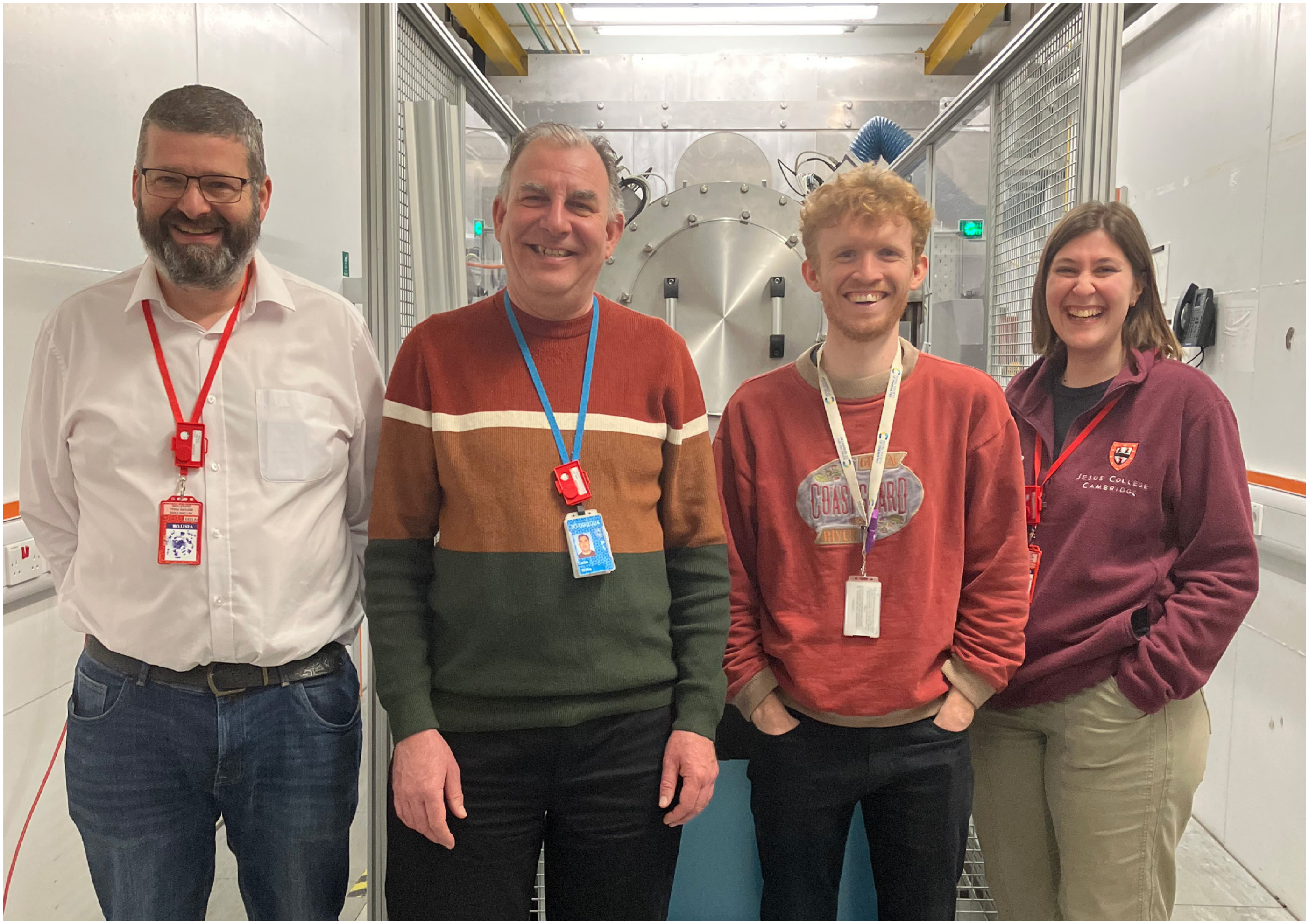
Surf has recently been upgraded to take advantage of the refurbishment of Target Station 1. Surf examines molecular structure at interfaces by reflecting neutrons from a surface, much like a mirror reflects light. Surf has been used to probe soft matter systems, in particular how surfactant/soap/detergent mixtures organise themselves at a solid or liquid interface.



Mario Campana, ISIS, and Shirin Nouhi, Uppsala University, use the Surf instrument to study the long-term health effects of chemicals, such as perfluoroalkyl surfactants, which are used in non-stick cookware, stain-resistant fabrics and water-repellent clothing. November 2018.

## INTER

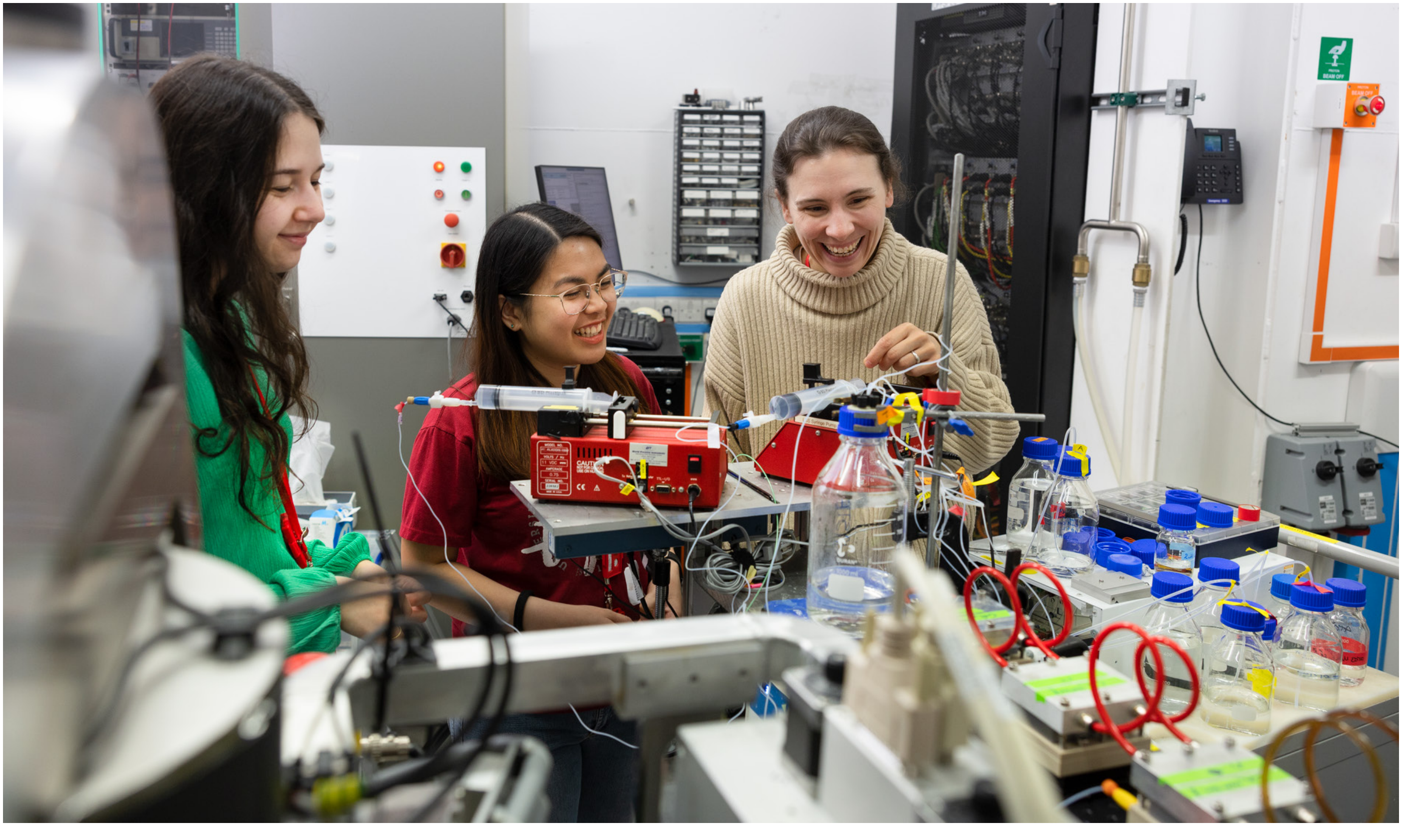
INTER, the first instrument to collect data on Target Station 2, studies the nanoscale structure and interactions of materials like detergents, polymers and bio-membranes at interfaces, and can track how these systems change with time or varying environmental conditions.



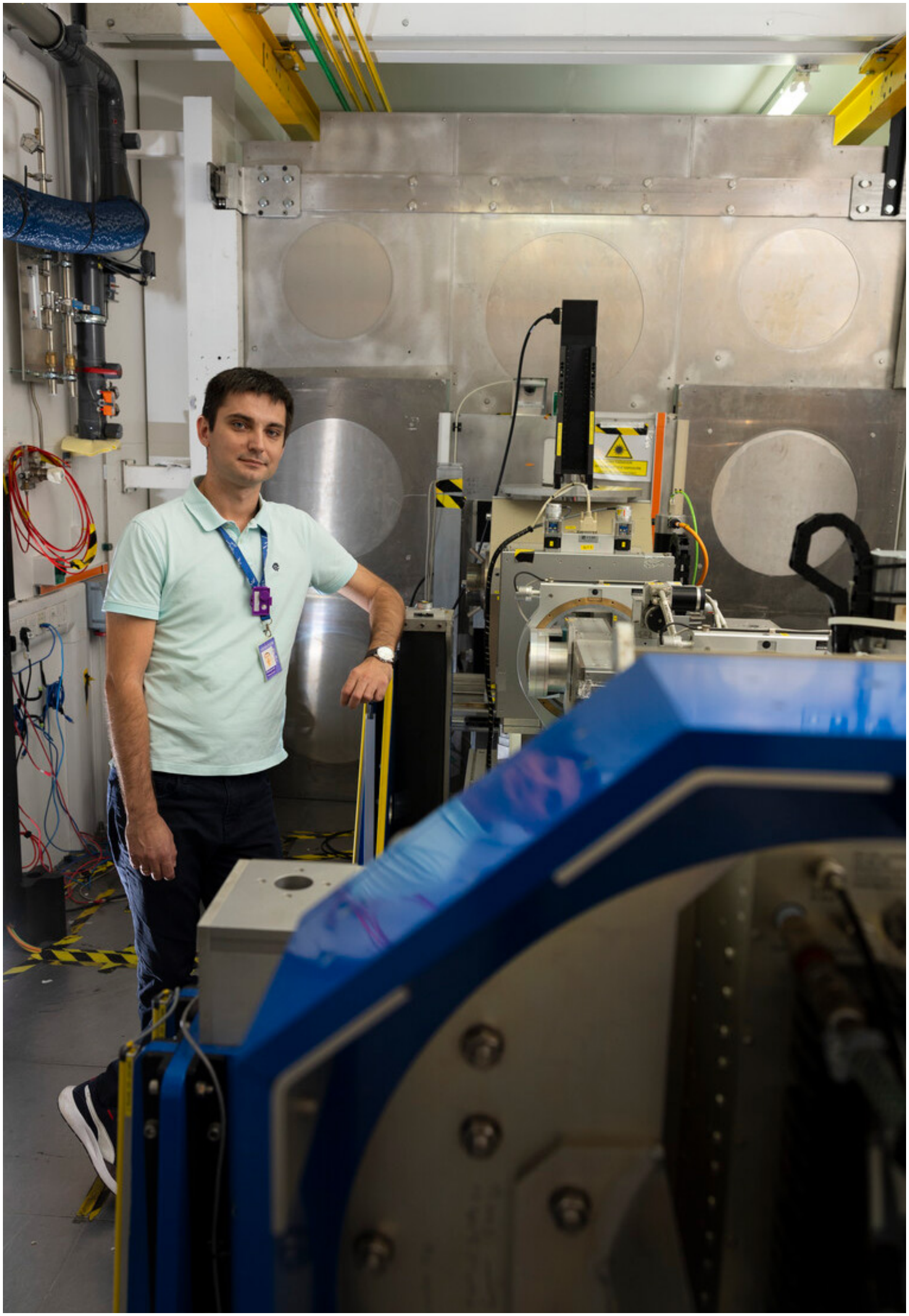

The first users since INTER's upgrade. Left to right: Alex Routh, University of Cambridge, Colin Willis, Infineum, Alexander Armstrong, ISIS and Infineum and Beatrice Boggio Robutti, University of Cambridge and Infineum, February 2024.

## OffSpec

OffSpec is a reflectometer that allows access to nanometre length scales in the plane of, and perpendicular to interfaces. Originally built via a collaboration with Delft University of Technology, it can use the technique of neutron spin echo to encode the path that neutrons take through the instrument to probe in-plane structure. Predominantly, measurements provide information about structures perpendicular to an interface. An increasing number of important science and technology issues are studied on OffSpec, such as next-generation antimicrobial technologies.



Maggie Holme, Debbie Nicdao and Vesa Halipi, Chalmers University of Technology, investigate the fusion mechanisms of asymmetric lipid vesicles and membranes using OffSpec.



## PolRef

PolRef profiles magnetic behaviour (the strength and orientation of magnetic atoms) as a function of depth in nanometre-thick, thin-film structures composed of magnetic and non-magnetic interfaces. Understanding how electrons traverse these interfaces is the basis of all electronic technologies and enables the development of smaller and more energy-efficient devices.

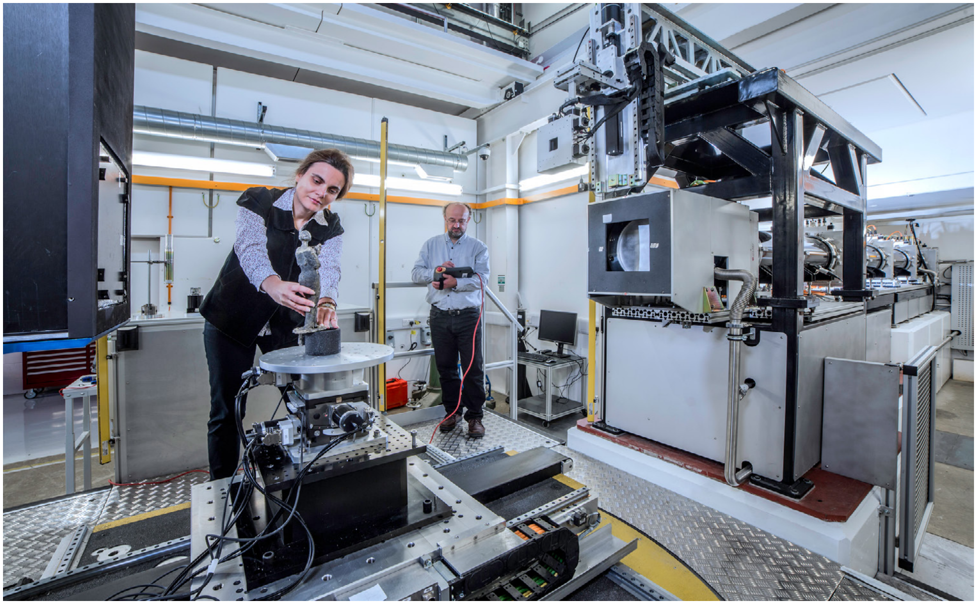
Instrument Scientist Oleksandr Tomchuk at PolRef in July 2024.

## Engineering and imaging

**Non-destructive mapping and analysis of engineering components, fundamental materials, archaeological objects and internal device processes.**

### IMAT

IMAT is the first neutron imaging beamline at ISIS. Since 2018, IMAT has enabled researchers to capture images of materials and processes inside devices, including engineering components, batteries, ancient artefacts and catalysts.



IMAT Instrument Scientists Genoveva Burca and Winfried Kockelmann prepare a cultural heritage artefact for examination.

“The conception, construction and ground breaking research done on IMAT epitomise the huge potential neutrons have in enabling a more profound understanding of the world we live in.”

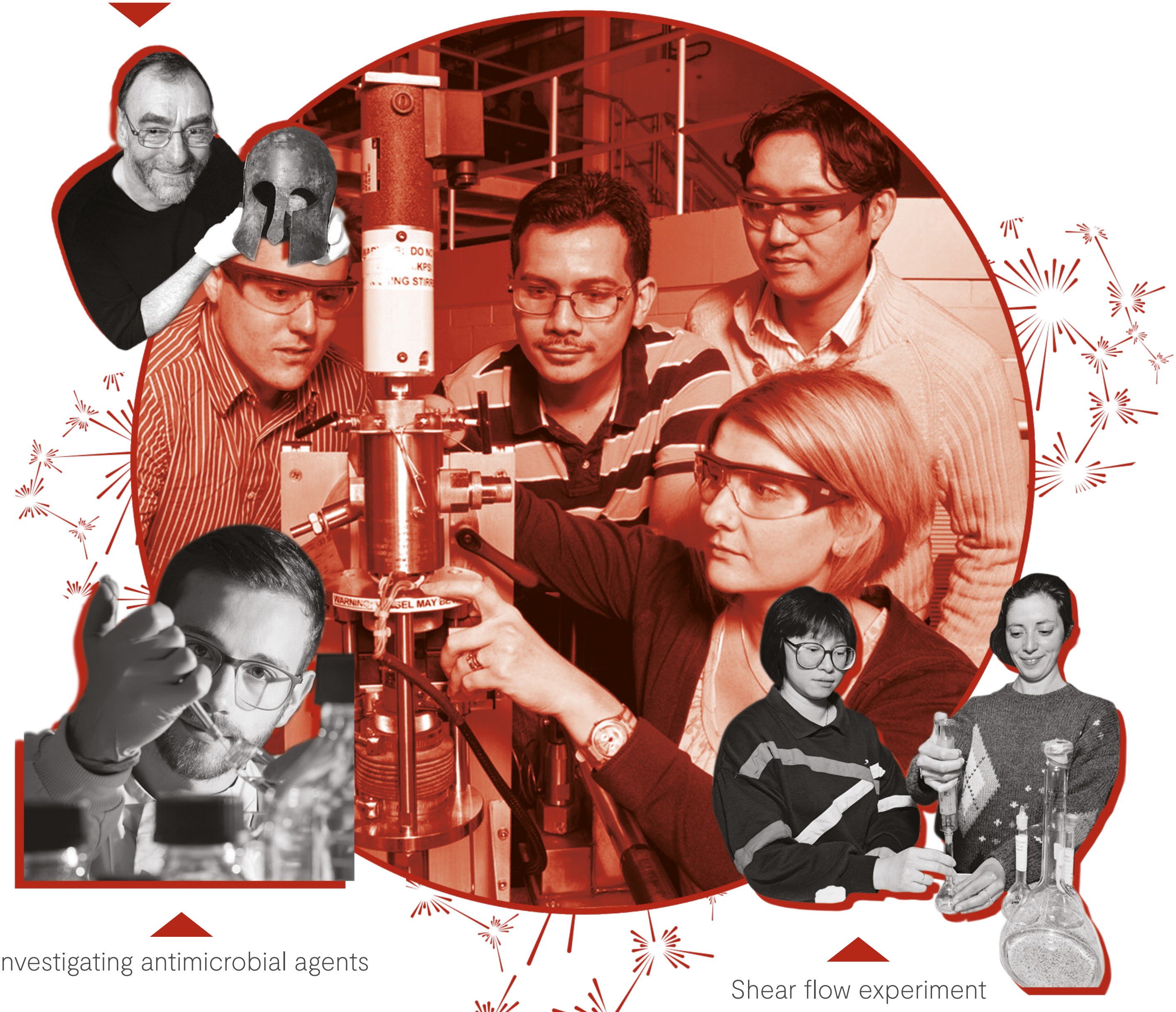
Genoveva Burca
former IMAT Instrument Scientist

## Engin-X

Engin-X, launched in 2003 as a tenfold upgrade of Engin, tracks distances between atoms to uncover hidden stresses deep within complex components, like those used in aeroengines and fusion reactors. This information helps engineers design safer and more reliable components.


Sue Kilcoyne, University of Huddersfield, and Katy Gannon, Borg Warner, position a turbine housing on Engin-X in March 2013. The experiment was designed to measure the residual stresses within the turbine housing.

> "The ability to mechanically test materials at temperatures as low as -253 °C is extremely unique. Engin-X has the specialised equipment that can do just that while also collecting diffraction data in situ."
>
> **Saurabh Kabra**
> former Group Leader, Engineering and Imaging



More eco-friendly solvents

Corinthian-type bronze helmet

Investigating antimicrobial agents

Shear flow experiment

# Science

**For four decades, ISIS has been a driving force in materials research. In this context, 'materials' refers to all substances that make up our physical world — engineering components, pharmaceuticals, computer chips and much more. At ISIS, machinery, instrumentation and expert knowledge come together to harness the power of neutrons and muons to uncover the arrangement and behaviour of atoms and molecules. This information is key to understanding and developing new and improved materials that drive innovation and tackle global challenges.**

Neutrons and muons have unique properties that provide distinct and valuable insights. Neutrons can penetrate deeply into materials, revealing their internal structure and properties without causing damage. They are especially sensitive to lighter elements, like hydrogen, making them invaluable for studying organic materials, polymers and biological systems, even when these are confined in complex sample environments. Additionally, neutrons can differentiate between isotopes of the same element, so that isotopic substitution (such as replacing hydrogen with deuterium) can be used to highlight specific structural features.

Muons, which are short-lived elementary particles, can also penetrate materials without causing damage. They are particularly effective at probing composition, magnetic properties and electronic behaviour, and as such are widely used in the study of energy materials, superconductors and cultural heritage objects.

Over the past 40 years, ISIS has received over 35,000 research proposals and allocated around 80,000 beam days to 60,000 researchers from 40 countries. This research has spanned a wide range of disciplines, including physics, engineering, materials science, biology, chemistry and heritage sciences, and contributed to a vast body of knowledge, including more than 15,000 research papers. These achievements have not only solidified ISIS's reputation as a world-class research facility but, more importantly, provided insights that address some of the world's most significant challenges.

The examples that follow can only give a flavour of the hugely diverse and impactful research undertaken at ISIS in the last forty years.

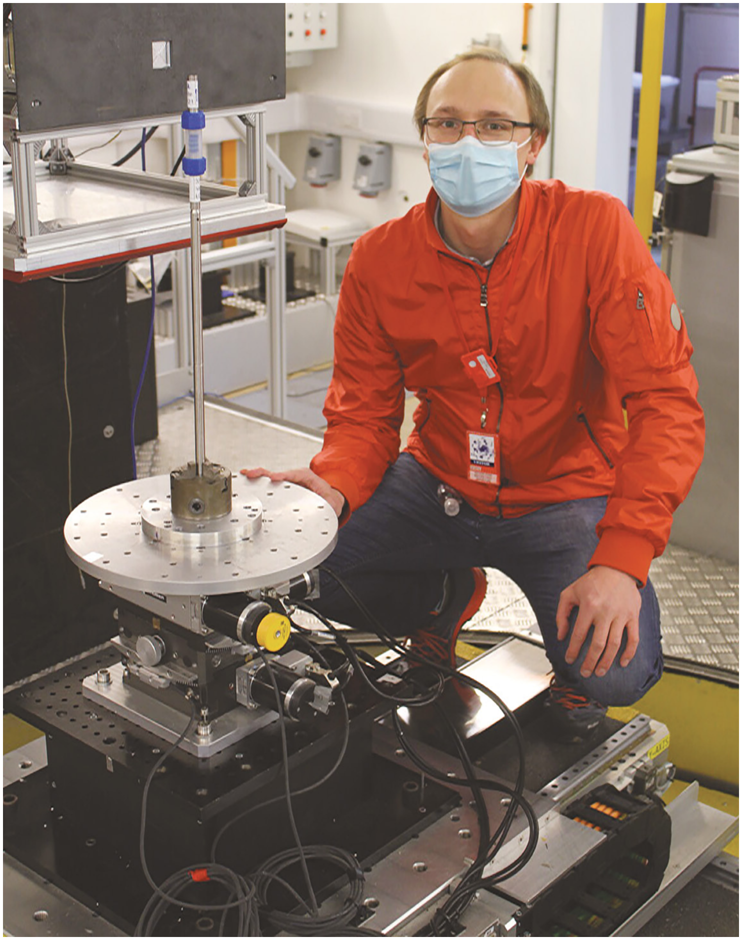
# Energy and the environment

**Human activity has profoundly impacted the environment, the climate and the availability of natural resources. To address this, we need to develop sustainable materials and processes that optimise the use of resources while minimising environmental harm. Neutron and muon techniques are being used to advance technologies such as hydrogen storage, next-generation batteries and renewable energy. They also offer insights into climate dynamics and environmental changes, as well as processes to reduce or capture harmful emissions. These innovations will be crucial for a more sustainable future.**

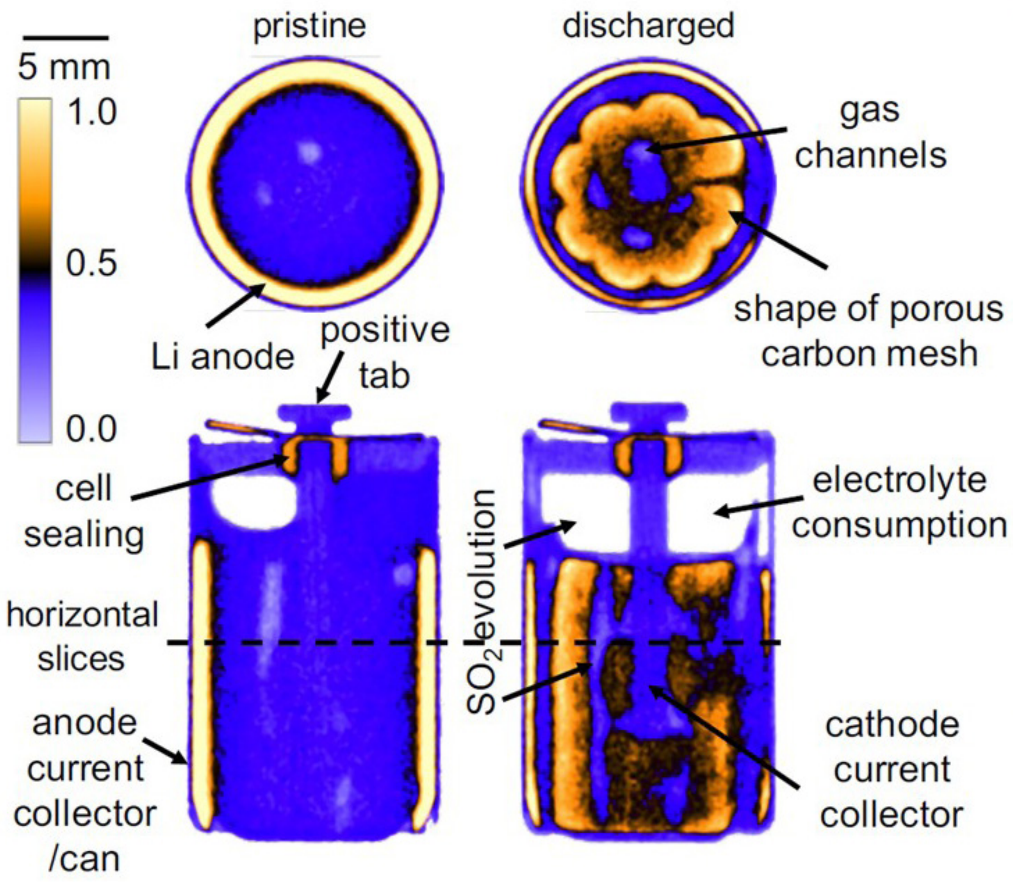
## Clean energy

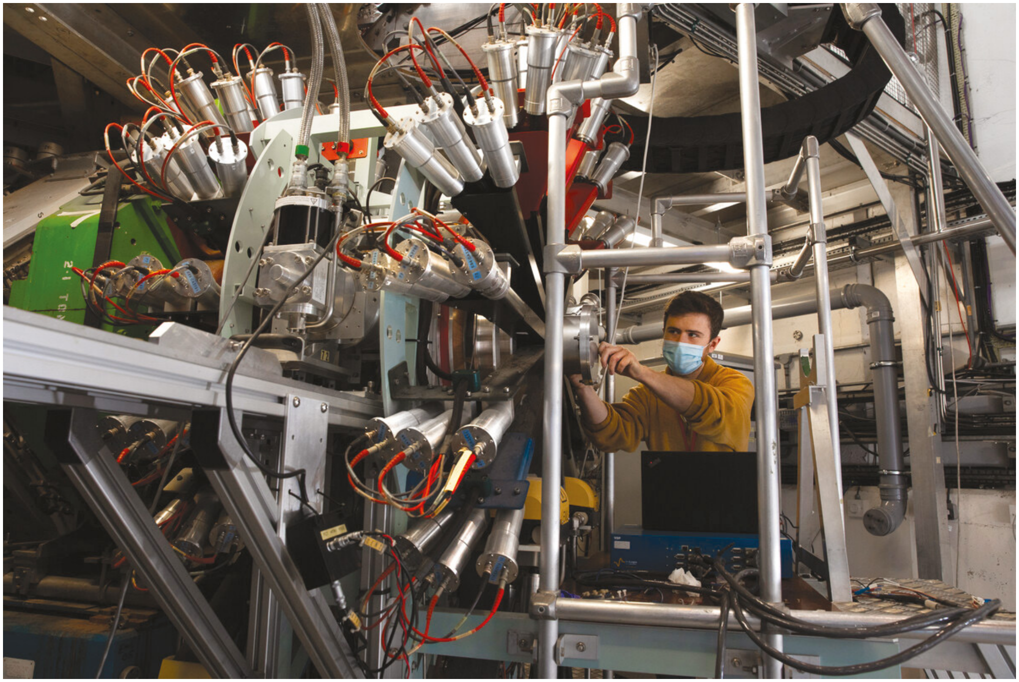
Neutron and muon techniques have improved our understanding of the critical components and interfaces in battery systems. Research at ISIS has supported the development of energy storage devices with improved power density, cycle life, cost-effectiveness, safety and sustainability.

During his ISIS Facility Development Studentship, Ralf Ziesche, here at IMAT in 2021, developed neutron imaging techniques to study electrochemical devices, such as batteries and fuel cells.



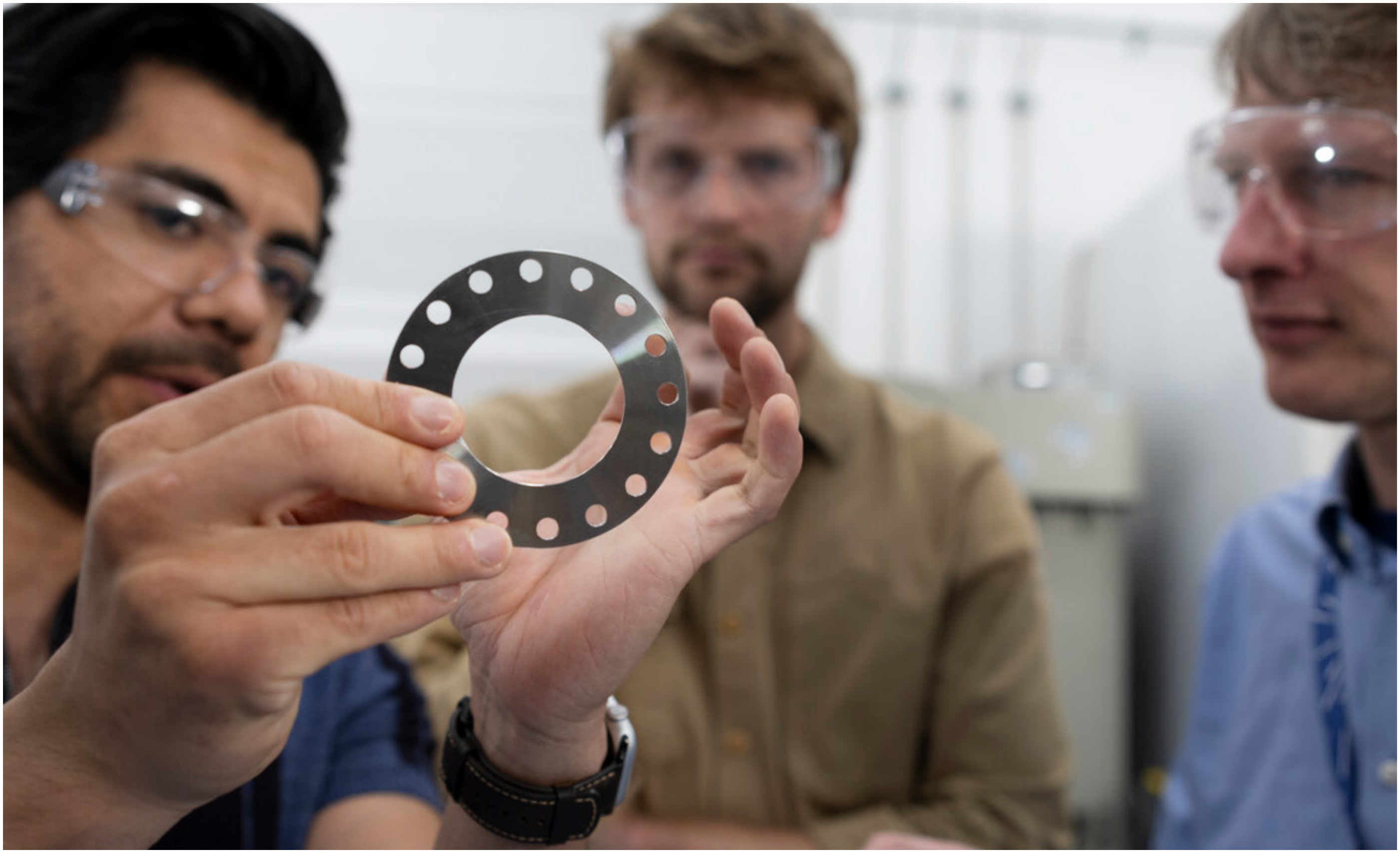
Ralf and his collaborators used the neutron’s sensitivity to lithium and hydrogen to image a commercial battery during discharge. With complementary X-ray techniques, these neutron studies improved understanding of the processes that impact battery performance.





During his PhD at the University of Sheffield, ISIS Facility Development Student, Innes McClelland, designed a cell for studying battery materials during their operation using muon spectroscopy on the Emu beamline.

> "The exciting development of operando muon spectroscopy opens up a wide range of opportunities for researchers working on energy storage materials, allowing a unique perspective of ionic diffusion from inside the materials themselves whilst in operation."
>
> **Innes McClelland**
> former ISIS Facility Development Student

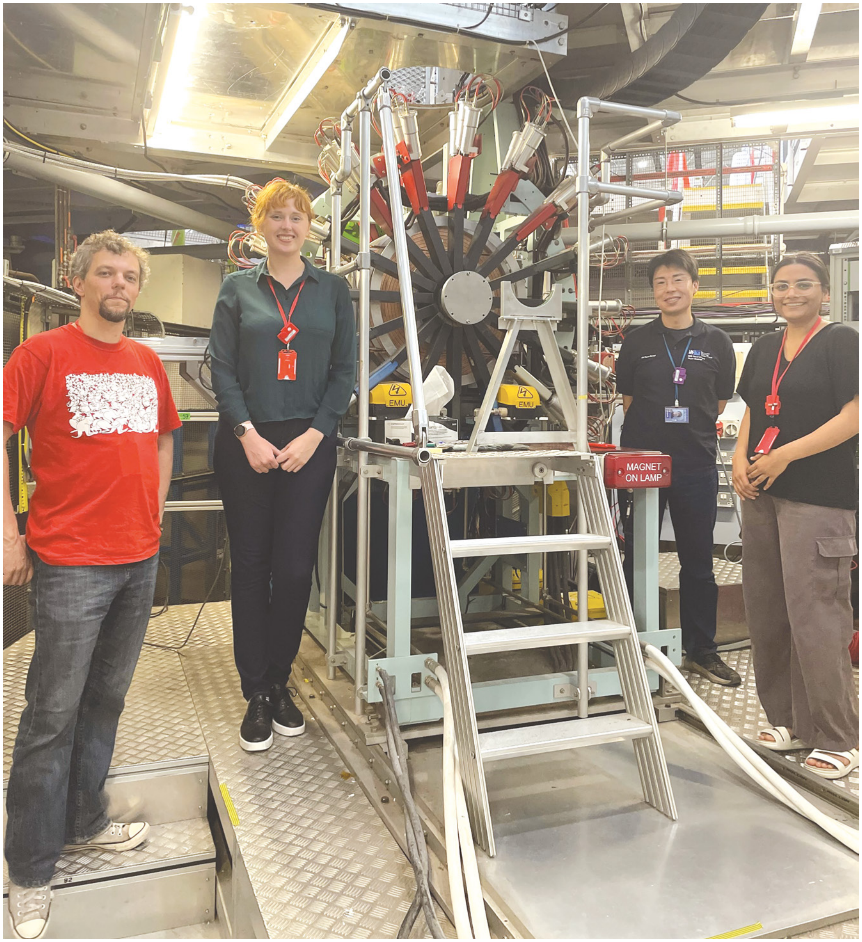


Gabriel Perez, Crystallography Group, James Le Houx, Energy Materials Group and Peter Baker, Muons Group, discuss the design of the Polaris electrochemical cell for operando diffraction studies. This cell has been used to investigate the structural evolution of various lithium and sodium ion batteries during charge and discharge.

With global net zero commitments, hydrogen is recognised as a gateway molecule to a sustainable, low-carbon energy future. Neutron techniques, which are highly sensitive to hydrogen, are playing a key role in understanding and developing hydrogenous zero-carbon materials that are efficient carbon-free energy carriers.

Ammonia is one hydrogen bond short of natural gas (methane), and has all the right credentials to be the carbon-free energy source beyond fossil fuels. Bill David's team at ISIS and the University of Oxford developed a novel method to decompose ammonia to hydrogen and nitrogen, and have successfully combusted a real-time ammonia-hydrogen blend directly from a partial decomposition of ammonia. This opens up opportunities for converting internal combustion engines from diesel and petrol to run on ammonia with zero carbon emissions.

Clockwise from left: Bill David, Martin Owen Jones, Sam Callear, Hazel Hunter, Tom Wood, Josh Makepeace and Mark Kibble at Polaris.

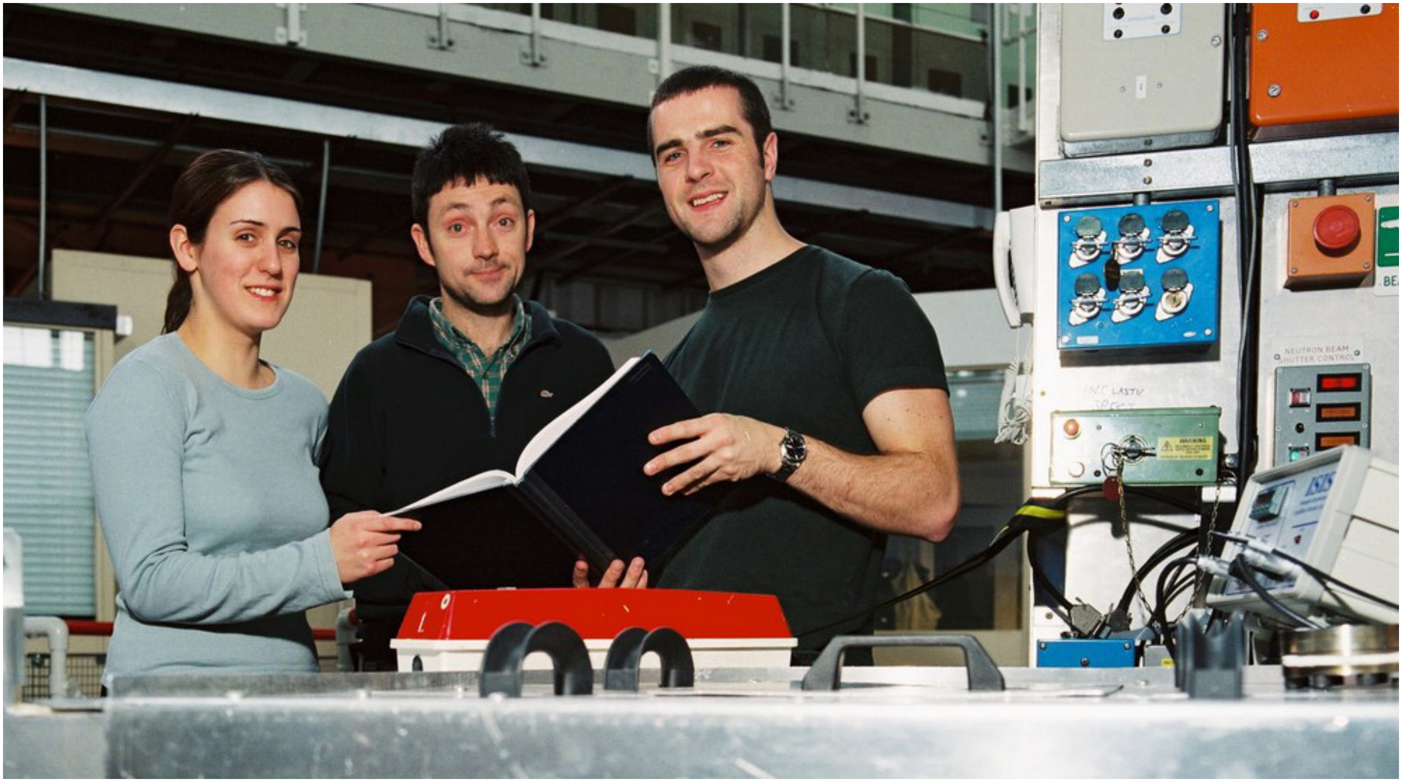



Harnessing solar energy through photovoltaics has become a widespread renewable energy source. Tim Niewelt, Sophie Pain and Anup Yadav from the University of Warwick, together with instrument scientist Koji Yokoyama, have conducted multiple studies on silicon for solar cells. In their initial experiment, they used HiFi for photoexcited muon spin spectroscopy — a technique developed at ISIS that combines muon spin spectroscopy with laser light illumination. They later returned to Emu to further investigate the interactions of muons with the silicon crystal lattice.

> "Our time working on Emu has definitely been productive as we have been able to gather so much data. With results from this experiment, we wish to continue our carrier lifetime measurement at HiFi laser and study beam damage by muons using muon beamlines."
>
> **Sophie Pain**
> University of Warwick

## Catalysts

Catalysts play a key role in enhancing the sustainability of many industrial processes that produce the materials we need for our daily lives. Over the years, numerous studies at ISIS have helped to improve our understanding of catalytic processes and develop new and more effective catalysts.



Users Emma Gibson, David Lennon, and Alaster McInroy, University of Glasgow, explore the properties of a solid-acid catalyst material using Tosca in 2004.

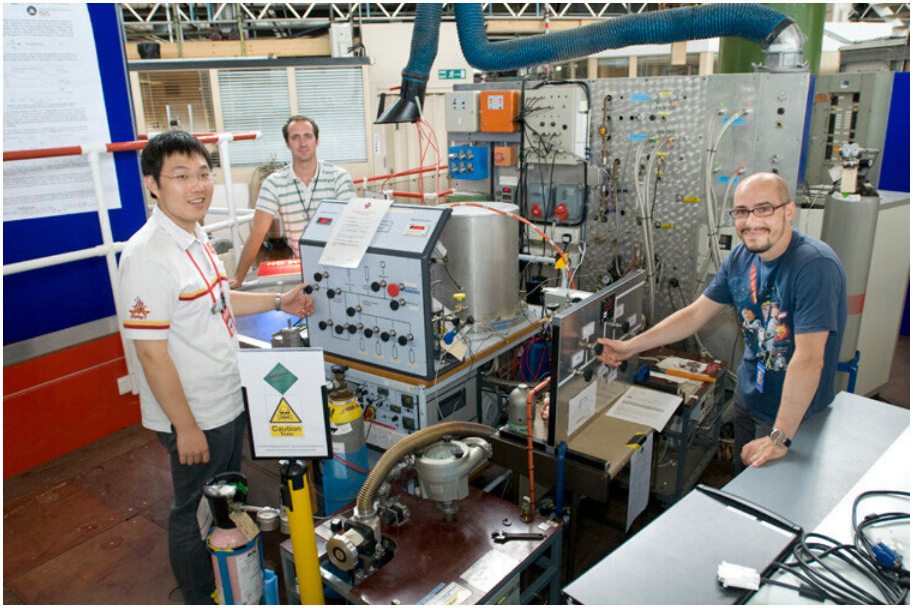
David Lennon's team have been regular visitors to ISIS. In 2024, they used IMAT to study a palladium-on-carbon catalyst used for hydrogenation reactions. This was the first time that neutron imaging had been used to observe the hydrogen adsorption and absorption processes in real time, offering new insights into the material's behaviour.

Marta Falkowska, University of Manchester, prepares samples for studies of catalytic arene hydrogenation on Nimrod in 2014. Catalytic hydrogenation is an important reaction for the synthesis of many compounds used in the chemical, pharmaceutical and food industries.


One of ISIS's longest running and most successful industrial collaborations is with Johnson Matthey, a major producer and developer of catalysts. Here, Edward Bilbé, Jon Booth, Maurits van Tol and Liz Rowsell from Johnson Matthey are visiting in September 2022, accompanied by Roger Eccleston and Hamish Cavaye, ISIS.

## Metal-organic frameworks

Metal-Organic Frameworks (MOFs) are materials with nanoscale porous structures. Their large internal surface areas and tuneable chemical and structural properties are of great interest for applications including catalysis, biomedicine, chemical sensors and to capture and store gas molecules.

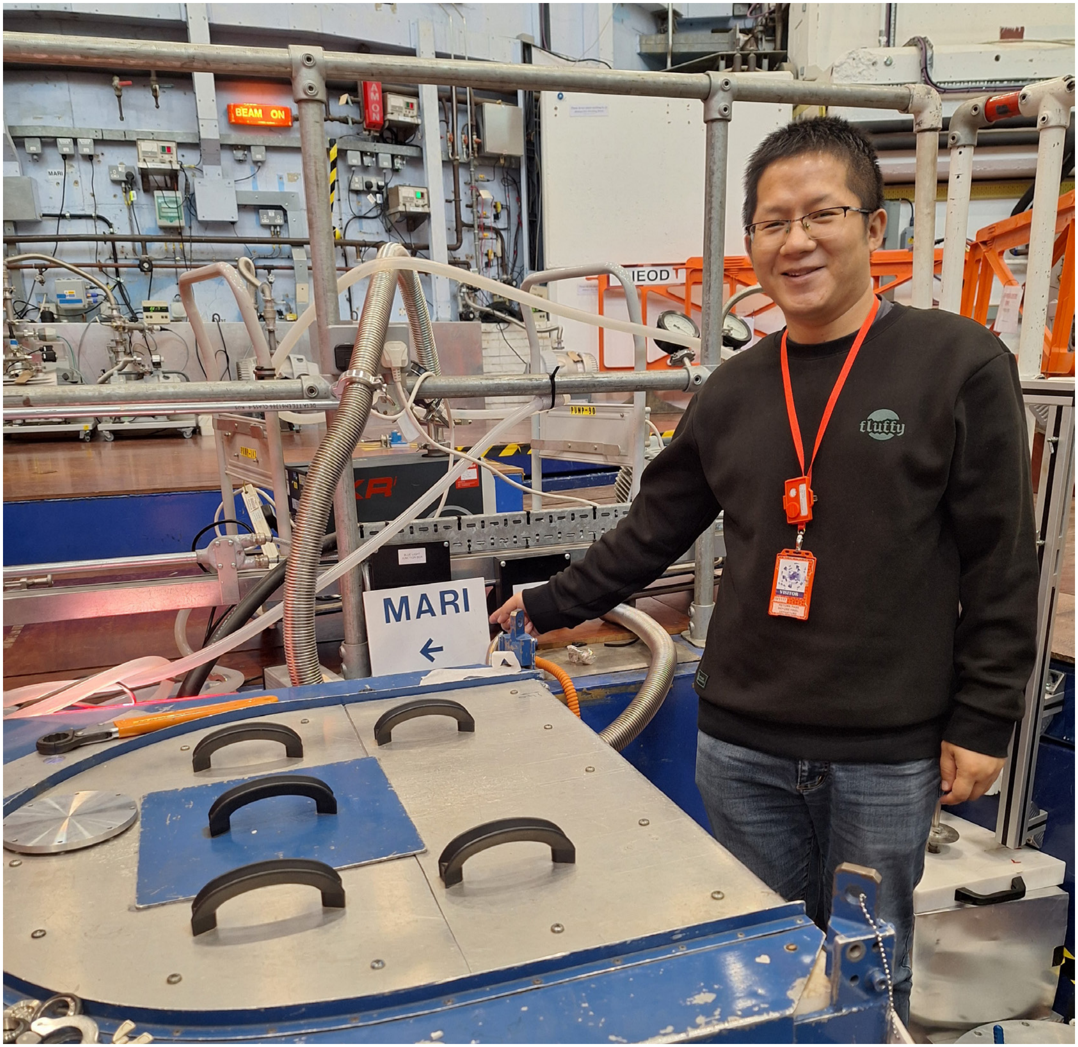


Left to right: Sihai Yang and Mathew Savage from the University of Manchester, and Ivan Da Silva from ISIS, working on Tosca. Sihai, a regular user at ISIS, received the ISIS Science Impact Award in 2019 for his work using neutrons to investigate a wide range of porous materials, including MOFs, for applications including toxic gas removal and catalysts for biofuel production.

> “By using cutting-edge neutron scattering techniques, we have made a number of key discoveries to explain how and why a material functions in the way that it does, and such information, coupled with computational studies, is critical to inform the design of future advanced materials to boost the economy and address many environmental and energy challenges.”
>
> Sihai Yang
> University of Manchester

## Thermoelectrics

The thermoelectric effect is a phenomenon in which a temperature difference can be converted into electric voltage and vice versa. It is of considerable interest in 'harvesting' waste heat, for example. Researchers from China, Japan and Australia have used Mari to study SrCuSb and related compounds, in the search for high-performance thermoelectrics that do not contain toxic elements such as tellurium.




Qingyong Ren, China Spallation Neutron Source, next to Mari in May 2024.

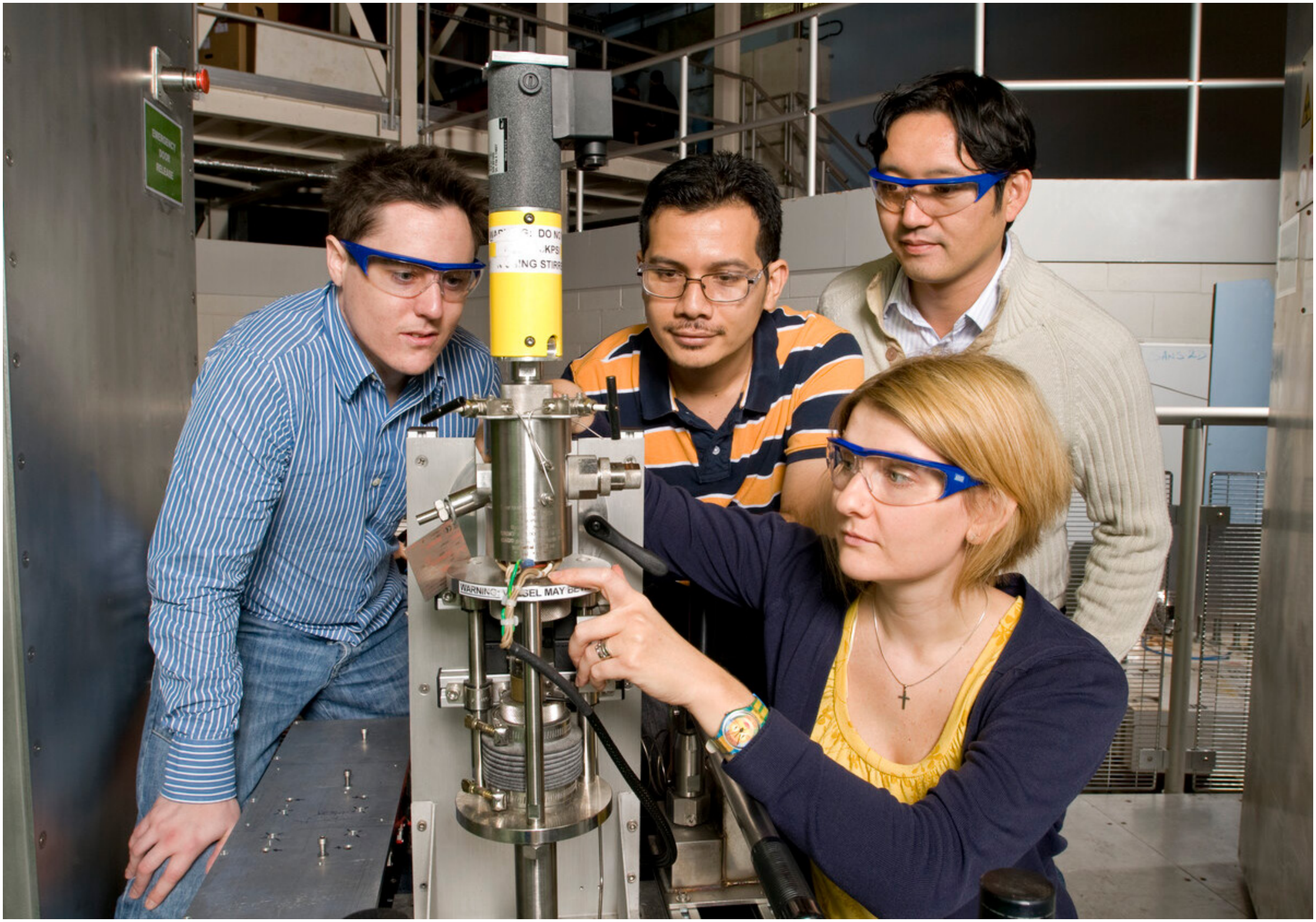
## Greener materials

Biobased materials are gaining popularity as sustainable alternatives to traditional materials made from petrochemical feedstocks due to their lower environmental impact throughout their life cycle.

In 2021, Mariela Martins Nolasco from the University of Aveiro in Portugal won the ISIS Society Impact Award for her work characterising the structure and dynamics of natural polymers, such as cellulose and bacterial cellulose, and bio-based synthetic polymers. This knowledge will help to develop new sustainable materials for use in emerging technologies such as medical devices and fuel cells.


Mariela Martins Nolasco at Tosca.

Over the years, experimental setups at ISIS have been developed to handle increasingly extreme and complex conditions, providing new insights to optimise materials and processes.



In 2010, Stephen Cummings, Azmi Mohamed and Masanubo Sagisaka from the University of Bristol, here with ISIS Instrument Scientist Sarah Rogers, set up a high-pressure small-angle neutron scattering experiment on SANS2D. Their work demonstrated that surfactants could be designed to enhance the solubility levels of carbon dioxide, potentially unlocking a range of applications as a more environmentally friendly alternative to petrochemical solvents.

## Environmental studies

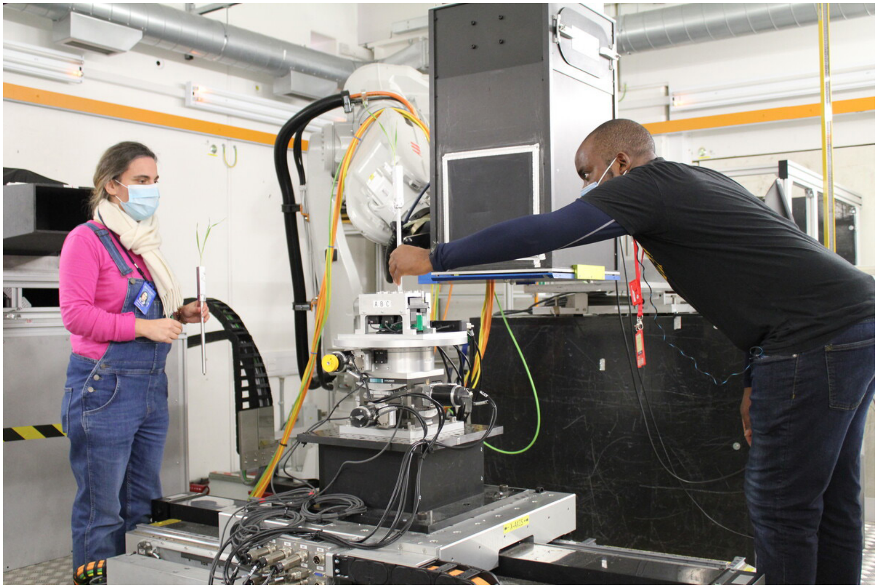
Neutron techniques at ISIS are providing insights into how human activity has impacted chemical and physical processes that occur in the atmosphere, and the implications for health and climate change.

In 2023, Martin King was awarded the ISIS Society Impact Award for his work investigating real-world atmospheric pollutants using neutron reflectometry. Martin and his group from Royal Holloway have conducted numerous experiments to understand how atmospheric aerosols, which are produced by both natural phenomena and human activities, impact the Earth's climate.


Stephanie Jones from Royal Holloway prepares an experiment on Surf to study the chemistry of aerosol particles.

## Soil and plant science

Two-thirds of the world's dietary energy intake comes from maize, wheat, rice, barley and rye, making their cultivation critical to global food security. A key factor in crop growth lies beneath the surface: the interactions between plant roots and the surrounding soil. Neutron imaging has emerged as a powerful, non-invasive tool for visualising 'live' root structures within soil. Genoveva Burca, former IMAT Instrument Scientist, and Tinashe Mawodza, University of Sheffield, are shown here using IMAT to map the soil moisture distribution and the root structure of wheat seedlings grown in a climate-smart soil enriched with biochar. Due to the increasing demand for such studies, ISIS now has a research greenhouse and a plant growth chamber next to IMAT.



# Quantum materials

**Quantum science explores the behaviour of materials at the smallest scales, revealing extraordinary phenomena like superconductivity, entanglement and superfluidity. The discovery and manipulation of quantum materials is being used to unlock transformative technologies, from quantum computing and ultra-secure communication to cutting-edge sensors. Neutrons and muons are powerful tools for exploring the quantum realm, allowing scientists to probe deep into materials to reveal their atomic-level structures, dynamics and magnetic properties. These techniques are often used to prove or disprove theories, sometimes years after they have been developed, or to drive the development of new theories.**

## Superconductors

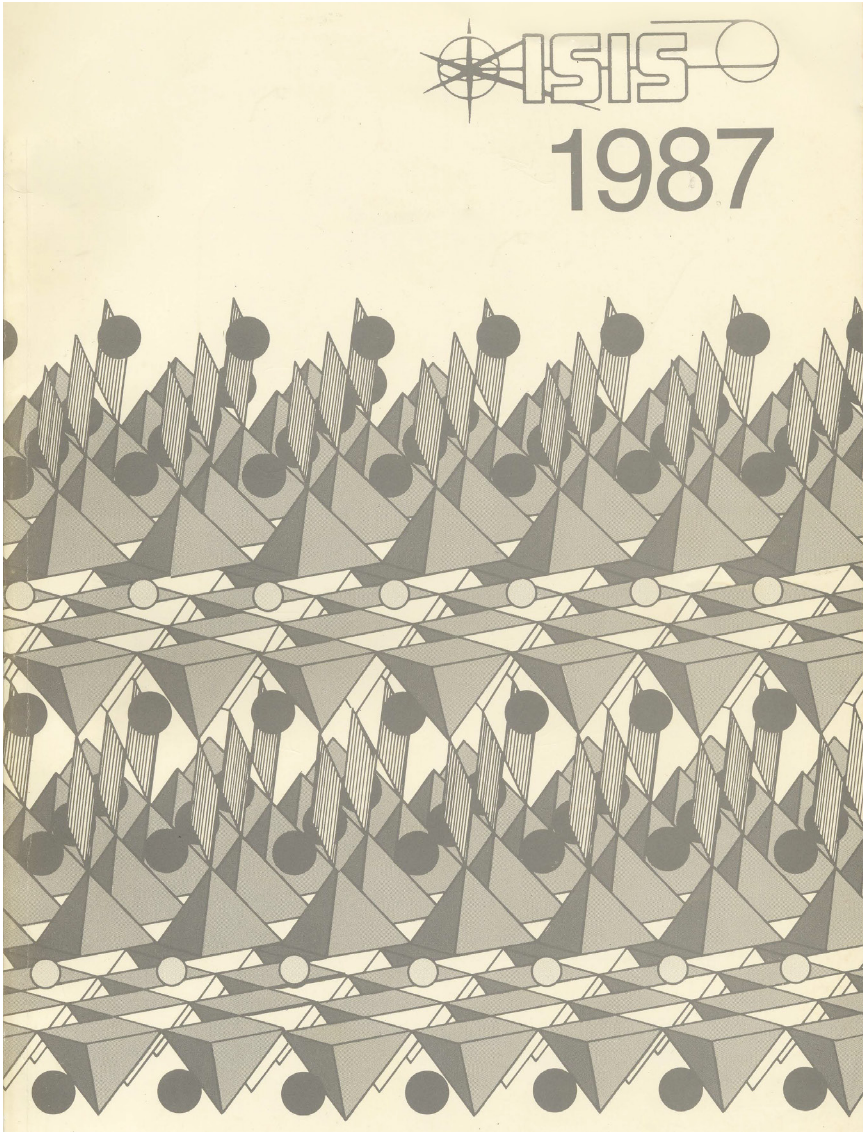
The discovery of high-temperature superconductors in 1986 led to an explosion of research that has continued ever since. At ISIS, neutron and muon techniques have been used to gain insights into the structure, chemistry and mechanisms of these materials. Over the years, this has resulted in a prolific body of research that has laid the groundwork for studies of ever more complex quantum phenomena.

Philip King, Associate Director of Partnerships and Programmes, observes as a magnet levitates above a cooled superconducting material due to the Meissner effect. This phenomenon occurs when a superconductor is cooled below its critical temperature and is used in MRI machines, levitating trains and high-speed magnetic bearings.

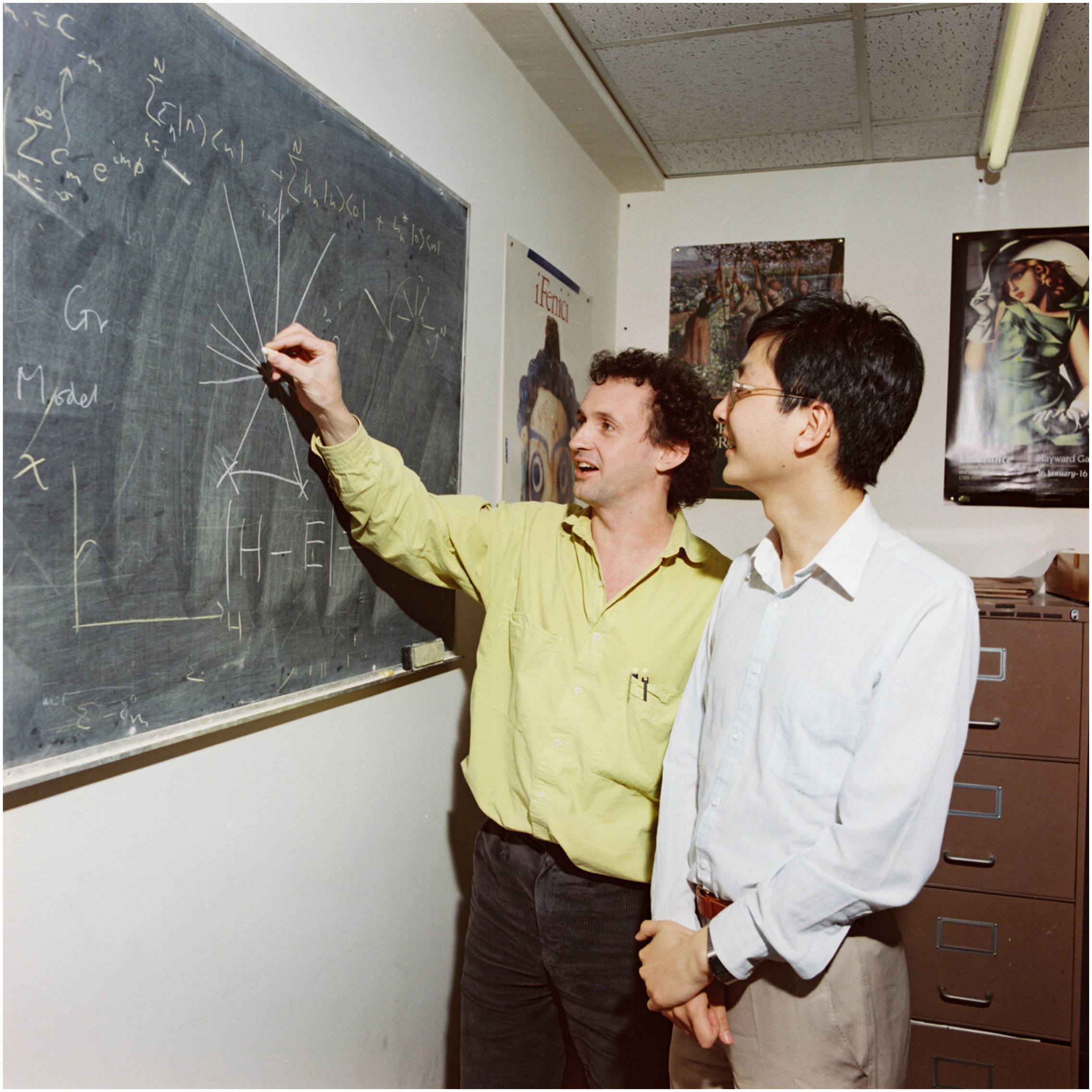
Neutron powder diffraction is the technique of choice in determining the atomic ordering of materials composed of light and heavy elements. This is particularly true for high temperature superconductors because neutrons are particularly sensitive to the positions of the all-important oxygen atoms, which are surrounded by heavy metal atoms. A small reduction in the amount of oxygen in the crystal structure turns the high-temperature superconductor into just another magnetic material.

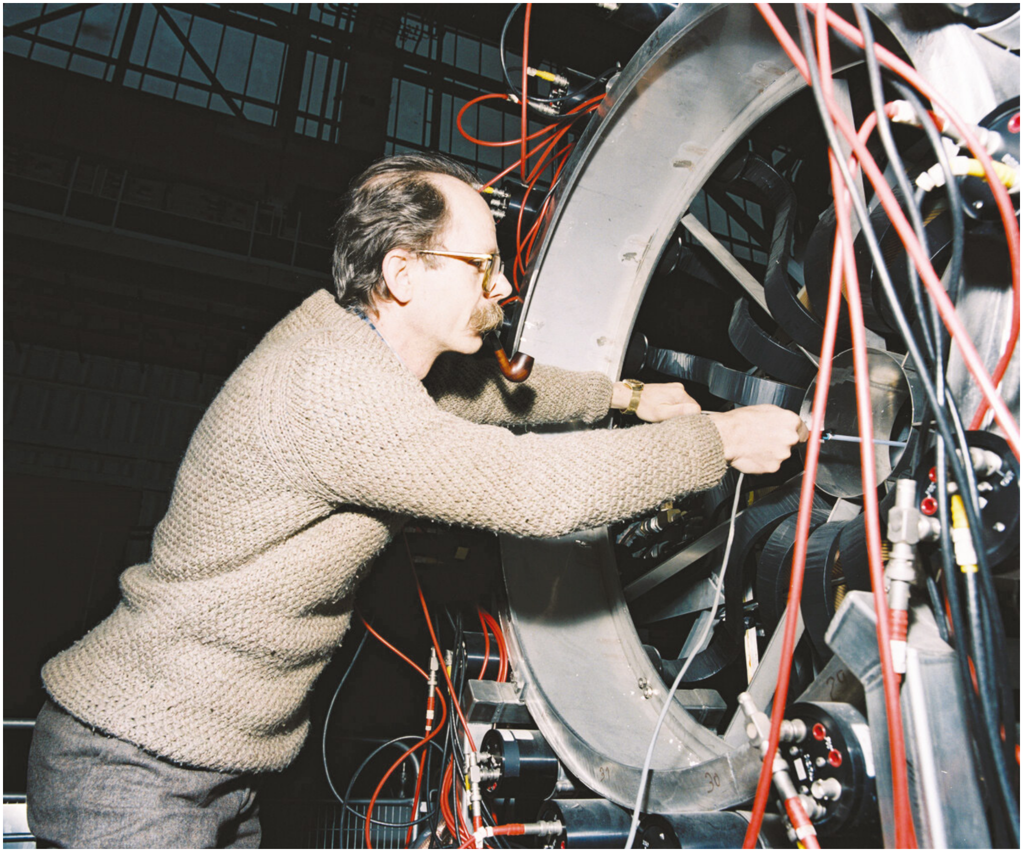
The 1987 Nature paper on the structure of yttrium barium copper oxide, from experiments on HRPD by Bill David and British and American colleagues, is one of the highest cited publications from ISIS.

A cartoon version of this structure was used as the front page of the 1987 ISIS Annual Report.



In the late 1980s, neutron and Raman scattering experiments showed that any theory of high-temperature superconductors must consider how charge carriers move through and affect the magnetic structure of the material. In 1989, Mike Gunn, ISIS Theory Group, and Derek Lee, University of Cambridge, work on calculations regarding holes as charge carriers in antiferromagnets.





ISIS user Cesare Bucci, University of Parma, was a pioneer in the development of muon techniques to study superconductors.

Cesare places a sample in MuSR in April 1989.

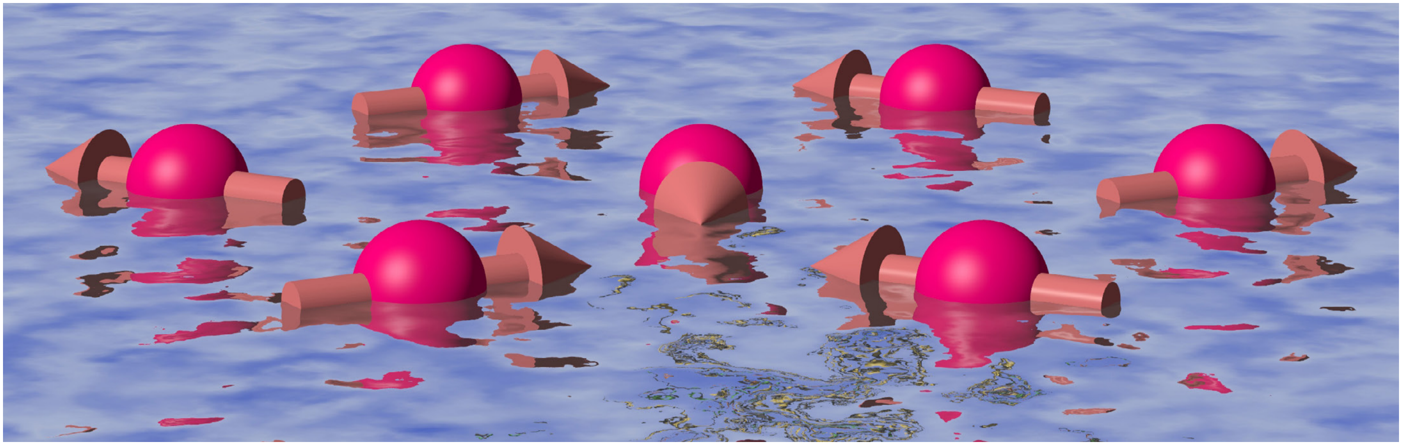
> “I remember Cesare played the clarinet or saxophone and he would play it in breaks and this wonderful music would drift across the target station.”
>
> **Adrian Hillier**
> Muon Group Leader

## Magnetism

Since they have a magnetic moment but no charge, neutrons are one of the most important probes for studying the structure and dynamics of magnetic materials. Muons, which also have a magnetic moment, provide highly complementary information and many researchers will use both techniques.

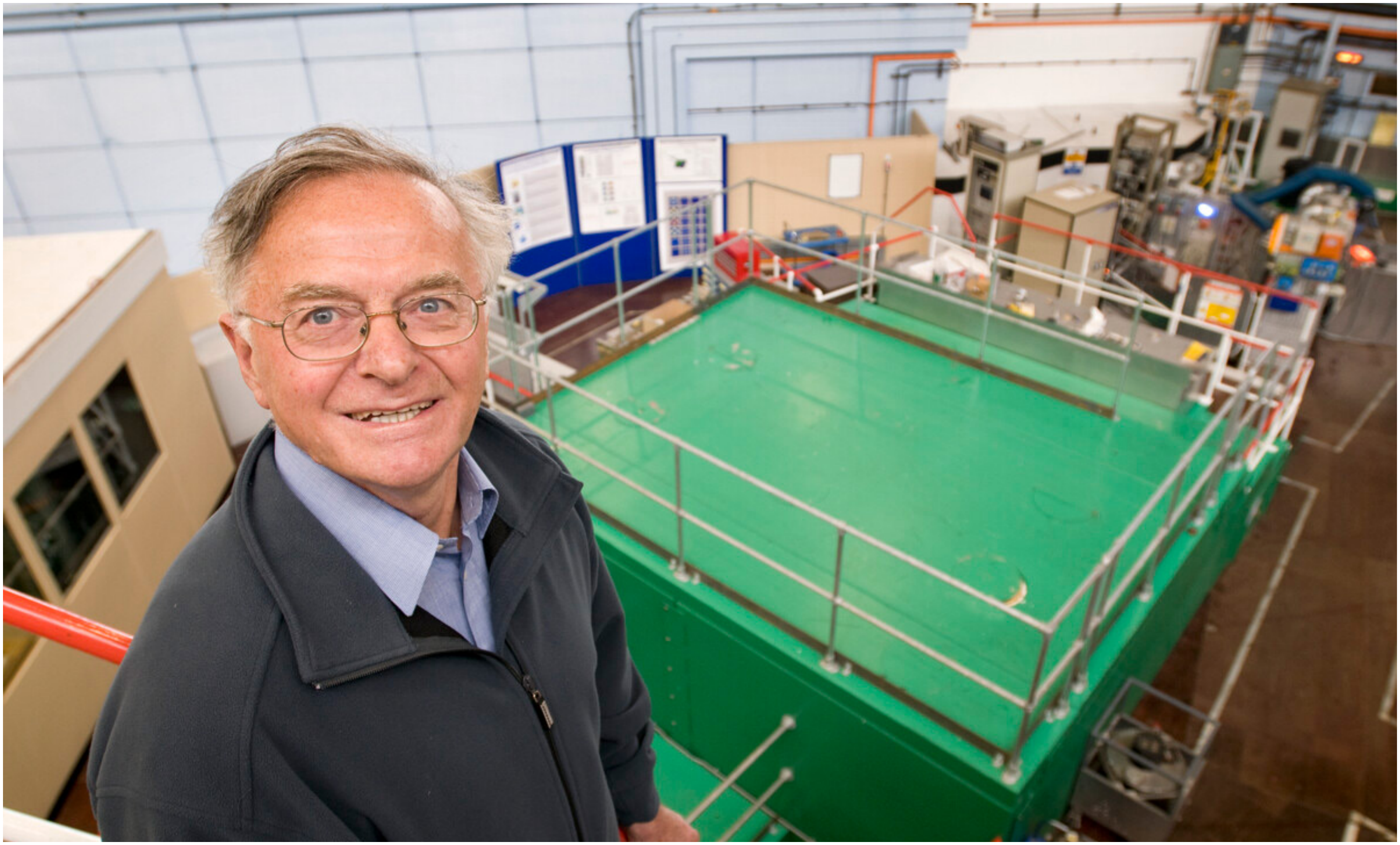
Maria de la Fuente and Philipp Bender, Universidad de Cantabria, prepare samples to study magnetic interparticle coupling and magnetisation processes in $TbCu_2$ super-antiferromagnets on SANS2D.

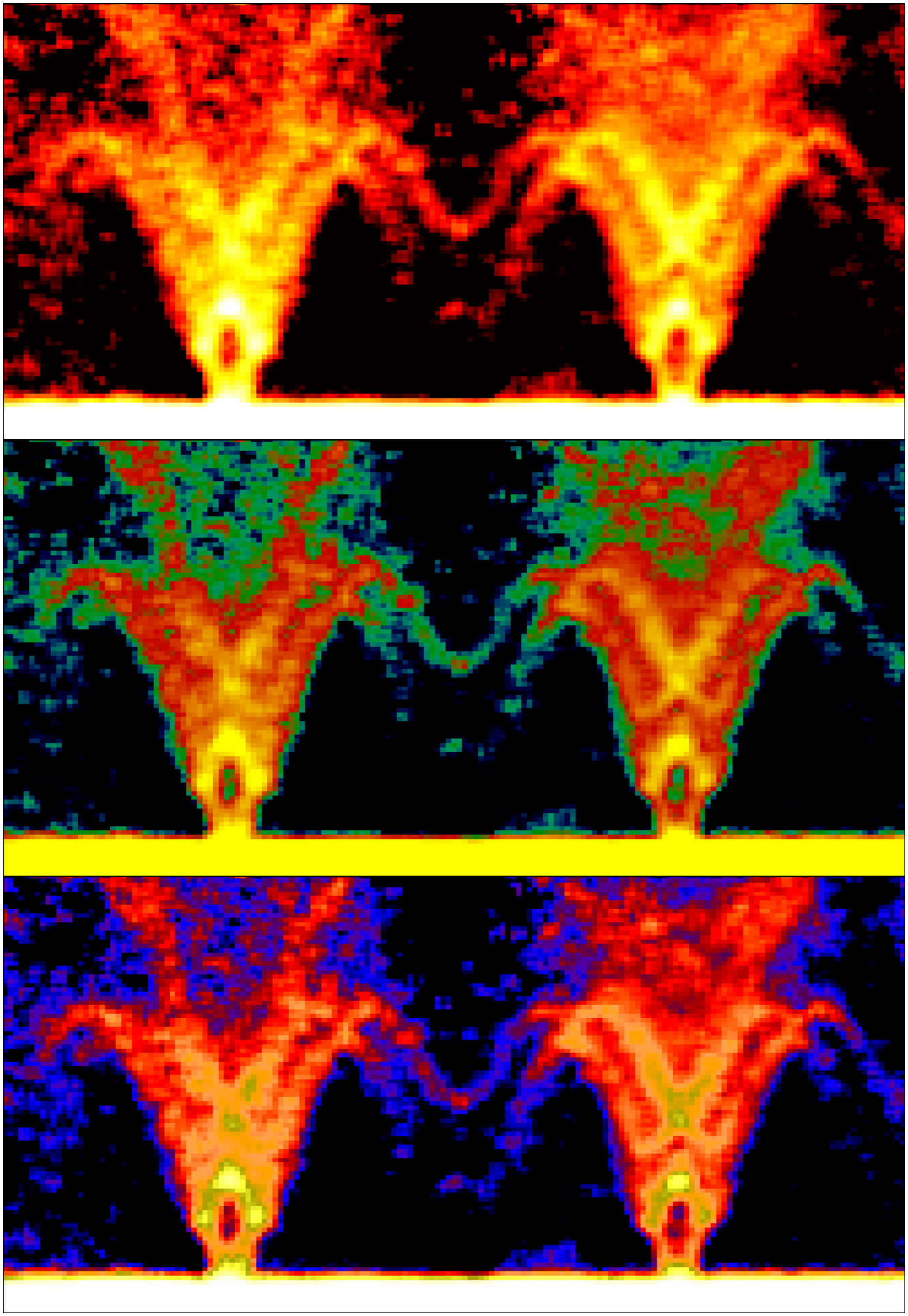
The Quantum Spin Liquid (QSL) state, predicted by theory over 40 years ago, involves magnetic moments behaving like a liquid, resisting freezing even at absolute zero. QSLs could have extraordinary properties and applications, but they are challenging to identify experimentally. Neutron scattering and muon spectroscopy have characterised a genuine spin-liquid state, validating theoretical predictions on relevant spin models.



> "This research is fundamental physics of the purest kind. The quantum spin liquid state is extremely fascinating, and we can imagine that in the future it could be of use in quantum computing and cryptography for the writing and deciphering of coded information."
>
> **Francis Pratt**
> ISIS Instrument Scientist

Roger Cowley, one of the most renowned figures in UK and international neutron scattering, carried out many seminal experiments on low dimensional magnetic systems, taking advantage of the very wide coverage enabled by pioneering ISIS spectrometers with large position sensitive detectors. Here he is in Target Station 1 in 2008.

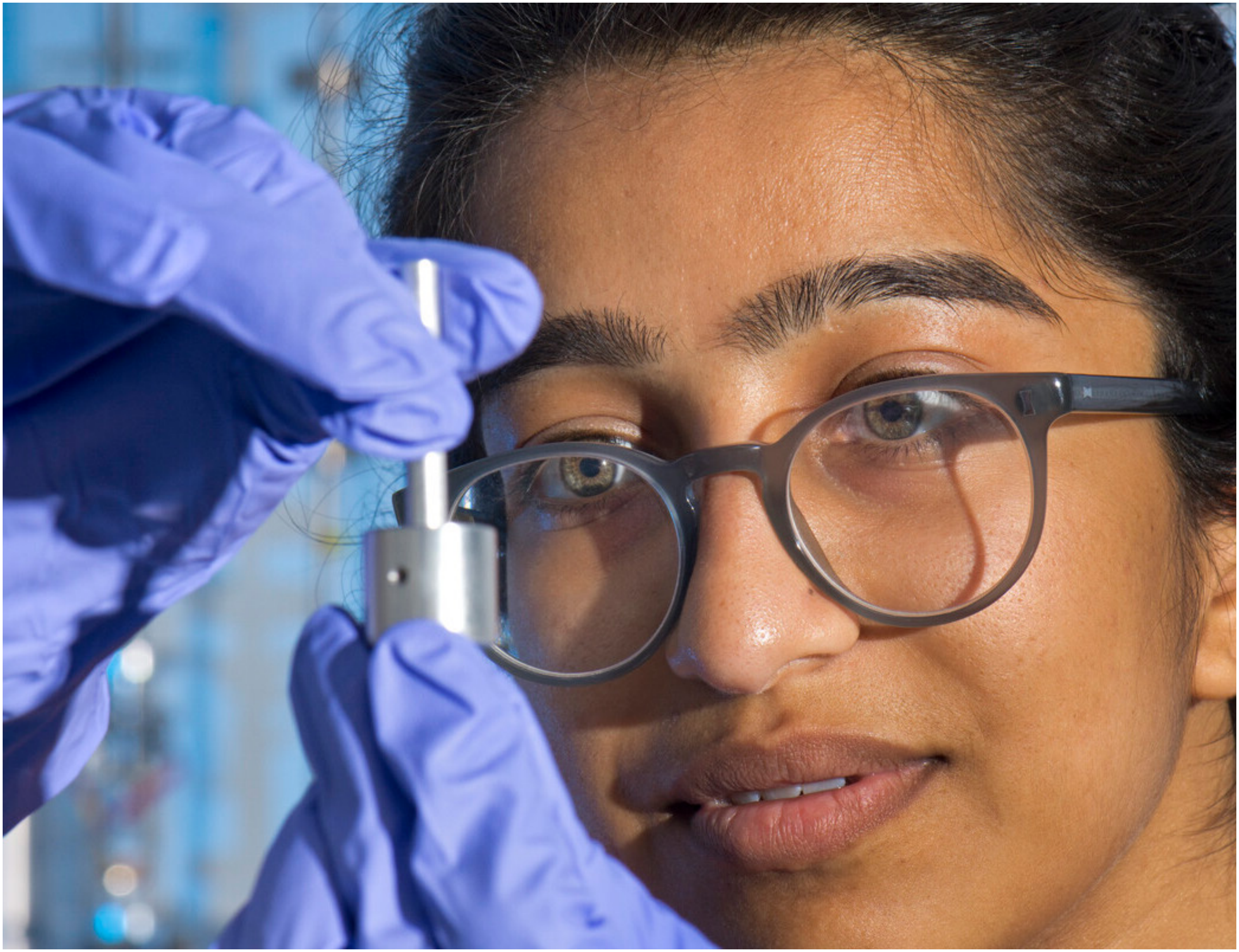


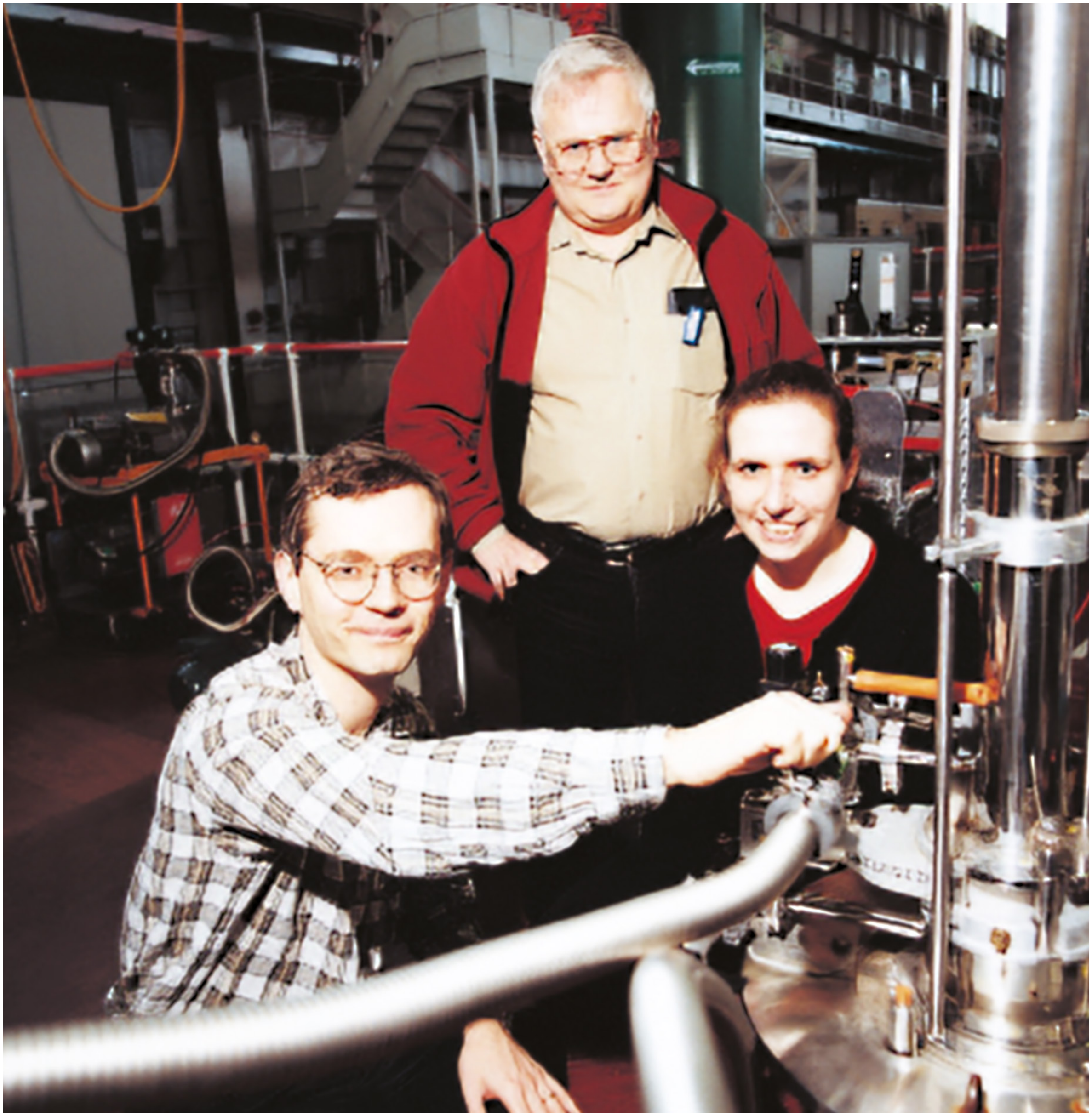


As well as important scientific results, ISIS spectrometers also regularly produce beautiful images of data. These ‘fireworks’ show the highly structured spectrum of an exotic phase of a novel one-dimensional magnetic material, measured on LET.

Image courtesy of David Schmidiger and Andrey Zheludev, ETH Zürich.

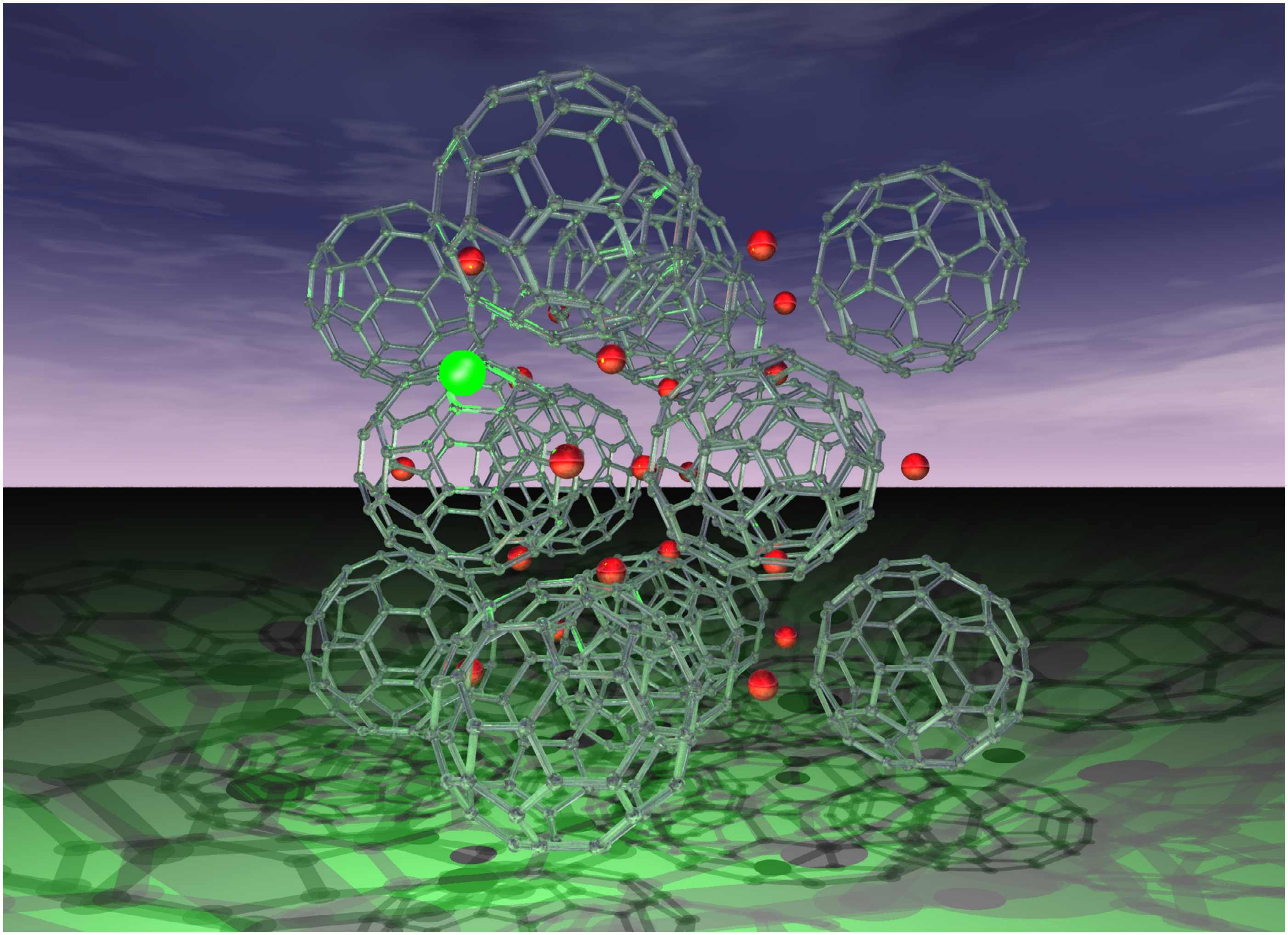
Anuradha Vibhakar, University of Oxford, prepares a sample for an experiment on WISH, aimed at determining the magnetic properties of manganite perovskites. This class of materials exhibits intriguing quantum properties, such as colossal magnetoresistance – a phenomenon where electrical resistance dramatically changes in the presence of a magnetic field. These properties are important for magnetic memory devices, magnetic-field sensors and other electronics.





Stephen Blundell and Ishbel Marshall, University of Oxford, preparing the MuSR dilution fridge for studies of the 2D spin gap system in $CaV_4O_9$, under the watchful eye of Chris Scott in 2000.

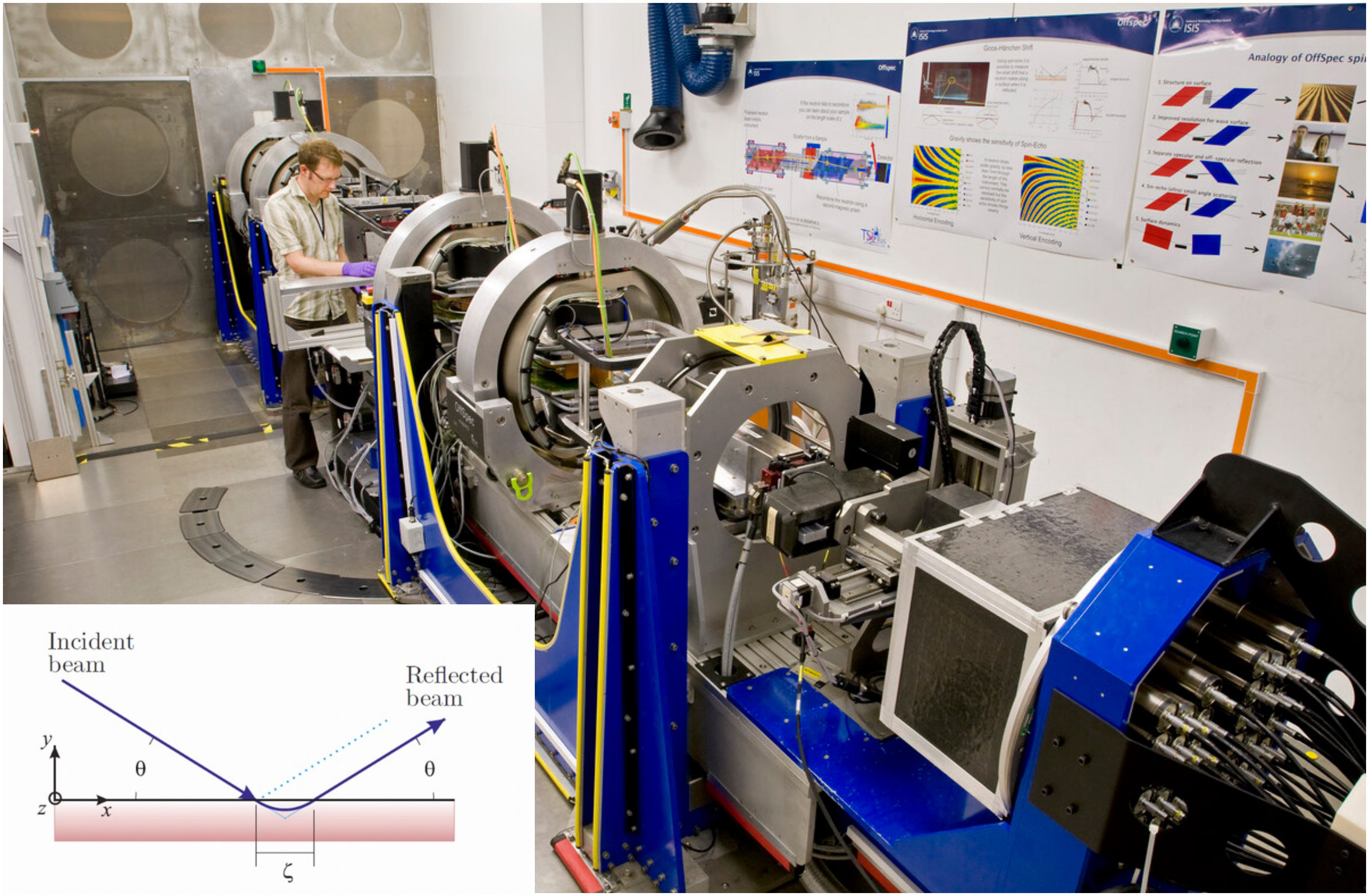
Endofullerenes are $C_{60}$ molecules with an atom, ion, or molecular cluster enclosed inside the carbon cage. They are enhancing our understanding of confined particles, which is key for advancing the field of quantum mechanics.



This image shows an implanted muon investigating the magnetic properties of the largest member of the family of face-centred-cubic $C_{60}$-based superconducting materials. This compound contains caesium, which expands the volume of each $C_{60}$ molecule beyond the point where they turn from superconductors into frustrated magnets. Image courtesy of Peter Baker.

## Optics

The Goos-Hänchen effect is an optical phenomenon in which linearly polarised light undergoes a very small lateral shift when totally internally reflected, an idea first attributed to Isaac Newton. The first observation of Goos-Hänchen for neutrons was made at ISIS via the direct and unambiguous measurement of polarisation change during reflection. The results provide insights for the design of neutron waveguides – an important component in neutron optics that are used to channel neutrons along a specific path.



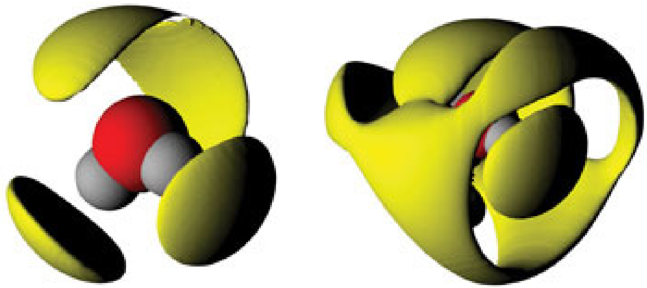

Robert Dalgliesh, ISIS Instrument Scientist and coauthor on this work, prepares a sample on the OffSpec instrument used to observe the Goos-Hänchen shift.

## Life science, bioscience and healthcare

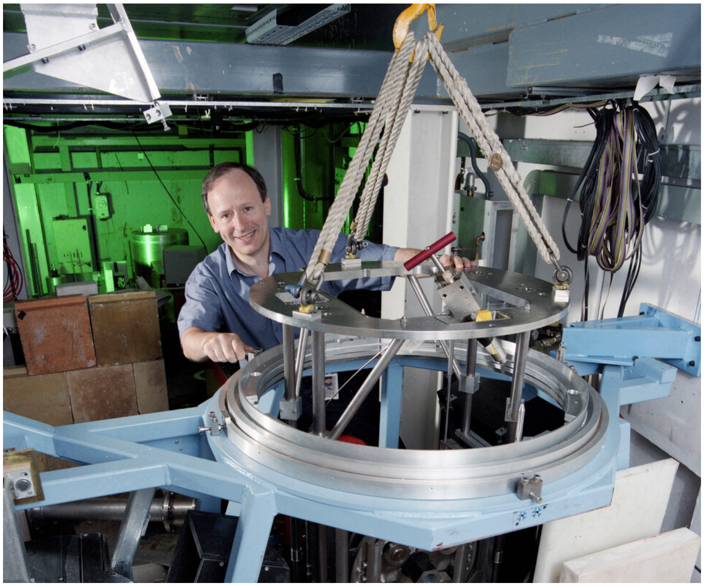
**Neutrons are sensitive to many of the elements most common to living matter, especially hydrogen. By studying entities such as proteins, or the membranes that form cell walls, we can analyse their structure and behaviour, gaining insights into how they influence biological processes and how we might intervene when these processes go awry.**

### Water

Water plays a vital role in supporting life on Earth. Although it seems like a simple molecule, water has complex chemical and physical properties. Over the years, research at ISIS has advanced our understanding of this ubiquitous molecule, for example how it changes form under pressure or on freezing to one of the many forms of ice. Powerful computer modelling techniques developed at ISIS have been used to interpret the experimental data.



Spatial density functions showing the distribution of the first (left) and second (right) neighbour water molecules around a central water molecule for liquid water at 298 K.



Richard Nelmes, Edinburgh University, during the installation of Pearl in 1996. Richard has been a major user and strong advocate for ISIS over many years. He was elected as a Fellow of the Royal Society in 2003 for his work on high-pressure crystal structures, including extensive work on the structure of ice and gas hydrates, which was carried out on Polaris and Pearl.


As technical capabilities have advanced, so too has the complexity of the systems that can be analysed at ISIS. More recently, researchers have used neutron scattering to study the movement of water inside human cells.

Maria Paula Marques from the University of Coimbra prepares a sample as part of a study investigating intracellular water as a target for anticancer drugs.

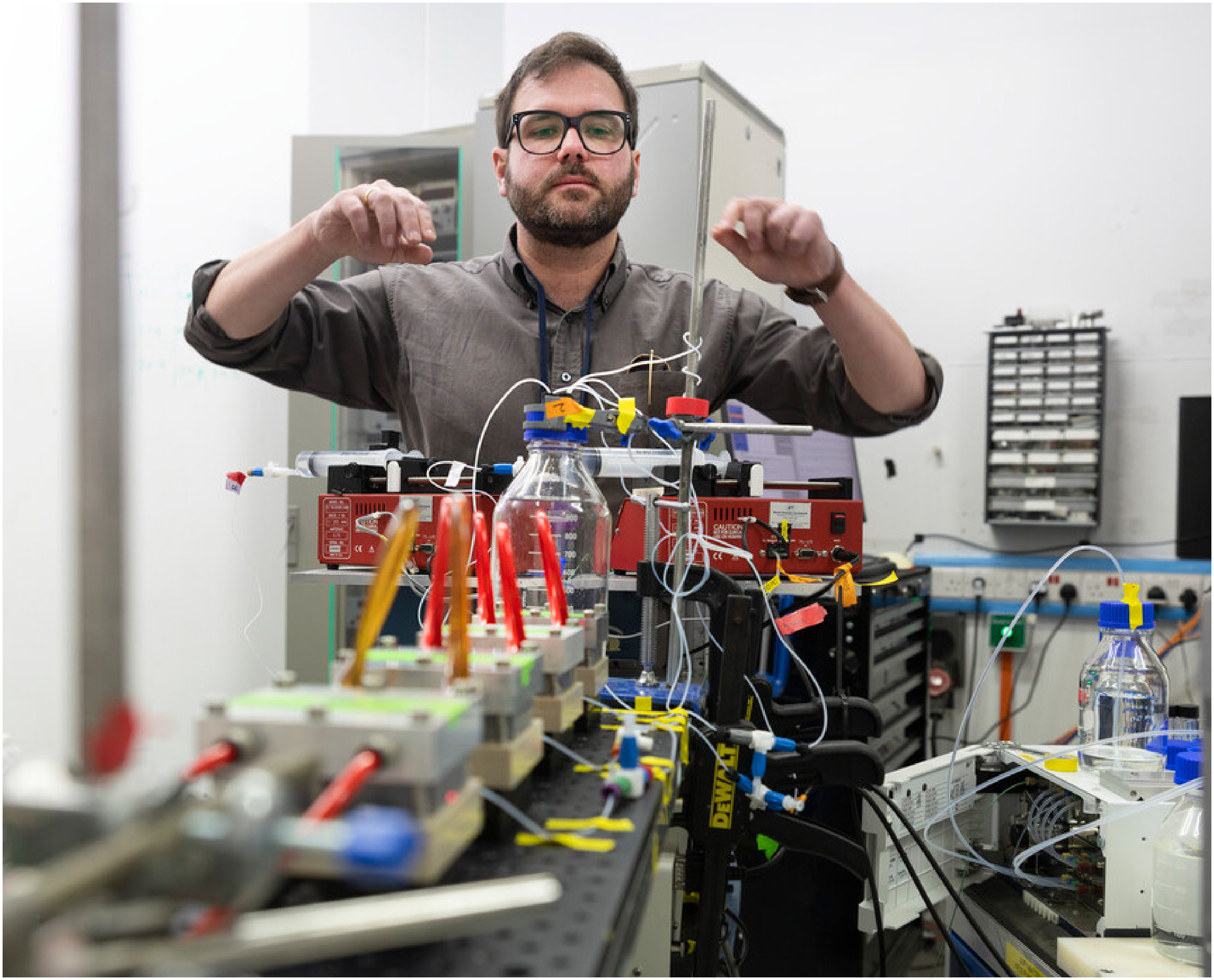
> “My team and I have been working at ISIS since 1999, starting with John Tomkinson. ISIS is, in our opinion, unique in providing cutting-edge instrumentation and top sample environment, peripheral labs, including a cell culture lab, and user support.”
>
> **Maria Paula Marques**
> University of Coimbra

## Cells and membranes

Particularly since the advent of Target Station 2, neutron techniques have been developed as powerful tools for studying the structures and interactions of complex, multi-component cell membranes. For example, neutron reflectometry has revealed how Polymyxin B, a last-resort antibiotic, penetrates the robust outer membrane of Gram-negative bacteria, offering crucial insights for developing new antibiotics.

Nicolo Paracini, University of Newcastle, prepares samples to study the interaction of antimicrobial agents with bacterial membrane models on PolRef.

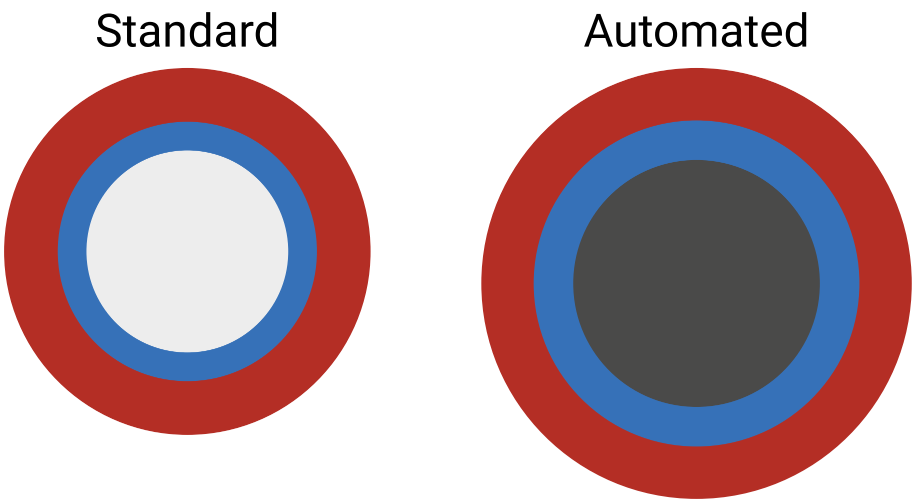
A Swedish-UK research collaboration used neutron reflectometry to uncover the molecular mechanisms behind the first stage of cell death (apoptosis), a process that plays a key role in the prevention of cancer. Luke Clifton, ISIS Instrument Scientist and a co-author on this research, sets up the OffSpec instrument used in this study.



## Drug delivery

mRNA technologies came to public attention as one of the methods used to produce COVID-19 vaccines, but they have much wider therapeutic applications. The mRNA itself has to be ‘encapsulated’ in something to prevent it degrading. One technique uses lipid nanoparticles, but the process has to be optimised for both biochemical performance and cost. Researchers from AstraZeneca, in collaboration with ISIS scientists, have used small-angle neutron and X-ray scattering to improve their understanding of the enhanced mRNA functional delivery of lipid nanoparticles formulated using a high-throughput platform. The deceptively simple picture shown is derived directly from the experimental data, and the darker grey circle at the centre of the ‘automated’ example is a clear mark of success.

### Lipid nanoparticles

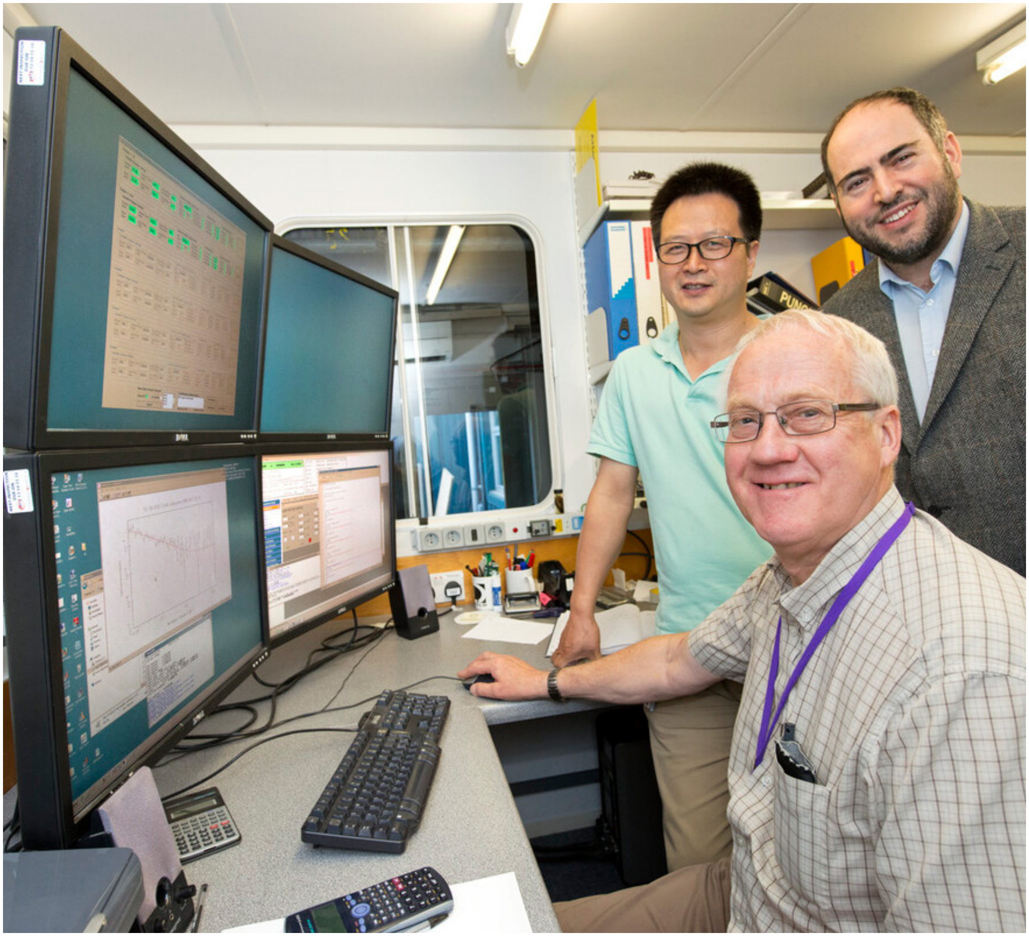



**Outer shell**: PEG layer
**Middle shell**: DSPC enriched lipids
**Core**: mRNA and lipids (mainly MC3 and Chol)
Note: dark grey indicates more mRNA present

## Surfactant science

Surfactants are molecules used in a wide range of health, home and personal care products, where they play a key role in cleaning, wetting, dispersing, emulsifying or foaming, among other functions.

In collaboration with researchers from the University of Oxford and other institutions, the consumer goods company, Unilever, has conducted numerous experiments at ISIS over the years. By using techniques such as small-angle neutron scattering and neutron reflectometry, they have studied the structure, behaviour and interactions of both natural and synthetic surfactants to help develop new formulations.



Left to right: Peixun Li, ISIS, Ian Tucker, Unilever and Jeff Penfold, (front), ISIS, in the Surf cabin in June 2015. Jeff Penfold was one of the pioneers of the neutron reflectometry technique.

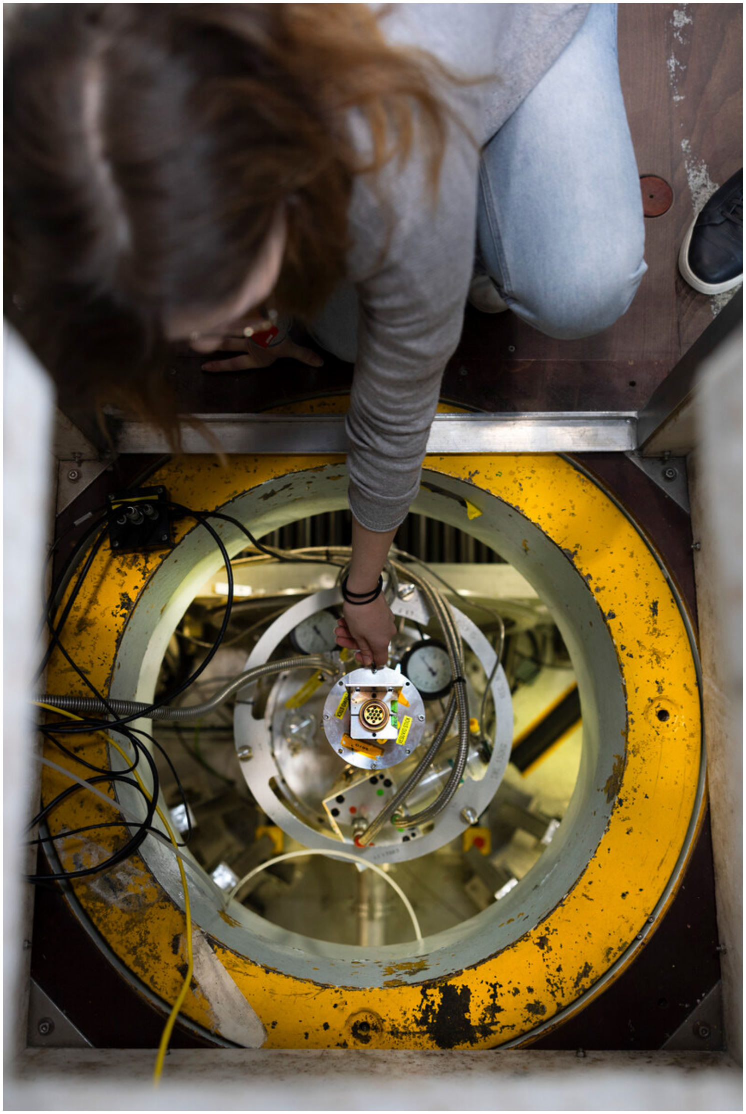
> Our experiments always seemed to be 'very hands on'. Each experiment lasted typically around 2–3 days, and during that time we worked ridiculously long hours. Our research using neutron reflectivity on surfactant and mixed surfactant adsorption challenged many of the perceived wisdoms in the field. The programme with Unilever was completely embedded in our overall programme and has provided a striking example of the relevance of neutron scattering to industry.
>
> **Jeff Penfold**
> former Instrument Scientist

Cara Morgan from the University of Oxford and Jordan Petkov from Unilever load surfactant mixture samples on to the INTER instrument.

## Amino acids, peptides and proteins

Amino acids are often referred to as the building blocks of life. When linked together to form peptides and proteins, they regulate and coordinate a wide spectrum of physiological and biochemical processes. Beyond their role in protein synthesis, amino acids also serve a variety of crucial functions, including providing energy and contributing to the formation of key biomolecules such as hormones, neurotransmitters and signalling molecules.

As part of ISIS's longstanding Italian partnership, researchers have used Vesuvio to measure the thermal neutron cross sections of all twenty amino acids. These findings help to improve our understanding of how amino acids interact with neutrons, which is useful for medical applications involving neutron-tissue interactions, such as boron neutron capture therapy, and for researchers studying biological systems, such as proteins and human tissues.



Lorna Dougan, University of Leeds is a regular user at ISIS. Her team have been using neutron scattering to provide new structural insights into protein networks, including in the physics of living systems and the hierarchical biomechanics of new biomaterials.


Lorna Dougan, Matt Hughes, Sophie Cussons and Christa Brown, University of Leeds during a visit to complete experiments on SANS2D to explore the structure of microbubbles embedded in protein hydrogels.

> "This study is a demonstration of the value that using small and wide-angle neutron scattering can bring to the biomaterials and biological physics communities. Our aim is to exploit the wonderful biological functionality of the bionanomachines (the proteins) in the networks."
>
> **Lorna Dougan**
> University of Leeds

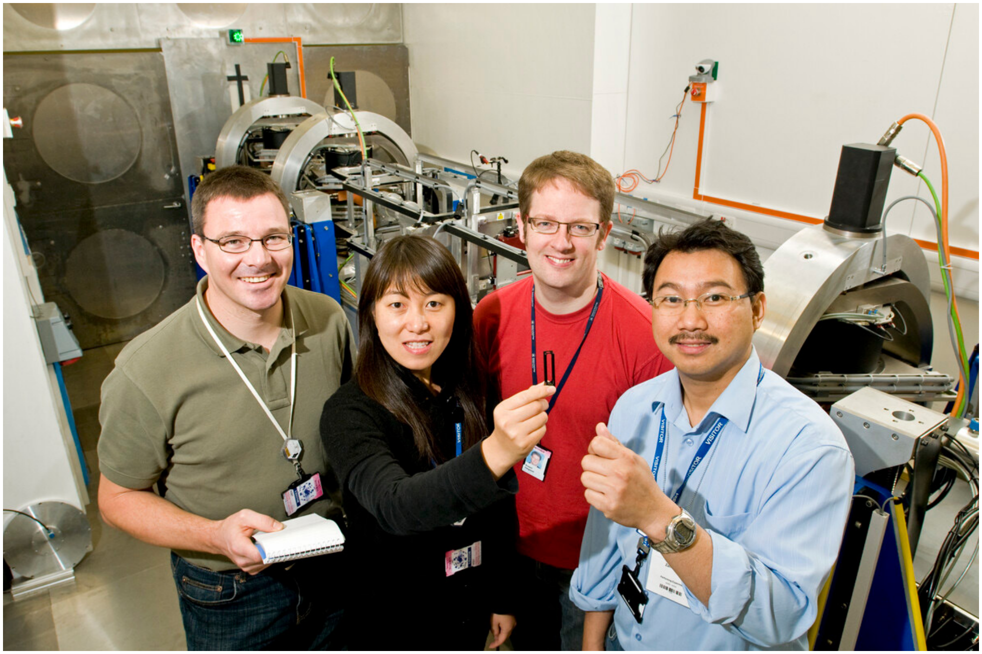
Antibodies, also known as immunoglobulins, are small proteins that play a vital role in the body's immune defence against bacteria and viruses.

In 2024, Stephen Perkins and Jayesh Bhatt from University College London received the ISIS Society Impact Award for their work in determining the molecular structures of therapeutic antibodies in solution. Using small-angle neutron scattering, they were able to gather unique insights that were not available using traditional methods like protein crystallography. Additionally, their computational work allowed them to produce detailed atomistic simulations of antibody structures in solution.

Left to right: Liz Rodriguez, Lucy Rayner, Stephen Perkins and Keying Li, University College London, prepare samples to study the solution structures of two immunologically important proteins, IgA and C3b, on SANS2D in June 2011.

## Biocompatible materials

The first users of OffSpec were David Bucknall, Georgia Institute of Technology, Jinhyun Hannah Lee and Zamri Radzi, University of Oxford, seen here with instrument scientist Rob Dalgliesh investigating hydrogels for their prospective role in cleft palate repair. The new potential treatment for these severe cases involves inserting a small plate made of an anisotropic hydrogel material (similar to that used in contact lenses) under the mucosa of the roof of the mouth of the patient. The hydrogel gradually expands as fluid is absorbed, encouraging skin growth over and around the plate – a process known as 'tissue expansion'. When sufficient skin has been generated to repair the palatal cleft, the plate is removed, and the cleft is repaired by using this additional tissue.



> "ISIS provided us with the high level of structural detail we needed to assess the new material. It gives unique and accurate results that we can't get with any other technique."
>
> **David Bucknall**
> Georgia Institute of Technology

Bioactive glasses are widely used as synthetic implant materials to repair and replace diseased or damaged bone in patients with small bone defects. They are also used in glass ceramic cements, and more recently there has been interest in their use in toothpaste to strengthen enamel.

Richard Martin from Aston University has been a longtime user of GEM and other ISIS instruments to study the atomic structure of various glasses, including bioactive glasses. The aim is to understand how their dissolution properties influence their bioactivity to better design future bioactive glasses.

Richard inspects a sample for a study of the structure of germanium zinc silicate glass for injectable bone cement applications on GEM in 2015.

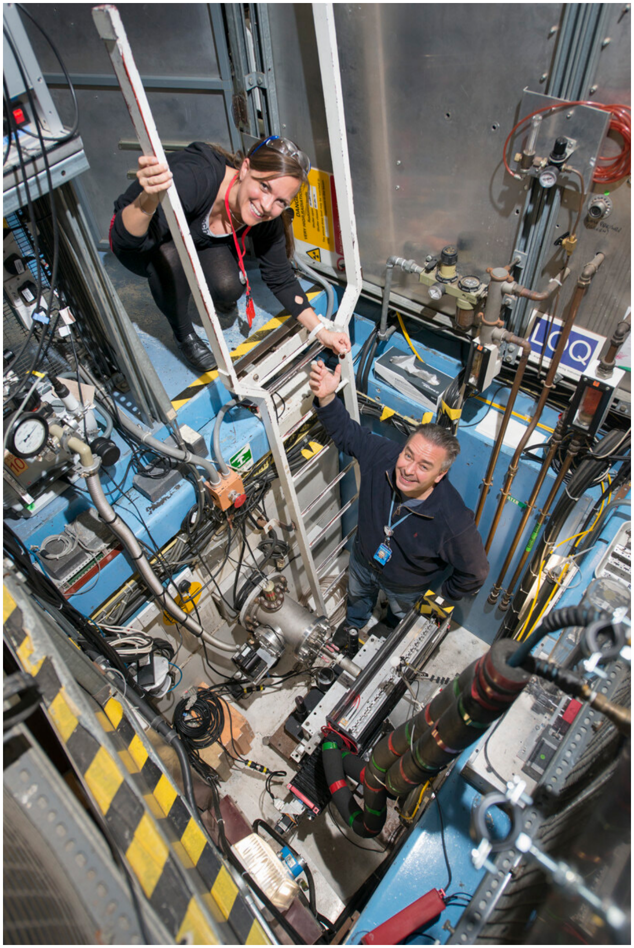
## Advanced materials, manufacturing and testing

**Neutron and muon techniques have found wide-ranging applications in the development of new and improved materials, optimising manufacturing processes and ensuring product quality through non-destructive testing. These insights have helped to drive innovation across many industries by enhancing material properties, improving production efficiency and detecting defects in critical components.**

### Chemicals

Additives in fuels and lubricants can help to reduce engine wear and improve fuel economy. Not only can this improve engine performance, but it can also help to reduce emissions.

Emma Packard and Peter Dowding from specialty chemicals company, Infineum, load samples on to LoQ to understand how calcium carbonate particles in their additives form.




"Our work at ISIS allows us to not only use the products we make more efficiently but to improve fuel economy in the future, as we can look at which molecules influence friction at the molecular level."

**Peter Dowding**
Principal Scientist, Infineum

## Polymers

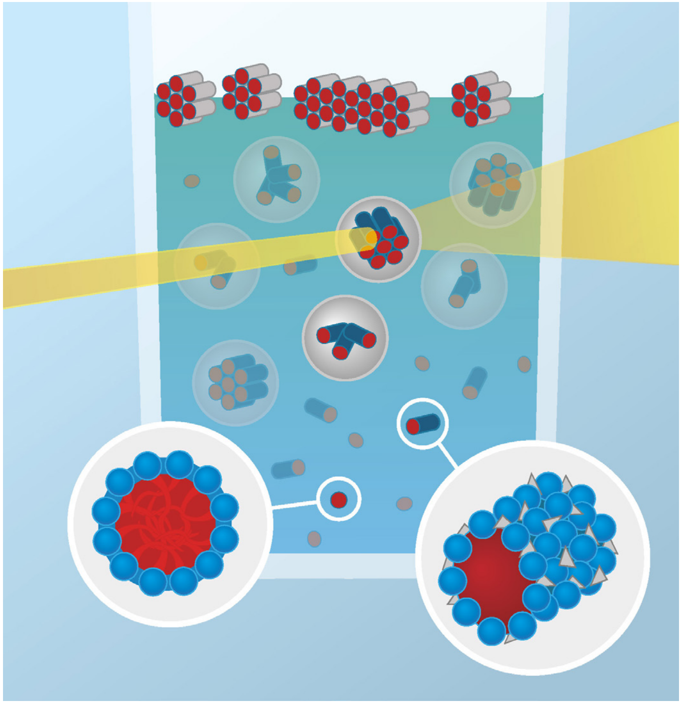
Polymers are an essential part of our everyday lives, being found in a wide range of household items, clothing, medical products and much more.

For industries that produce polymer-based products, it is important to understand how polymers behave when processed, especially during techniques like extrusion, which shapes materials. Here, users Lin Phoon and Valeria Arrighi, Imperial College London, prepare some copolymer micelle samples for their shear flow experiment in May 1991.

## Thin films

Thin films are extremely thin layers of material, often just a few nanometres thick, that are applied to a surface to modify its properties. They have many uses, including electronics, solar panels and optical coatings.

Karen Edler, University of Bath, and Arach Goldar, CEA-Saclay, studied polyelectrolyte-surfactant solutions on Surf in 2003 to create nanostructured thin films for applications, such as filtration and responsive delivery.

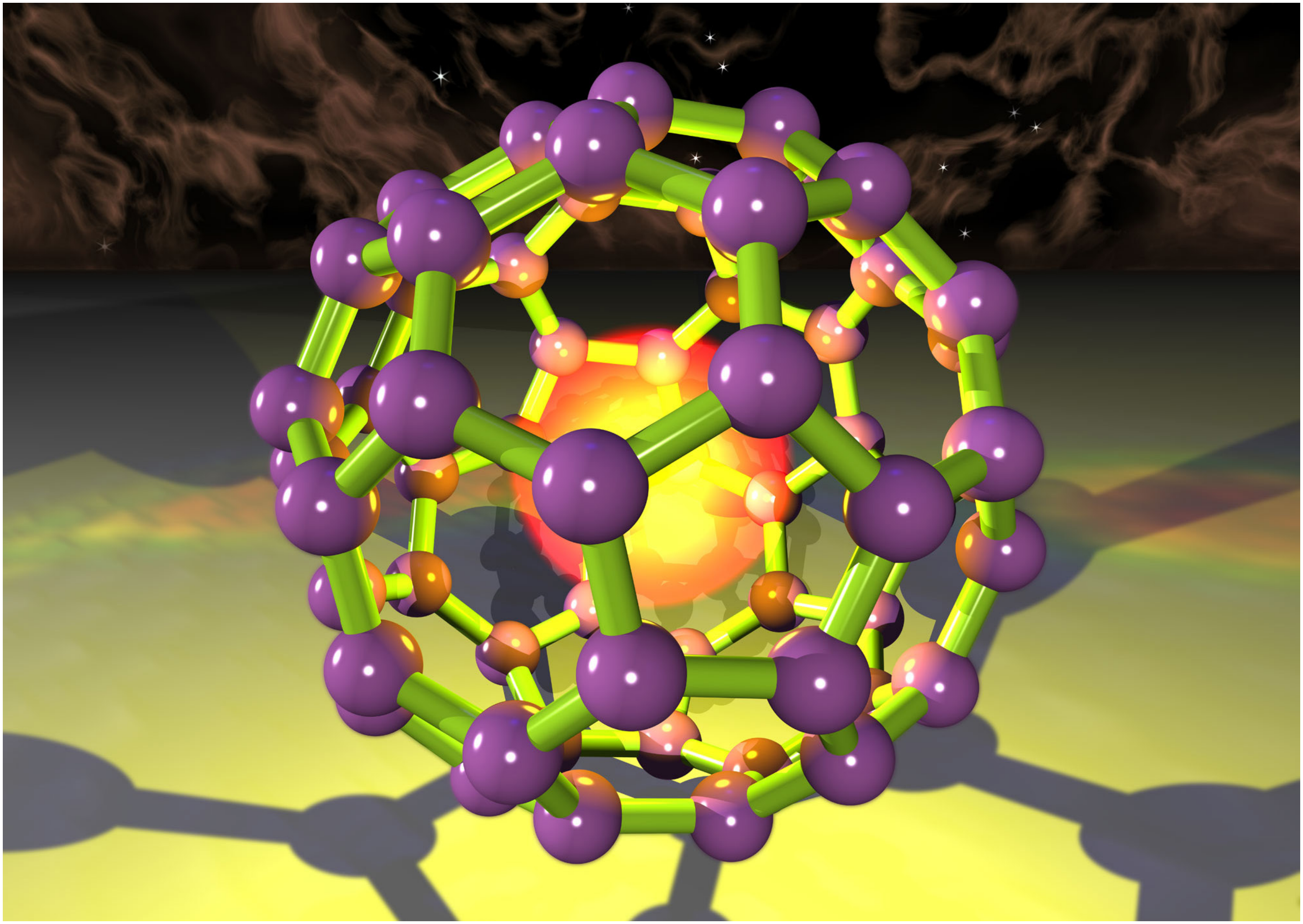


The Edler group have been regular users of the ISIS facility and, in 2020, in collaboration with groups from Indiana University and Delft University of Technology, combined spin-echo modulated small-angle neutron scattering and small-angle scattering for the first time to provide a complete picture of the initial solution formation stages of particles that go on to form mesoporous silica thin films.

## Buckyballs

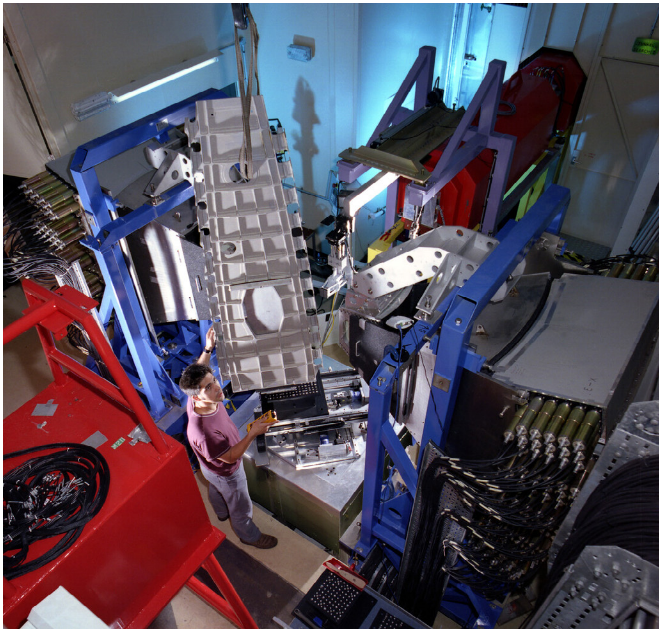
Complex mesh structures of carbon atoms were identified experimentally around the time that ISIS started operation. The detailed crystal structure and behaviour of $C_{60}$ molecules (also known as buckyballs) were first solved at ISIS by Bill David and collaborators using HRPD; their Nature paper has been cited nearly 1000 times. The molecules, initially disordered at room temperature, form an ordered structure below 249 K to optimise electron interactions.

Image courtesy of Rob Dalgliesh.



## Engineering materials

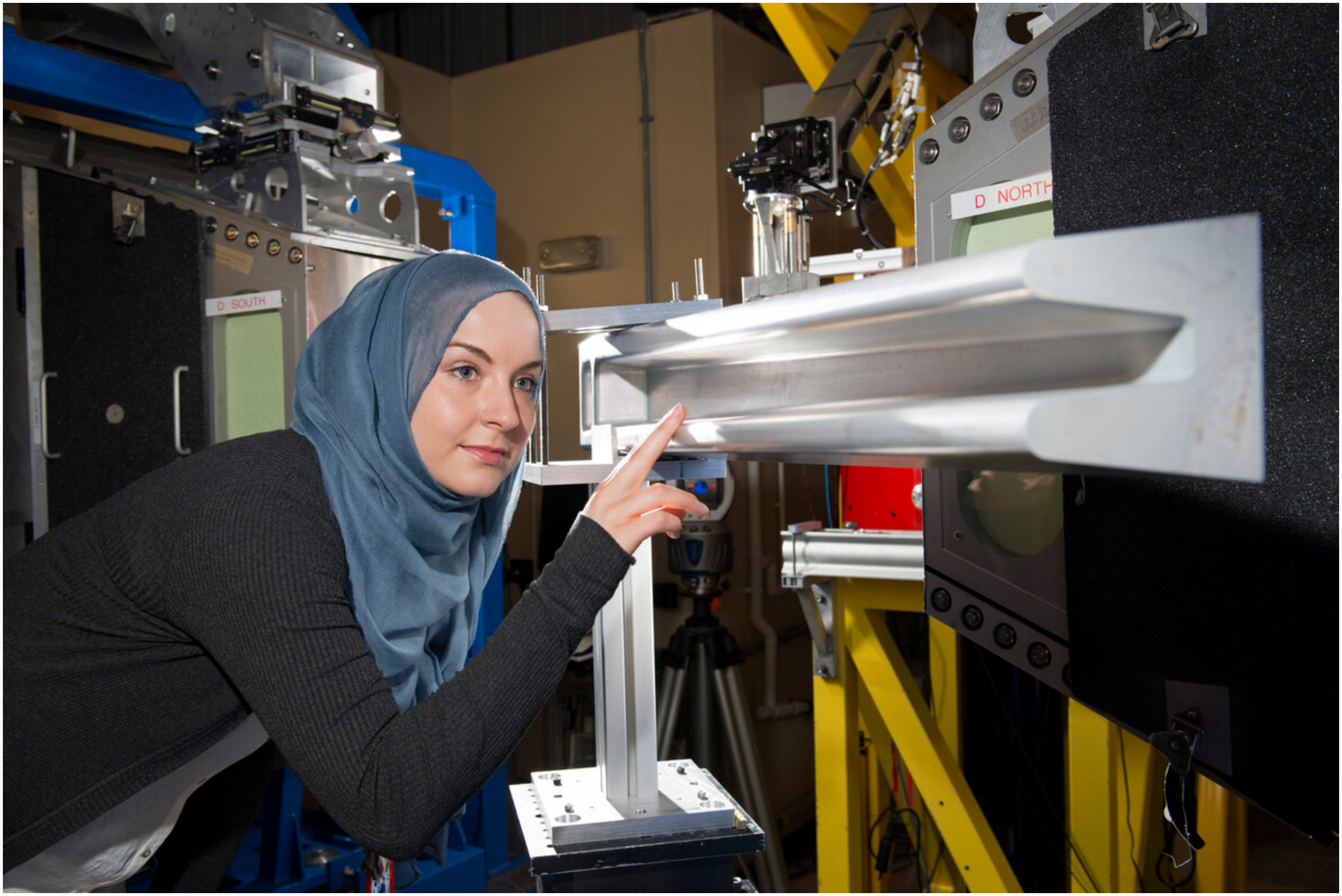
From train wheels to turbines, neutron diffraction and imaging have become important techniques for analysing stresses, strains and internal defects in engineering materials. Over the years, many companies have used ISIS to non-destructively inspect critical components to ensure safety and reliability and to improve manufacturing processes.



Novel metal processing methods, such as friction stir welding, can generate residual stresses in engineering components that can cause unwanted distortions. Understanding how these stresses develop and are distributed within the material is key to avoid failures. Aircraft manufacturer Airbus has been coming to ISIS for many years to research the integrity of welds in aluminium alloys, and to assess their suitability for future aircraft programmes.

Javier Santisteban installs an Airbus wing rib on Engin-X in April 2003. This is the largest sample ever studied at ISIS.

> “Residual stress measurement at ISIS has been invaluable in researching and developing existing and novel material manufacturing and processing techniques. The fact neutron diffraction is a non-destructive technique means it can even be used to improve component performance in manufactured parts.”
>
> **Richard Burguete**
> Experimental Mechanics Specialist, Airbus




Other aircraft manufacturers also use ISIS. In October 2016, Gladys Benghalia from the University of Strathclyde used Engin-X to look at stresses in an aluminium component, part of a Boeing aircraft tail frame.

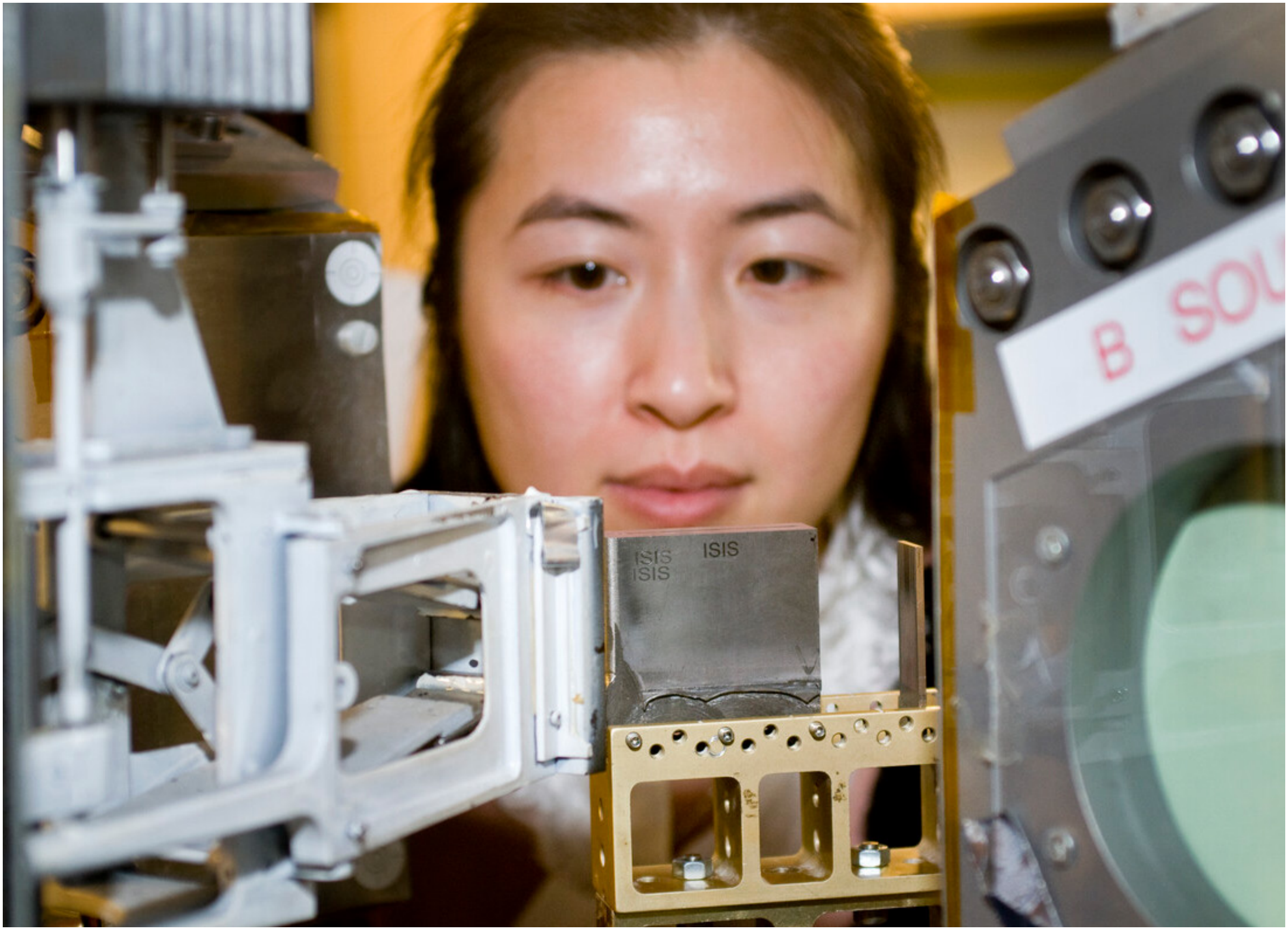
Together with the Open University, EDF Energy used SANS2D to understand how cracks form after the discovery of cracking in a weld led them to temporarily close some of their Advanced Gas-cooled Reactors (AGRs). Their analysis helped to improve how welds are assessed in safety critical components and whether reactor lifetimes can be extended, contributing to considerable mitigation of $CO_2$ emissions.

The Hartlepool nuclear power station is owned and operated by EDF Energy. © EDF Energy.

> "When each Advanced Gas-cooled Reactor can generate £700,000 of electricity a day, extending their lifespans has a significant impact on the UK economy and the security of energy supply."
>
> **Hedieh Jazaeri**
> Open University

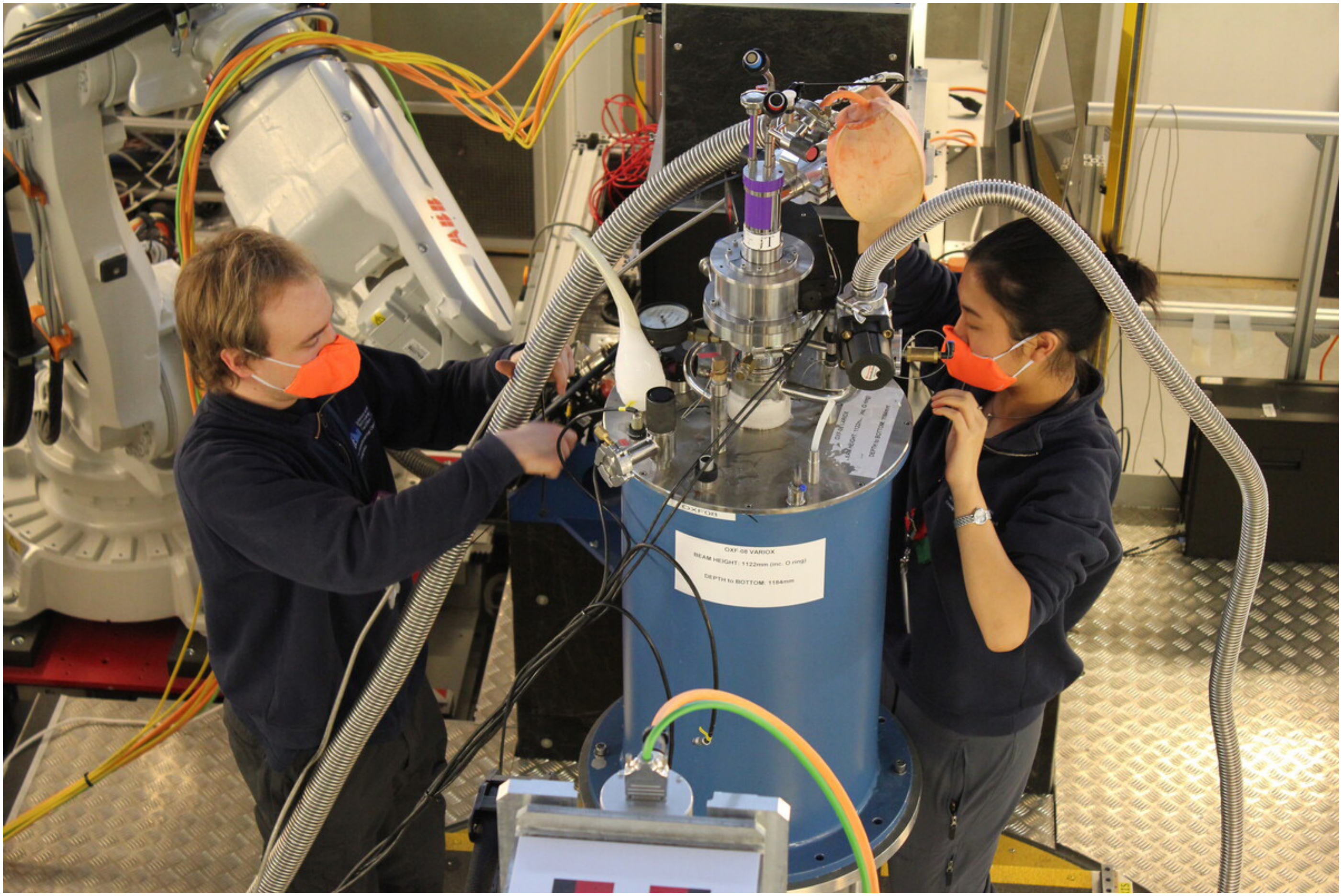
## Improving ISIS technology

ISIS instruments can also be very valuable in understanding the materials engineering challenges that ISIS itself has.




Instrument Scientist, Shu Yan Zhang examines the ISIS target for stresses and strains using Engin-X in 2013.

In 2021, the ISIS Cryogenics Team used IMAT to collect images of an operational dilution refrigerator to see what happens inside. Dilution refrigerators are used in many different experiments to cool samples to ultra-low temperatures. Alex Jones and placement student Sasha Horney prepare the experiment on IMAT.



## Electronics

When cosmic rays strike the Earth's atmosphere, they produce high-energy neutrons, which can cause errors in modern high-density electronics. This issue is particularly significant for safety-critical systems, such as those used in planes and cars, and is a key concern for these sectors. In October 2007, ISIS Instrument Scientist Chris Frost, shown here, made the case for a dedicated instrument at Target Station 2 to study these effects. He obviously succeeded, as the ChipIr instrument has been in operation since 2017 and has ISIS's highest industrial use.

Paolo Rech, University of Trento, sets up a microchip for testing on ChipIr. Paolo was one of the first users of the ChipIr beamline and has remained a regular user ever since. In 2020, he was awarded the ISIS Society Impact Award for his work investigating the effect of neutrons on the computing behind autonomous vehicles and developing ways to improve its reliability.

"ChipIr is one of the best facilities to test complex artificial intelligence (AI) systems. The setup is made easy by the dedicated infrastructure and the support of the instrument scientists, Carlo Cazzaniga and Maria Kastriotou. Thanks to the beam time provided, we succeeded in understanding how neutrons corrupt the execution of AI applications and how this corruption propagates in the neural network leading to a misprediction. This information is essential to design dedicated hardening solutions to prevent AI failures in safety-critical applications. The experiments at ISIS are a huge help in moving towards reliable AI and I am looking forward to testing innovative technologies, such as neuromorphic chips or – why not? – even quantum chips."

**Paolo Rech**
University of Trento

# Cultural heritage

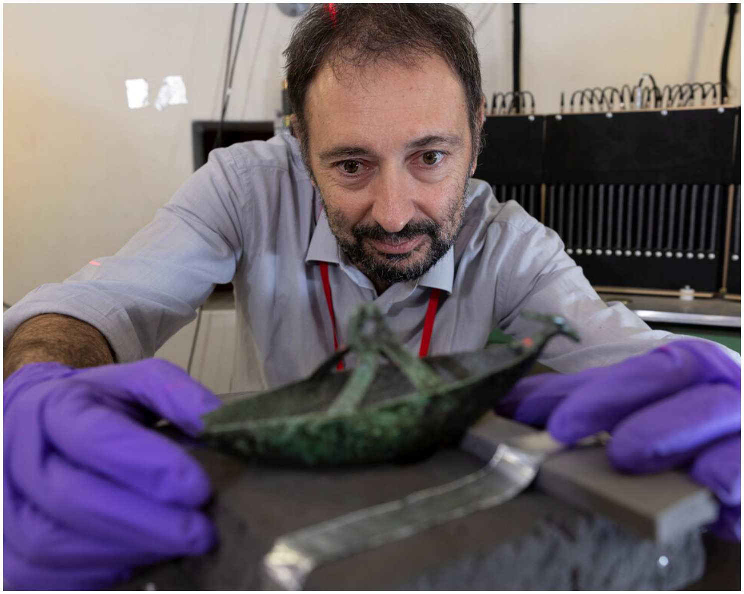
**The same neutron and muon techniques used to study advanced materials are also applied to historical artifacts. These methods allow researchers to look inside objects to uncover their composition, craftsmanship, repairs, origin, and age — all without causing damage. Over the past 40 years, ISIS has examined a wide range of priceless cultural artifacts, from ancient Roman gold coins to 12,000-year-old human prostate stones from Sudan, and even 40-million-year-old fossilised crabs.**

The Arms and Armour section of the Wallace Collection, London, contains over two thousand items and is one of the most important collections in Europe. A variety of pieces have been studied non-destructively at ISIS, offering insights into their production as well as their history.

Ines Instrument Scientist, Antonella Scherillo, examines one of the daggers from the collection in November 2015. In 2018, the Wallace Collection was awarded the ISIS Society Impact Award for their non-invasive analysis of arms and armour.

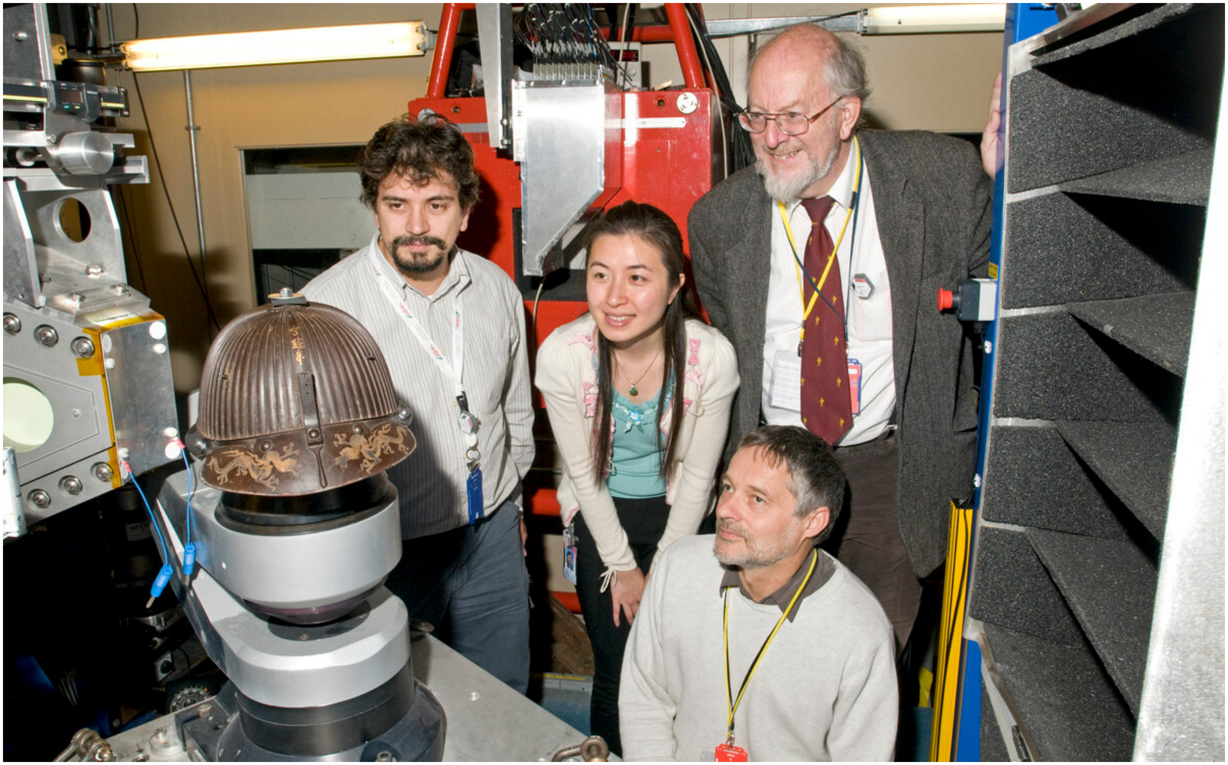
Nuragic boats, small sculptures dating back to the late Bronze and early Iron Ages, are rare examples of ancient Sardinian craftsmanship. These boat-shaped artifacts, which often feature animal figures, may have been used as lamps or votive objects, though their exact purpose remains unknown. In 2023, Piernicola Oliva, University of Sassari, brought several Nuragic artefacts for study using IMAT and Ines, uncovering secrets of their manufacture.

A Nuragic artefact depicting a warrior from Soprintendenza di Sassari e Nuoro.



Piernicola Oliva prepares to study a Nuragic boat model from the National Archaeological Museum of Florence.

After the Portuguese introduced firearms to Japan in the 16th century, samurai armour evolved to suit the new style of warfare. The easiest solution, related to high demand, was to simplify helmets by making them using thick sturdy plates of iron and steel. Another option was to increase the protective capability of helmets made of consecutive lamellar plates, allowing movement under mechanical load. Experiments conducted on Engin-X have revealed the impressive engineering in these helmets. Their outer design functions like a car's crumple zone; upon impact, deformation redistributes the force among neighbouring plates, maintaining the helmet's integrity and protecting the wearer.



Left to right: Francesco Grazzi, National Research Council of Italy, Shu Yan Zhang, ISIS, Alan Williams, The Wallace Collection and the University of Reading, and Jon James (front), The Open University, inspect an 18th century Japanese helmet on the Engin-X beamline.

The 15th century Gates of Paradise of the Baptistery in Florence, Italy, are viewed by thousands of tourists every day. These doors are copies, but in 2009, some of the real 'Ghiberti heads' that decorate the gates came to ISIS for non-destructive studies using both neutrons and muons.

Neutrons and muons have been used to analyse ancient European coins, revealing their composition both at the surface and deep within the metal. This analysis helps trace the origins of the coins and, when the minting date is known, the composition can often be linked to historical events. For example, it is common to find reduced amounts of precious metals during periods of economic hardship.

This is one of the ancient Roman gold coins studied using the RIKEN-RAL muon beamlines at ISIS. Researchers from the Universities of Oxford and Warwick brought coins from the reigns of Tiberius, Hadrian and Julian II to investigate whether they were surface-enriched or mixed with other metals, providing insights into the economic conditions of the period.


> "We know that the Romans deliberately surfaced enriched their silver coins to 'hide' the fact there was a lot of copper in them, so it is plausible something similar happened to the gold. Our work at ISIS enabled us to sample the very centre of these coins totally non-destructively and conclusively show that the high purity seen on the surface was representative of the composition of the 'core' of the coin."
>
> **George Green**
> University of Oxford

One of the first user experiments on IMAT was a study of archaeological vases and pots from the Egyptian Museum in Turin. The team also used Engin-X, with the aim of revealing the contents of the sealed objects in a hunt for the Seven Sacred Oils of Ancient Egypt and finding clues about their manufacture and use.

Matilde Borla, Soprintendenza Archeologia Piemonte, and Valentina Turina, Musco Egizio di Torino, at IMAT in October 2016.

A 2500-year-old Corinthian-type bronze helmet being put into position on ROTAX by Roy Garner, The Manchester Museum, in 2003. Measurements revealed a different bronze composition of the noseguard compared with the rest of the helmet, suggesting the noseguard was not part of the original structure.

## Prehistoric creatures

In 2021, the first UK users of IMAT uncovered remarkable 3D details of soft tissues in an exceptionally preserved fossil. Their work shed new light on how ammonites swam through oceans and defended themselves from predators 165 million years ago. Imran Rahman loads the ammonite on to the IMAT sample holder.

In July 2024, researchers Marcella Berg and Jerit Mitchell, University of Regina, brought a 66-million-year-old T-rex bone to IMAT for an exploratory experiment to investigate the preservation of blood vessels.

## The User Office

The User Office, established more than 25 years ago, plays a crucial role in supporting experiments at ISIS. The team not only handles logistics for thousands of user visits every year, but also coordinates the biannual peer review process for hundreds of beamtime proposals. Additionally, they organise meetings, workshops and training sessions, fostering collaboration and knowledge-sharing across the scientific community. Their work is key to maintaining a large and friendly ISIS user community, and to the success of all the science (and much more) illustrated on these pages.


Left to right: Kerry Larman, Emma Gozzard, Emma Roberts and Lisa Wiltshire in May 2022.

ISIS control room's first desk

ISIS main control room

MEDUSA terminal

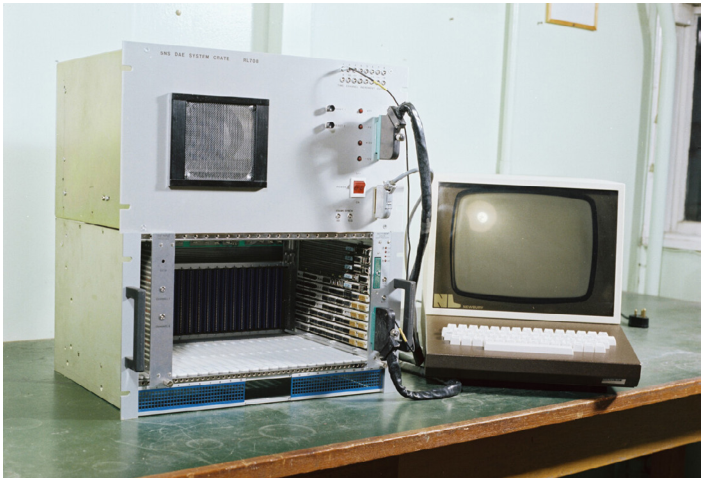
High Performance Computing Centre

# Evolution of computing

**Computing has been an essential part of ISIS's four-decade-long-journey, contributing to both facility operation and experimental data analysis. Keeping up to date with technological advances has been a critical factor in the success of ISIS, as the development and expansion of computing allowed for increasingly complex experiments and enhanced use of beamtime, meeting the needs of users. Computing has always been used to interface with data acquisition and to control experiments through the sample environment. Now, computing touches the entire journey of a user at ISIS, from initial proposal through to data collection and analysis, and finally, publication.**

During the early days of ISIS, computers were less powerful than a mobile phone, with memory measured in megabytes not gigabytes. In 1984, the Virtual Address eXtension/Virtual Memory System (VAX/VMS) minicomputers on beamlines cost £40,000 each and had to be craned into portacabins due to their weight. Networks and protocols were still being developed with no widespread internet. Support from home was by landline phone or 300 baud dial-up modem for a terminal connection. With limited commercial equipment available, ISIS built, from scratch, a Cambridge ring network in-house, to link scientific areas with user offices. Data was first copied to a computer, then on to 100 MB magnetic tapes, and then to an optical disk jukebox. Graphical user interfaces were simple, and software was often written in FORTRAN, an early programming language suited to scientific computing. ISIS scientists, together with the Computing Group developed a data manipulation and visualisation program called GENIE to help users analyse their data.

Over the following decades, computers became smaller and faster, storage increased, network capacities improved and the cost of computing decreased. Parallel and high-performance computing introduced sophisticated simulations and data analysis. The internet made cross-facility software collaborations easier and remote experiments possible. Time evolution of experiments can now be followed by employing streaming technologies and storing individual neutron collection events. New programming languages and software paradigms have contributed significantly to the wider applicability of computing. Quantum computing, artificial intelligence and machine learning are new exciting developments for data analysis that ISIS is exploring. ISIS has come full circle with research undertaken here now contributing to advancements in computer hard drive technology, and the use of neutron-tolerant processors in radiation-prone environments.



The first two decades of ISIS coincided with the early era of computing where computational resources, such as processing power and memory, were limited. Here, Paul Haskell is working at the first ISIS control room to generate the earliest beams, October 1981.

The Data Acquisition Electronics (DAE) system, photographed in June 1981, was the first system at ISIS to acquire data. The DAE recorded the arrival time of neutrons scattered by the sample at the detectors, storing this as a histogram of counts against arrival time relative to the accelerator pulse. The information was crucial for analysis – knowing the position of the detector and how long the neutron took to get there allowed details of the atomic structure of the sample to be determined.

> “We owe enormous thanks to our Technology and Particle Physics Departments, who gave us the knowledge we needed. They knew how to handle vast amounts of data, so that was a very important breakthrough for ISIS in the early days.”
>
> **Andrew Taylor**
> former ISIS Director

The ISIS Control room in 1985 had additional computers to monitor the latest instruments, which at the time included HRPD, Iris and LoQ.

Left to right: Mike Armstrong, Tony Borden and Di Wright. As more instruments were added, a more integrated setup was needed, which was completed in 1987.

MEDUSA was the first-generation Computer-Aided Design (CAD) program adopted by ISIS for designing beamlines. Martin Southern works on one of the MEDUSA terminals in February 1988.

Each instrument required a dedicated workstation terminal – here, Bill Pulford is setting up HRPD's workstation terminal in June 1989.

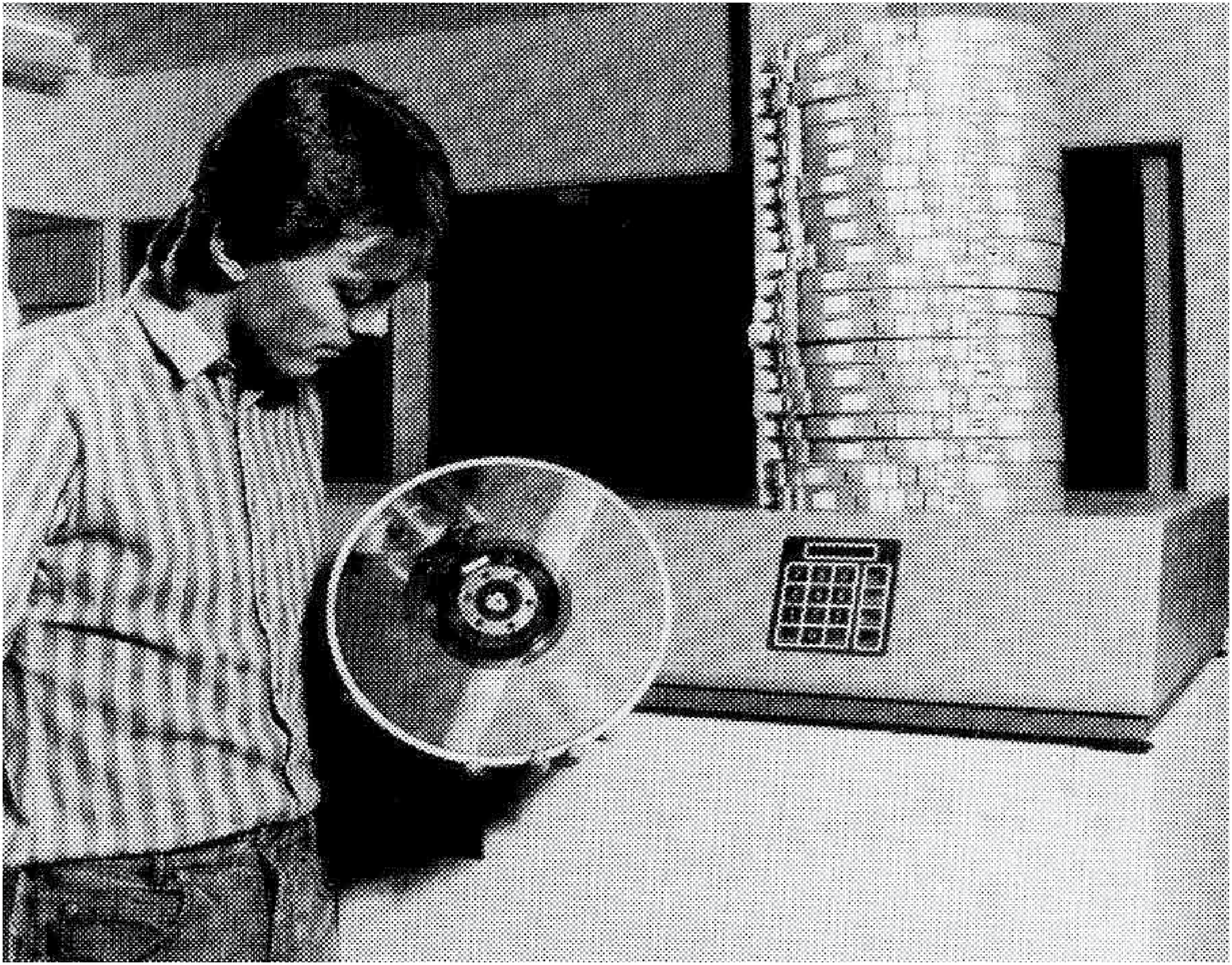
Locally written software, the Instrument Control Program (ICP) and Dashboard, ran on the Virtual Address eXtension/Virtual Memory System (VAX/VMS) workstation to control and monitor the Data Acquisition Electronics, as well as the sample environment. The ICP saved the collected data to file locally for later analysis and transferred the files to the central archive. Command scripts could also be built to automate a sequence of measurements.

A user working at the MuSR instrument cabin, April 1989.

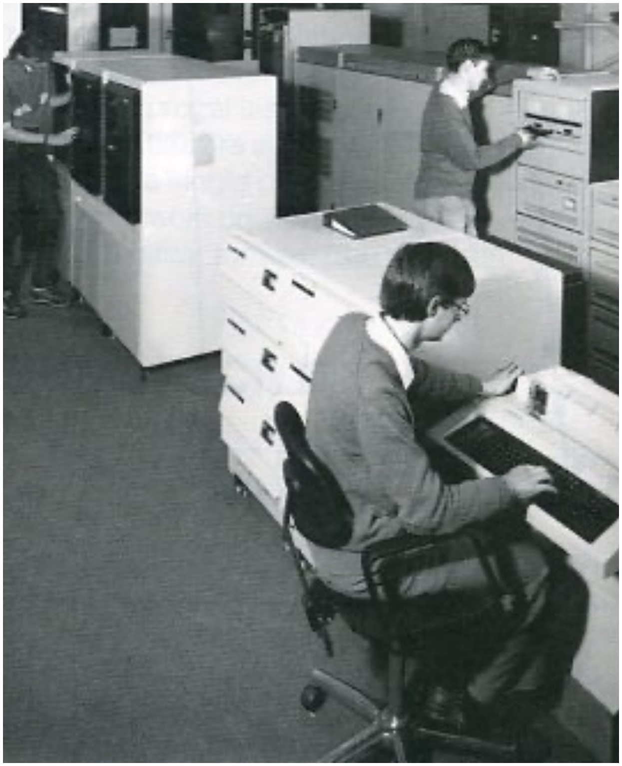
At this time, the cabins were very similar for most of the instruments. There would have been a rather large Virtual Address eXtension (VAX) computer in the room along with the Data Acquisition Electronics.

> “In my early days on LAD, Spencer Howells, Alan Soper and I produced a large suite of software for correcting the data. I had to learn lots of scientific programming and still do a lot of programming to this day.”
>
> **Alex Hannon**
> Instrument Scientist, Disordered Materials Group

ISIS data analysis staff Kenneth Shankland and Devinder Sivia work on the application of Bayesian analysis, 1994. This statistical methodology was applied successfully to many areas, including in a probabilistic approach to space-group determination from powder diffraction data, and resulted in software that was later supplied with commercial software.



Data taken during experiments requires archiving, which was originally done using magnetic tapes, but later changed to a 40 GB secure optical disk juke box drive. Mark Sturdy holds one of the new optical disks in 1988. Each of these could store as much data as the stack of high-density tapes.

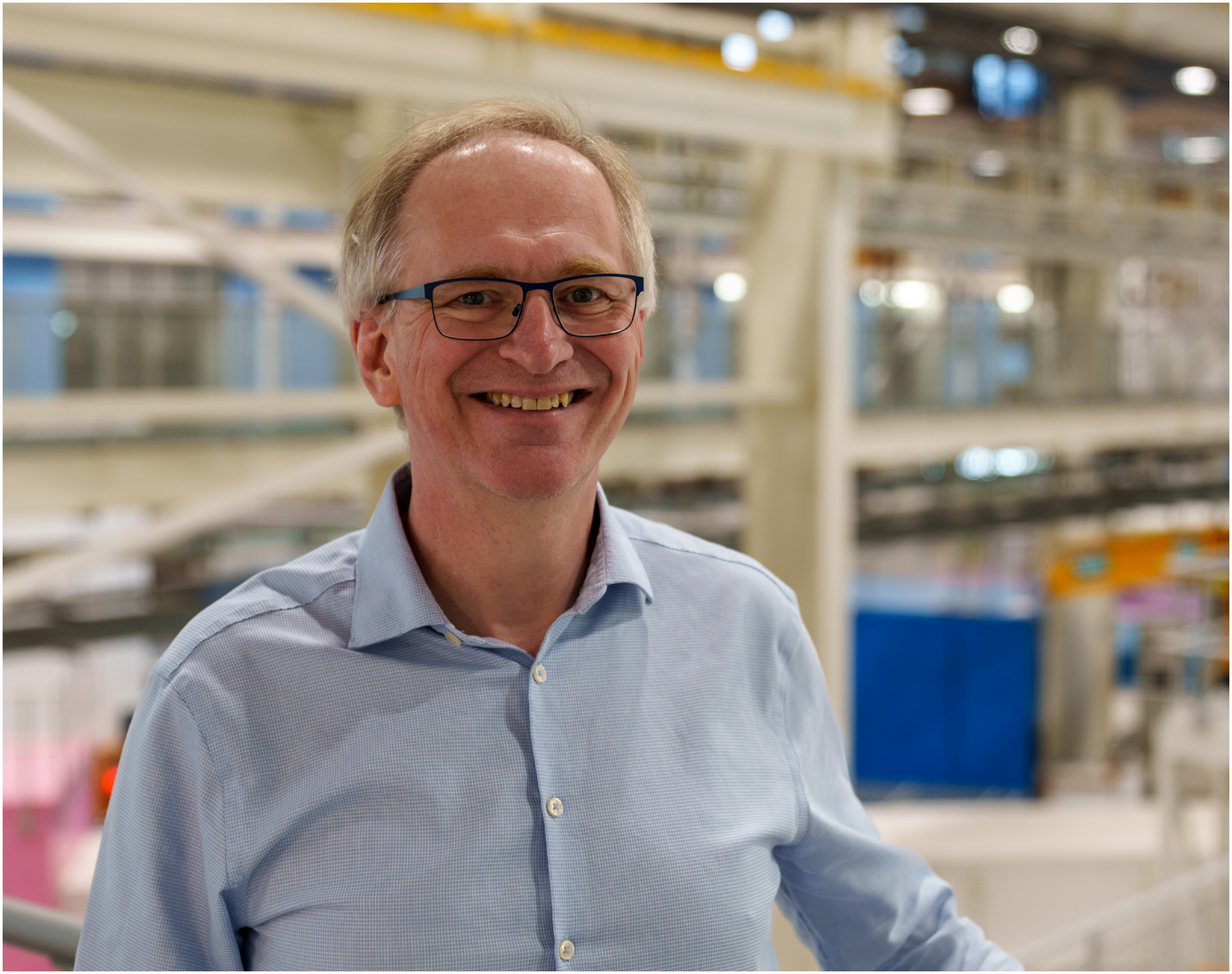


Target Station 1's new computing room after the upgrade of ISIS's central computer system in 1988, with Chris Moreton-Smith typing in foreground, Mark Sturdy at the tape drives and Graham Houston at the disks. At this time, staff and users logged into this multi-user system from terminals in offices and instrument cabins. This computer was used to do most data analysis, office work and emails, and occasionally to play the odd game! During busy periods, 50-60 people would be logged on, so the upgrade to a system with a massive 28 MB of random-access memory (RAM) was a great benefit.

> "To put this into context, even an iPhone today has 2048 MB of RAM, so it could have supported around 5000 scientists back then. I remember that after the original purchase of this system, which cost around £0.5 million, we were all taken down to the pub for a celebratory meal. The new hub only just squeezed into the room allocated – rather hot, cramped, and noisy as a result!"
>
> **Chris Moreton-Smith**
> Systems Development Manager

John Ellis and Neil Grafton in the Main Control Room, March 1998. The control room is now even more integrated using networked computers.

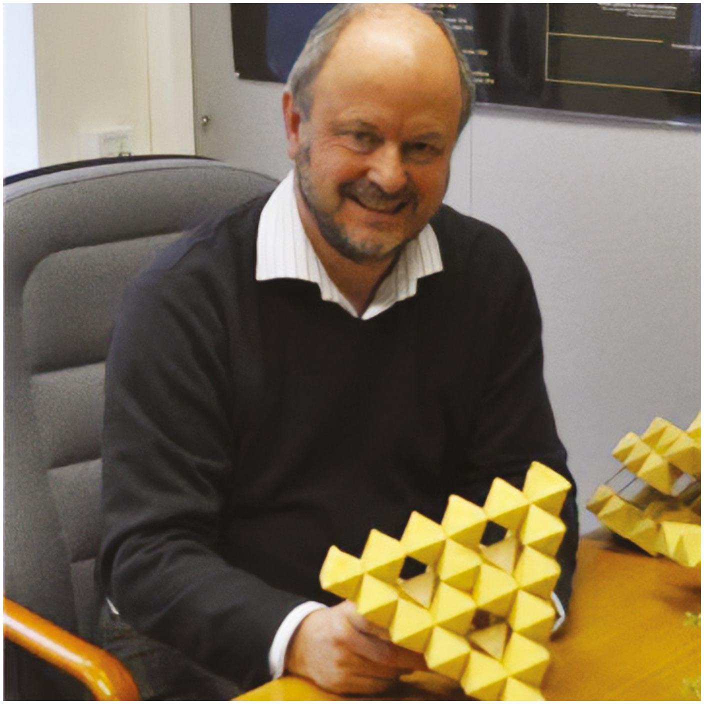
ISIS staff have developed data analysis codes that have been adopted around the world and have under-pinned major science programmes. Toby Perring was awarded the 2023 Walter Hälg prize of the European Neutron Scattering Association for his development of the HORACE code that is used to analyse neutron spectroscopy data from single crystal samples.



Toby at Target Station 2.

Alan Soper, elected as a Fellow of the Royal Society in 2014, developed the EPSR code used to analyse the structure of disordered materials.

Alan at the ISIS Facility Access Panels, December 2011.



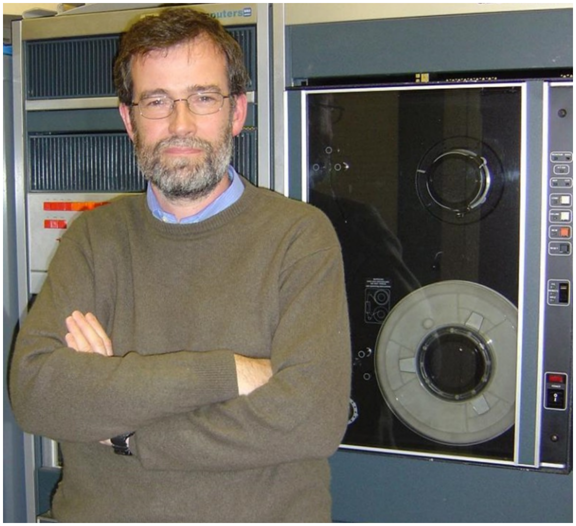
Bill David, elected FRS in 2016, was the original author of the display and analysis program, GENIE and developed crystallographic software that includes DASH, a program for solving molecular crystal structures from powder diffraction.

Bill holding a homemade crystal structure model of the lithium battery cathode material, $LiMn_2O_4$.

From a handful of software engineers in the early 2000s to over 80 in 2024, computing underpins the management of the extended user programme, increasingly complex facility operations and research workflow. Many computing staff now work remotely or hybrid, so an all-staff planning day is held three times a year to bring staff from across the division together in person.

Demand for scalable and robust software soared with the opening of Target Station 2 in 2008. With an increase in instruments, data reduction needed to be standardised so users and instrument scientists could easily move between instruments. Moreover, with a growing number of users and experiments, more processes needed to be automated across the facility.

George Flecknell, Elaine Campbell and Willow Grove-Oliver at the ISIS Computing Division Day in February 2024.



Bob Mannix (then Accelerator Controls Group Leader) at the General Electric Company (GEC) computer, just before its retirement in 2004. At the time it was believed to be the oldest GEC computer still working.

The GEC 4000 series computers were installed at RAL during the 1970s to control particle accelerator beamlines, physics experiments and telecommunication systems. One GEC 4000 machine was moved from RAL to the London Science Museum, the others remained in use in the ISIS controls system while their removal was finalised as their applications are converted.

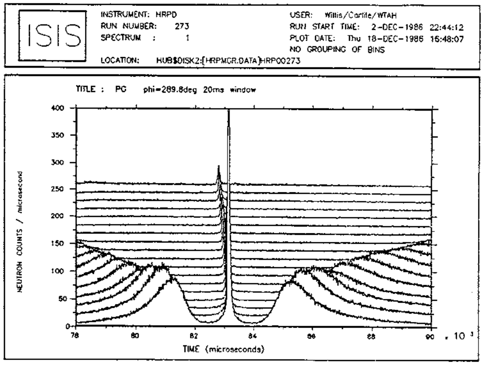
Data reduction and analysis were originally performed using GENIE. This program was written by ISIS scientists and the Computing Group during the 1980s to specifically analyse time-of-flight neutron data and was a critical contribution to early ISIS scientific success. This software provided an interpreted command line code with simple vector graphics for display and basic spectra operations for grouping and manipulation. More sophisticated calculations could be performed using programs written in FORTRAN, called from the GENIE command line, or as stand-alone programs. Users generally continued computing at their home institute with these standalone programs. The ideas incorporated in GENIE were carried forward in its successor ‘Open GENIE’, the ‘Open’ being taken from the term ‘Open system’ and indicating its goal of portability. Open GENIE was able to be run natively on Windows, UNIX, Mac and OpenVMS and is still in use today.

**P U N C H**

**G E N I E   M A N U A L**

**Version 2.3**

**"A LANGUAGE FOR SPECTRUM MANIPULATION AND DISPLAY"**




W I F DAVID   M W JOHNSON   K J KNOWLES   C M MORETON-SMITH
G D CROSBIE   E P CAMPBELL   S P GRAHAM   J S LYALL

RUTHERFORD APPLETON LABORATORY
Neutron Division
December 1986
RAL-86-102

Front cover of the Punch Genie Manual, 1986.

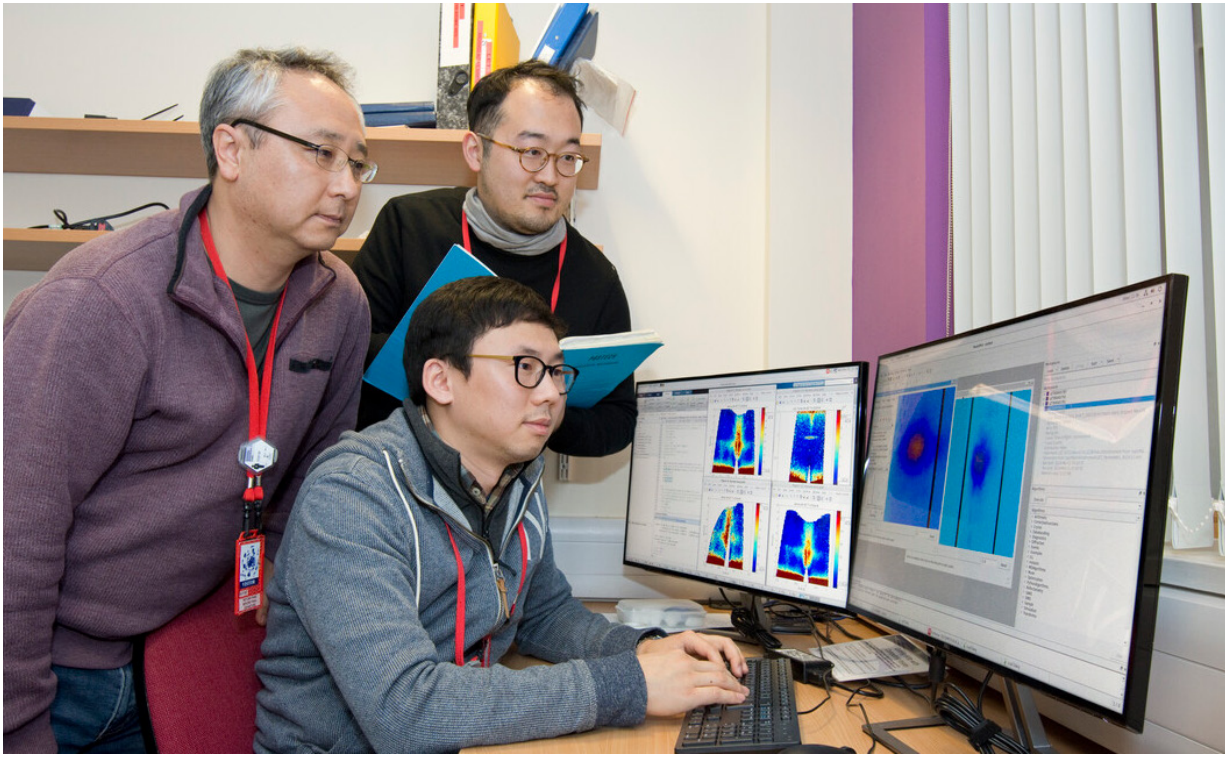
> “One of the reasons for ISIS's success was the data display and analysis program GENIE. GENIE was written amazingly quickly, in about a year before first neutrons by a team led by Mike Johnson. Bill David played a major role in its design and coding which resulted in (probably) the world's first real-time data analysis and display software. The software was later adopted by other labs in the USA (Los Alamos) and Japan (KEK).”
>
> **Andrew Taylor**
> former Director of ISIS

Mike Johnson (left) and Bill David (right) working on the first version of the GENIE software, 1984.

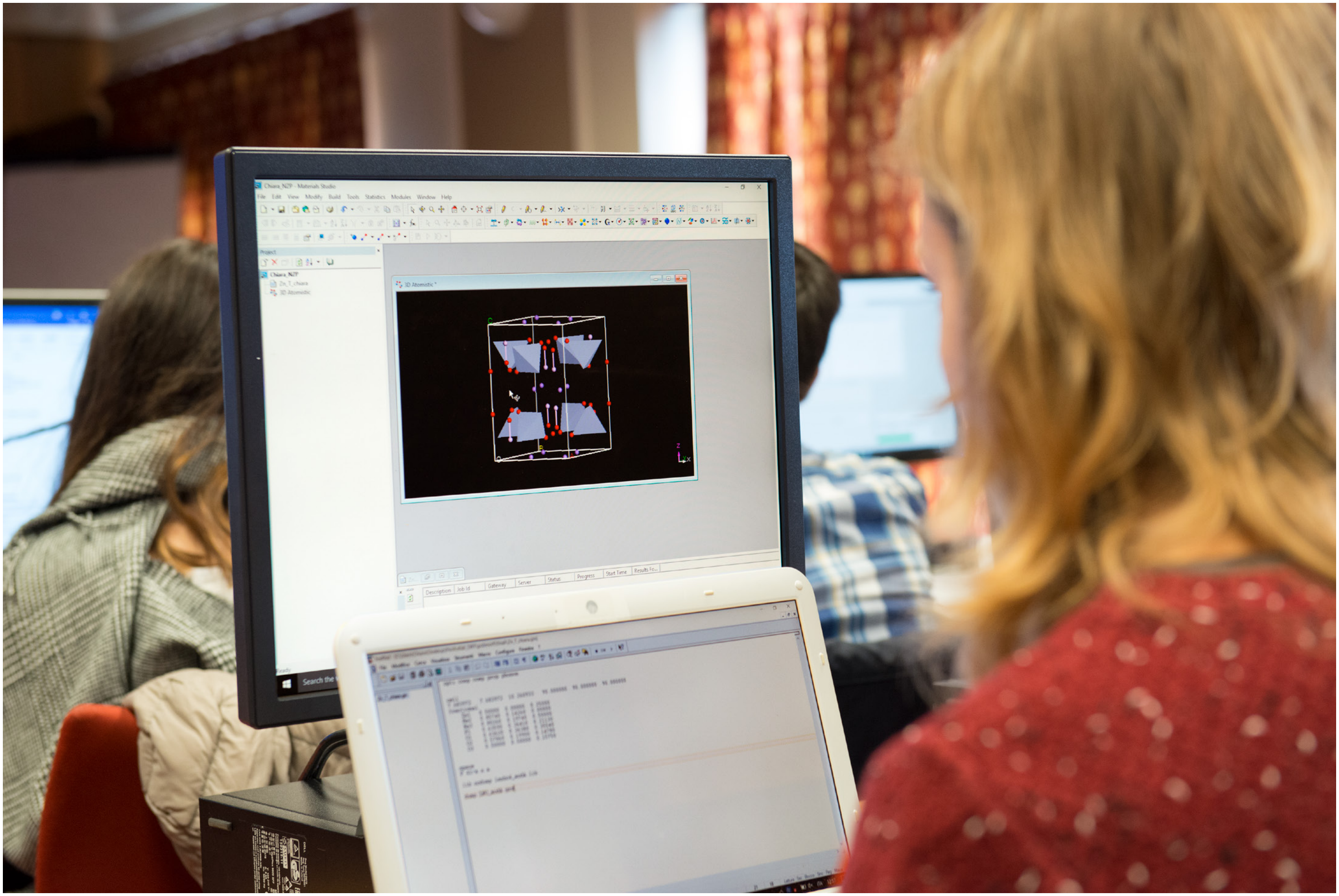
> “For those of us involved in instrument design and data analysis software, the reward is seeing the tools we have developed used by scientists and engineers from around the world to do important science and solve real-world problems.”
>
> **Mike Johnson**
> former Head of the Instrumentation Division

The centralised data reduction software, Mantid, was developed from 2007 onwards. It provides a framework that supports high-performance computing and visualisation of materials science data.

Launched with Tessella, Mantid was an open-source project capable of running on three major platforms, Windows, Mac and Linux. Several of the old GENIE codes were then migrated to Mantid. The Mantid project became international when Oak Ridge National Laboratory and Institut Laue-Langevin joined. This enabled collaboration in program development and more efficient use of limited resources, using a common data file structure, NeXus, which was developed in an earlier international collaboration and made analysis from different instruments and facilities easier.



Left to right: Sungdae Ji, Seunghwan Do and Jaeyu Kim, Max Planck POSTECH, testing the agreement between theory and experiment by modelling quantum spin liquid data from LET in March 2018.



The ISIS Molecular Spectroscopy Group and Institut Laue-Langevin Computing for Science Group held the first MDANSE (Molecular Dynamics and Lattice Dynamics to Analyse Neutron Scattering Experiments) workshop at The Cosener's House, Abingdon in November 2016. This collaboration started from two European technical development projects in the 1990's, ENNI and XENNI, led by Mike Johnson.


Accelerator diagnostics provide information about the status of the ISIS beam, allowing the machine to be run safely and efficiently. Beam measurements such as intensity, position and profile are acquired and displayed, allowing the performance and stability of the beam to be determined. It is also crucial to monitor the number of particles lost during the acceleration process so they can be kept to a minimum. Diagnostic systems will automatically turn the machine off if these loss levels get too high.

Sarah Fisher working on diagnostics software at ISIS.

Being demonstrated here is the new data acquisition system for the Super-MuSR instrument on ISIS Scientific Software Day. Thanks to increases in computer performance and reduction in the cost of electronic hardware, fully digitised detector output traces can be streamed for later software analysis to determine muon events. This ‘data pipeline’ approach improves detection performance and data quality.


With the improvement of computing, it is now possible to use sophisticated computing tools more widely. Many of ISIS's electronics requirements cannot be purchased commercially and bespoke in-house designs are required. Chad Silk from ISIS Electronics Group views Printed Circuit Board (PCB) design data. The finished product will allow components to be placed on the board and connected together in the desired way.

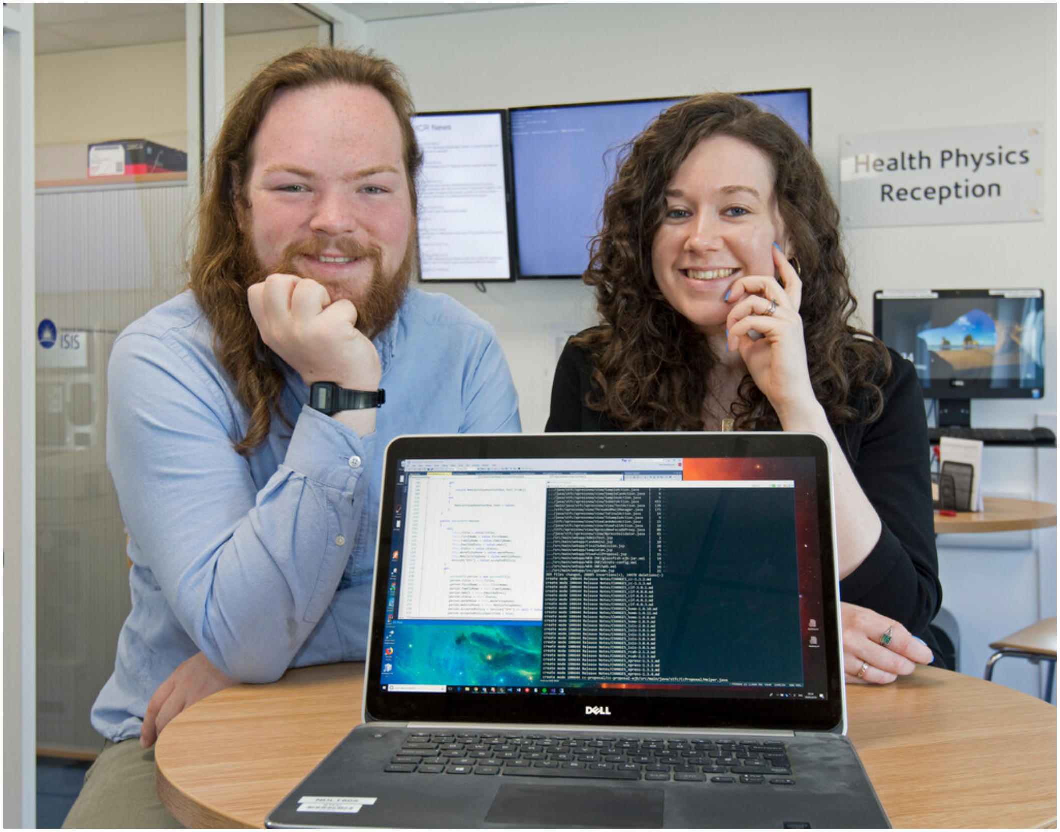

Computing apprentice Jack Harper at Larmor in 2016. As computing has advanced, taking a laptop to instruments is now routine for commissioning, performing checks or setting up for experiments.

> “ISIS is a fascinating place to work and I enjoy the applied side of using my software skills to control devices, particularly motion control.”
>
> **Jack Harper**
> Software Engineer, Experiment Controls

Software engineers are needed to build and maintain a huge range of software for ISIS. Their work includes building and supporting systems for online proposals, allocations, scheduling and visits, as well as control systems, data processing tools like Mantid, and various data analysis packages.

Gbenga Omirinde, Caila Finn, Gemma Guest and Sukhvinder Singh from the ISIS Computing Division see what the Mantid team have been working on.

RAL Computing apprentices Dylan Chambers and Simon Fernandes coding web applications used by the User Office to manage the user programme.




Former computing graduates Thomas Attwood and Ffion Argent outside the dosimetry office following the release of the online ISIS Safety Test and the User Check system to help manage security in the experimental halls.

> "I started at STFC in 2015 on the graduate scheme as a software developer. I loved joining the company with a cohort of graduates, and made very good friends that I still keep in touch with now. The scheme was a really good opportunity to develop professional skills like leadership and communication whilst also developing my technical skills, which has definitely helped me progress in my career."
>
> **Ffion Argent**
> Users & Auth Team Leader

RAL apprentice Kieran Howlett in a server aisle in the High Performance Computing (HPC) Centre. ISIS is increasingly using the SCARF HPC facility for data acquisition, storage and analysis.

Over the past 40 years, advances in computing, coupled with those in neutron scattering and instrumentation, have led ISIS to groundbreaking discoveries and technological innovations. Future advances will enable the study of increasingly complex materials and processes, driving further scientific discovery and technological innovation. The continuous co-evolution of computational methods and neutron instrumentation will lead to even greater capabilities and insights, reinforcing the critical role of computing in the advancement of neutron and muon science.

ISIS-Italy partnership

Indian ministerial visit


RIKEN-RAL agreement

Memorandum of Understanding between ISIS and TU Delft

# International partnerships

**International collaboration has been a strength of ISIS since its inception. Long-standing partners such as Italy, Sweden and India have been with ISIS all through its 40-year history, and other international collaborations have enabled facility developments that would not have otherwise been possible – most ISIS instruments have seen international partner contributions.**

International partnerships strengthen the quality and breadth of science performed at ISIS. They bring additional expertise – scientifically and technically – which enhances ISIS science and instrumentation. They provide collaboration opportunities for ISIS staff and other UK researchers, demonstrate the world-class nature of the facility and highlight its strong international reach and reputation.

## Italy

**One of ISIS's longest-standing partnerships is with Italy. Dating back to 1984, the collaboration with the Consiglio Nazionale delle Ricerche (CNR) has seen collaboration on numerous instruments including MuSR, Prisma, Emu, Tosca, Vesuvio, Ines, Nimrod, IMAT, ChipIr and, looking forward, Tosca+ as part of the Endeavour Programme.**

Opening of the PRISMA (PRogetto dell'Istituto di Struttura della MAteria de CNR) spectrometer at ISIS, November 1988 by Luigi Bernardi, CNR President (second from right).

Enrico Garaci, CNR President, visited ISIS in November 1996 and is seen here with ISIS's Colin Carlile and Uschi Steigenberger.


Inauguration of Nimrod by Luciano Maiani, President of the CNR, in March 2009.

Robert McGreevy, ISIS Director and Cristina Messa, Vice President CNR, signing an ISIS-CNR partnership agreement in March 2014. Carla Andreani, Roberto Di Lauro, Italian Scientific Attaché London and Giuseppe Gorini look on.

ISIS's IMAT instrument was inaugurated in October 2016. Former ISIS Director, Robert McGreevy, H.E. Pasquale Terracciano, Italian Ambassador in London, and Corrado Spinella, Director of the Department of Physical Sciences and Technology of Matter, CNR, toast to the success of the instrument.


Celebrating 40 years of ISIS-Italy partnership at RAL in February 2024.

Left to right: Inigo Lambertini, Ambassador of Italy to the UK, Maria Chiara Carrozza, President of the CNR, Mark Thomson, Executive Chair of STFC, and Roger Eccleston, ISIS Director.

> "A memory that will stay with me is Philip King introducing me before my talk at the 40th year anniversary of the ISIS-Italy partnership. He said that I have been at ISIS for half the time the collaboration has been in place. It made me feel old, but also part of something that had and will have an impact on a broad range of science areas."
>
> **Antonella Scherillo**
> Ines Instrument Scientist

Carla Andreani, University of Rome Tor Vergata, with Andrew Taylor, former ISIS Director, during an event at ISIS in 2019 to mark the Mari spectrometer upgrade. Carla has been at the heart of the ISIS-Italy partnership since its inception. She was awarded the Giuseppe Occhialini Medal in 2016 by the Institute of Physics 'for her outstanding contributions to novel experimental techniques and methods in neutron spectroscopy and her tireless commitment to fostering the British-Italian collaboration in neutron science.'

## Sweden

**The first agreement between ISIS and the Swedish Research Council (Vetenskapsradet, VR) was signed in 1988. Further agreements included contributions to Polaris and IMAT coordinated through Chalmers Technical University. The partnership was significantly expanded in 2014 and renewed in 2019 to assist Sweden in developing its user community in preparation for future operation of the European Spallation Source (ESS).**

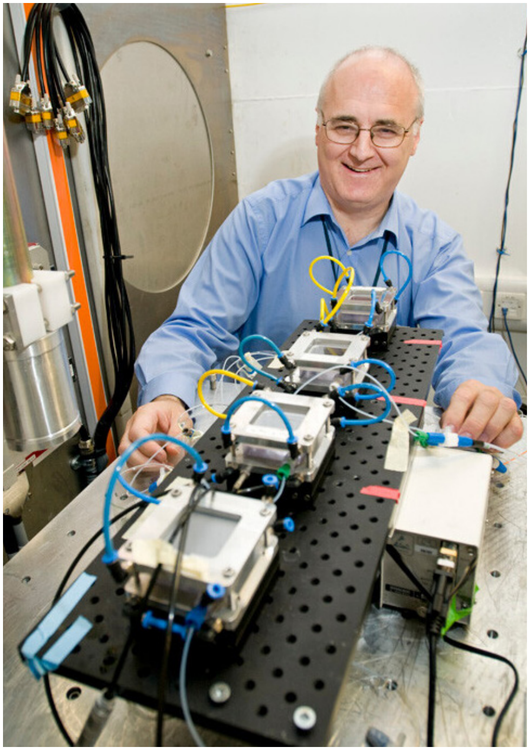

Lars Kloo, representing the Swedish Research Council, Vetenskapsradet (VR), headed a delegation from Sweden that visited ISIS in May 2012. Here, Lars is officially opening Polaris after its upgrade.

> "We are always proud to be working with international partners to take forward ISIS science and instrumentation. In May this year, we welcomed Professor Lars Kloo and colleagues to celebrate the Sweden-ISIS partnership. Sweden, together with Spain, contributed significantly to the upgrade of the Polaris diffractometer which was commissioned earlier this year and is already producing exciting new science."
>
> **Uschi Steigenberger**
> from her foreword for the 2012 Annual Review

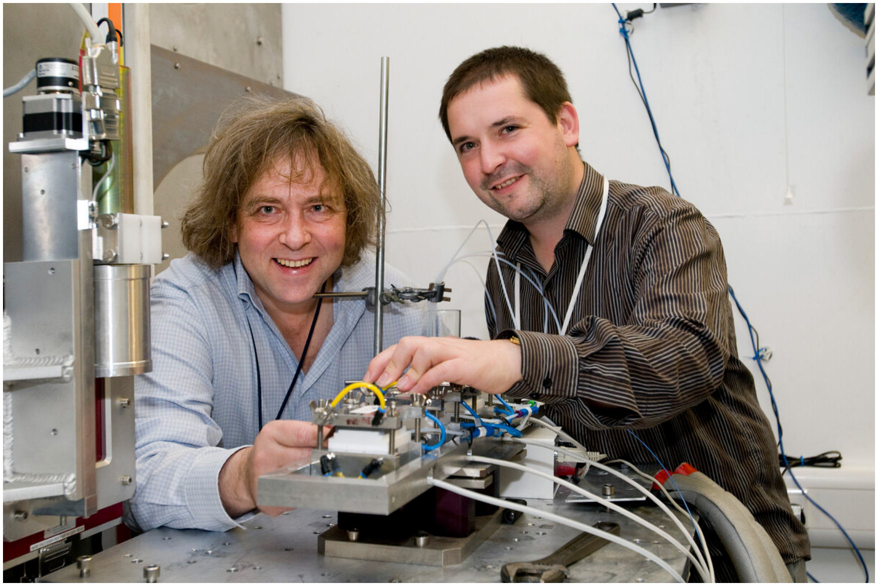
A delegation from Sweden's Council for Research Infrastructures, including Björn Halleröd, Secretary General of VR, visited ISIS in September 2018 to mark 30 years of ISIS-Sweden partnership.

Sten Eriksson, Chalmers University, here at the newly upgraded Polaris in 2012, was key to the ISIS-Sweden partnership and held the grants from VR for ISIS collaboration. He passed away in 2018.

> “ISIS supports an international community of around 3000 scientists including many from Sweden. This agreement will ensure that Swedish researchers can access state-of-the-art instrumentation and expertise and add to their own skills and knowledge base.”
>
> **Sten Eriksson**
> on the announcement of new funding in STFC News, February 2015



Adrian Rennie, Uppsala University, working on INTER in 2013.



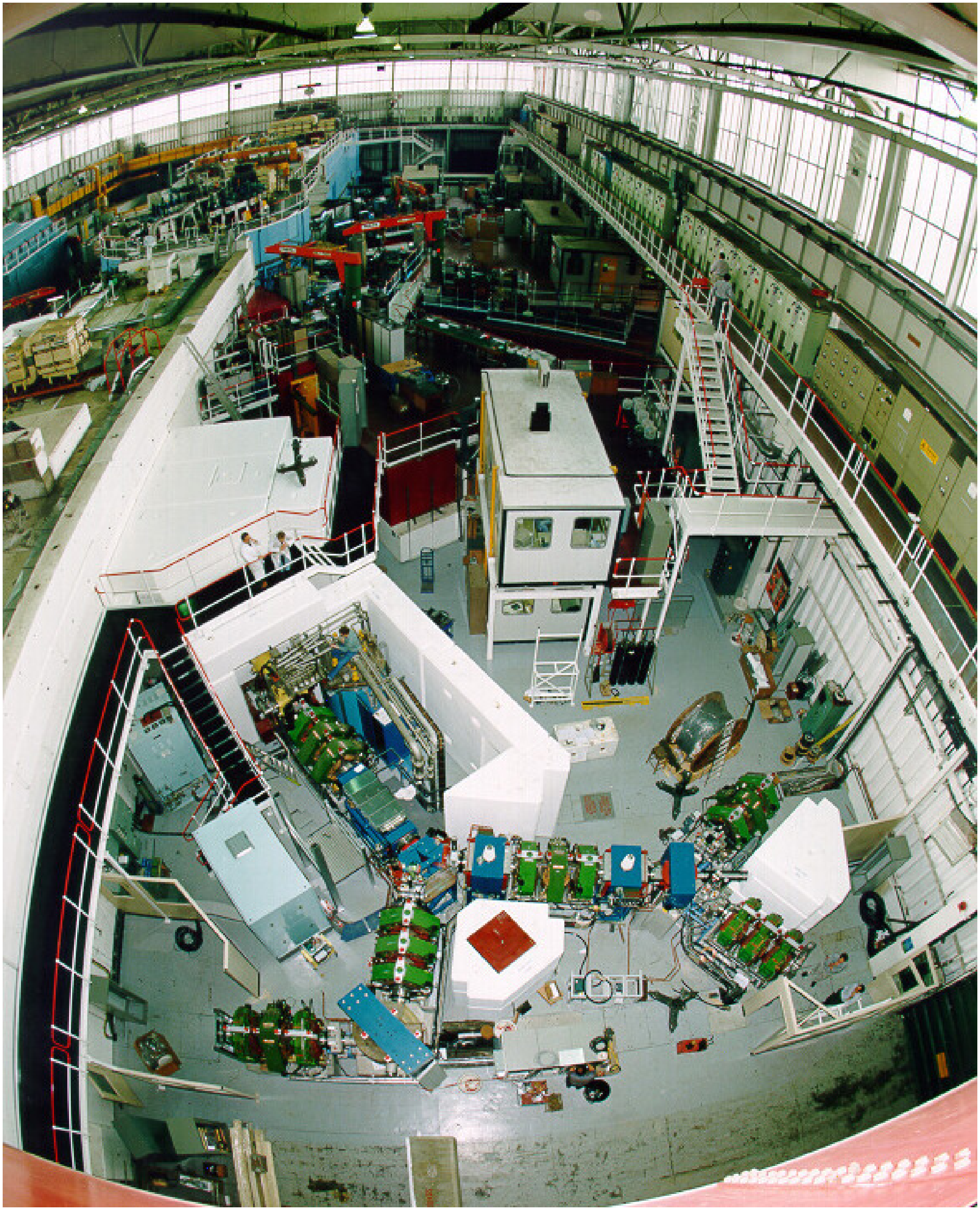
Tommy Nylander and Richard Campbell, Lund University, on Polaris in 2010. Tommy has been a prolific user of ISIS for more than 30 years. He ran his first experiment on CRISP in 1999 and has since carried out experiments on a range of instruments including INTER, Surf and SANS2D, which has resulted in more than a dozen papers.

## Japan

**ISIS has had many agreements with Japan over the past 40 years, the longest-standing of which was the 33-year partnership with RIKEN for construction, development and operation of the RIKEN-RAL Muon Facility. The first RIKEN-RAL agreement was signed in 1990 and led to the creation of four muon experiment areas. In addition, partnership agreements with RIKEN, KEK and JAEA have seen the construction of Mari, Maps and GEM neutron instruments, as well as accelerator collaboration.**


Inauguration of the Mari spectrometer by Mrs Hiroko Ishikawa, November 1990. The Mari spectrometer was funded by the Japanese Ministry of Education, Science and Culture (Monbusho) as part of the UK-Japan Collaboration on neutron scattering. This collaboration, initiated in 1986, was the creation of the late Yoshikazu Ishikawa and the spectrometer is named after his daughter, Mari.

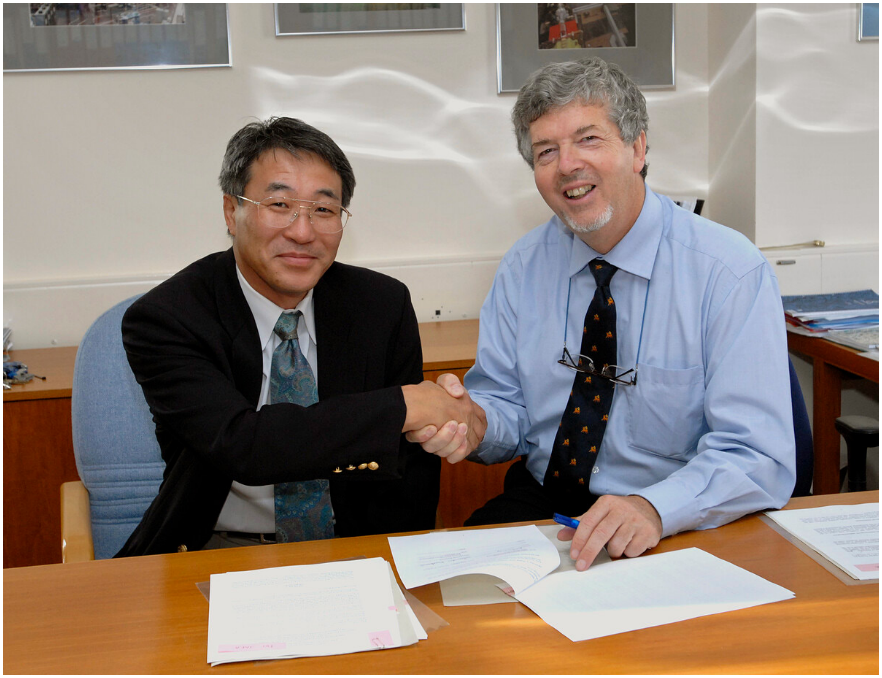
> “My eldest daughter was also called Mari and my second was born in Oxford right after starting our stay in UK. My colleagues took care of us and made a special arrangement about communication. They provided me with a bleeper to inform me during my work in case the baby was on the way! This is a typical example, but the entire time, people were very kind and friendly to me and my family.”
>
> **Masa Arai**
> former Mari Instrument Scientist who went on to become Director of JPARC-MLF



The RIKEN-RAL facility upon its completion in 1984.

Akito Arima, RIKEN President, with Ken Nagamine, at the inauguration of the RIKEN-RAL Muon Facility in 1995. Ken Nagamine from RIKEN was a driving force behind the creation of the RIKEN-RAL Muon Facility.

> "A key early focus of the facility was the study of muon catalysed fusion – in which adding muons to a mixture of deuterium and tritium causes a genuine fusion reaction between the nuclei. Professor Nagamine often used to say that muons were very good at bringing things together in partnership – deuterium and tritium nuclei in muon catalysed fusion, but more significantly, the people and the teams from Japan and the UK that worked together to create and operate the RIKEN-RAL Muon Facility."
>
> **Philip King**
> former Director of the RIKEN office at RAL



Memorandum of Understanding signing between Japan Atomic Energy Agency and ISIS by Masatoshi Arai and Andrew Taylor on 25 September 2006. Masa and Andrew remain good friends to this day, having worked together as instrument scientists on Mari.


Ken Nagmine (RIKEN) toasts the facility at the 20-year celebration event at RAL in 2010. During the celebration, a new 10-year agreement was signed by Ryoji Noyori, Nobel laureate in Chemistry and President of RIKEN, and Keith Mason, STFC CEO.


A celebration on 11 September 2015 marked 25 years since the signing of the RIKEN-RAL contract and 20 years since the inauguration of the facility. Left to right: Philip King, ISIS, Robert McGreevy, ISIS Director, Isao Watanabe, RIKEN, Ken Nagamine, formerly RIKEN, Eiko Torikai, University of Yamanashi, and Katsu Ishida, RIKEN.


Signing of a new Memorandum of Understanding between RIKEN and ISIS, 14 March 2023. Hiroyoshi Sakurai, RIKEN Nishina Centre Director, with Roger Eccleston, ISIS Director.


The RIKEN-RAL partnership was recognised by the Japanese government in 2023 by the award of a Commendation from the Japanese Foreign Minister to Philip King, ISIS, presented by the Japanese Ambassador to the UK, Hajime Hayashi.

# India

**India became the first ISIS international partner, with an agreement signed in 1983 contributing to development of one of the very first ISIS instruments, Iris. In 2016, ISIS signed a new agreement with the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), through the NanoMission of the Indian Department of Science and Technology, for collaboration between UK and Indian scientists in neutron scattering and muon spectroscopy. This collaboration included contributions to the instrument Zoom in Target Station 2.**

Paul Williams, Director of the Rutherford Appleton Laboratory, signing the second ISIS-India agreement in 1994 with BA Dasannachary, Bhabha Atomic Research Centre. In the back row stand Colin Carlile, Keith Ross, University of Birmingham and Andrew Taylor.

C.N.R. Rao, JNCASR, and Robert McGreevy, ISIS Director, sign a Memorandum of Understanding, 15 January 2015.

The Indian Minister for Science and Technology and Earth Sciences, Harsh Vardhan, and Robert McGreevy, ISIS Director, at Target Station 2 in November 2016.


Ashutosh Sharma, Secretary of the Department of Science and Technology, Government of India, stands by Zoom during his visit in April 2018.


Indian Minister of State Science and Technology, Minister of State Earth Sciences, Jitendra Singh visited ISIS in April 2023.

> "Indian researchers have used ISIS to make an impact in a broad spectrum of research, ranging from collaborations with industrial giant Tata Steel, who have used the Engin-X instrument to improve their products, to fundamental research into nanoparticles, technologically relevant multiferroics and superconductivity. Long may the partnership continue!"
>
> **Roger Eccleston**
> on the occasion of the Indian Minister's visit in 2023

## The Netherlands

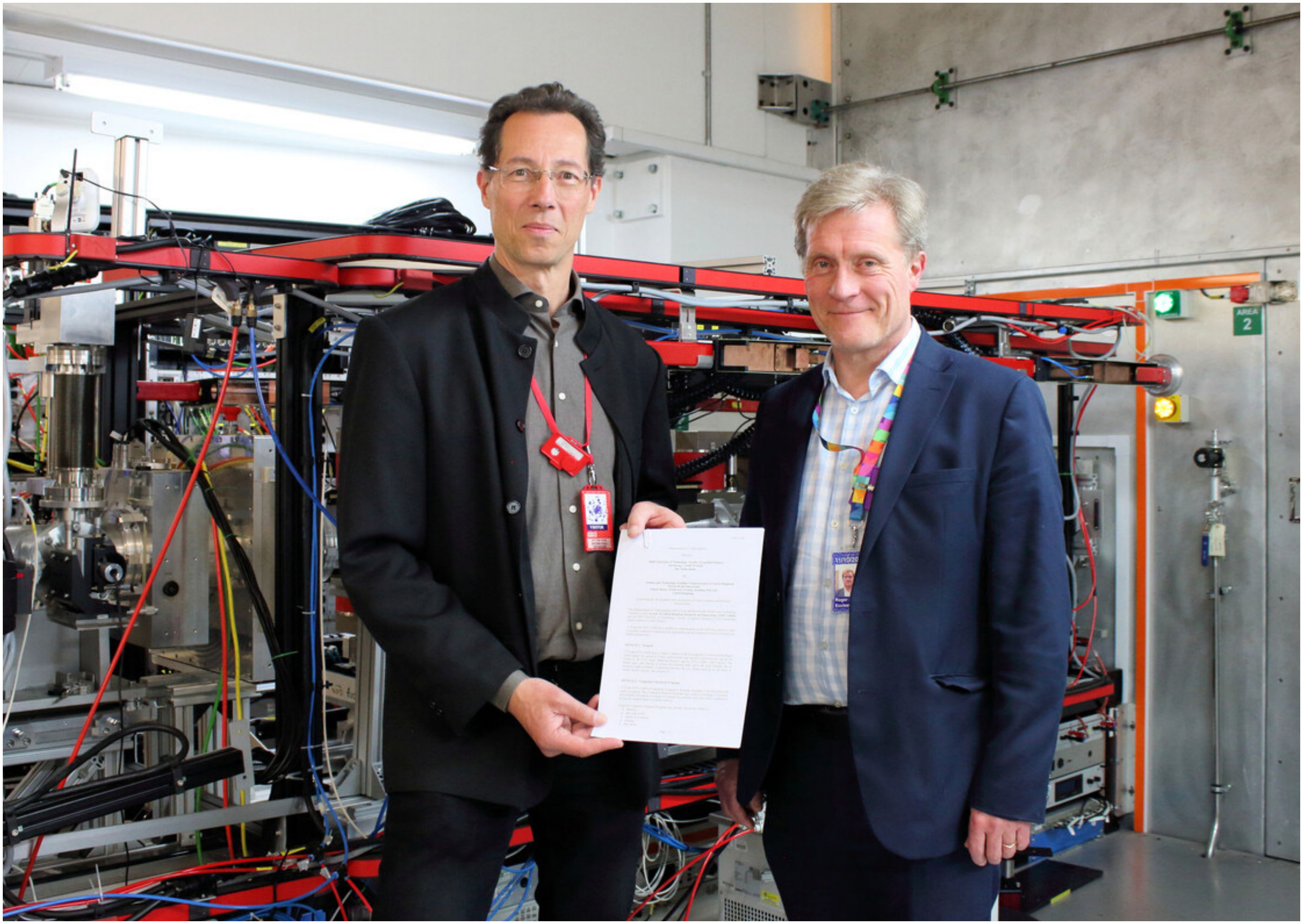
**The ISIS-Netherlands partnership is also one that dates back many years. ISIS and its community have particularly benefited from expertise in neutron spin manipulation techniques at Delft University of Technology, which, along with funding from Netherlands research organisation NWO, has led to the creation of the instruments, OffSpec and Larmor.**

Bill Mitchell, Chairman of the Science and Engineering Research Council, and Jan Borgman, Chair of the Netherlands Organisation for Scientific Research (NWO) sign an umbrella agreement for Netherlands use of ISIS in June 1988.

Tim van der Hagen and Karel Luyben, Delft University of Technology, at OffSpec during its formal opening in September 2009.

Members of the Netherlands user community attending a celebratory event at ISIS in 2019 to mark the end of the NWO grant and the completion of the final instrument components for Larmor.

> "By working closely together with our colleagues in the Netherlands, we have demonstrated that we are able to build the world's most advanced neutron instruments and use them to develop a unique understanding of modern materials science."
>
> **Uschi Steigenberger**
> at the opening of Larmor



Wim Bouwman, Delft University of Technology (TU Delft), with ISIS Director, Roger Eccleston in the Larmor instrument on the occasion of the signing of a new Memorandum of Understanding between ISIS and TU Delft in 2023.

## Other collaborations


Patxi Lopez, Lehendakari Basque Government President, unveiling a commemorative plaque in 2011 for the contribution to ISIS by the industry in the Basque region.

Miguel Quintanilla, Secretary of State for Universities and Research, Spain, inspects the LET vacuum tank in February 2008. The vacuum tank was delivered to ISIS from Spain, where it was manufactured.


Martina Hirayama, State Secretary for Education, Research and Innovation, Switzerland, visited ISIS in May 2023. ISIS has very strong links with the Paul Scherrer Institute in Switzerland.


Jack Carpenter, the 'father' of spallation neutron sources, cuts a cake to celebrate the 40th anniversary of the International Collaboration on Advanced Neutron Sources. The Rutherford Laboratory was one of the founders of ICANS in 1977. This collaboration has been enormously beneficial in the development of relevant techniques and the success of ISIS.

> "Without the work of Jack Carpenter, ISIS would not have happened."
>
> **Robert McGreevy**
> former ISIS Director


Robert McGreevy, then ISIS Director, and Dimitri Argyriou, European Spallation Source, Science Director sign a Memorandum of Understanding between the European Spallation Source and the Science and Technology Facilities Council in December 2015.

Helmut Schober, European Spallation Source Director General (right) and Roger Eccleston, ISIS Director (left) signing a Memorandum of Understanding for collaboration between the two facilities in December 2022.

Paul Langan, Institut Laue-Langevin Director, and Roger Eccleston, ISIS Director, sign a Memorandum of Understanding for partnership between the two facilities in July 2022.


Manuel Heitor, Portuguese Minister of Science, Technology and Higher Education visited ISIS in February 2017 and is seen here with Maria Paula Marques, University of Coimbra.


ISIS was one of the founding members of the League of advanced European Neutron Sources (LENS). The LENS statutes were signed at a meeting in Liblice, Czech Republic, in March 2019. Robert McGreevy, ISIS Director, was the second Chair of LENS following Helmut Schober, who was at that time Institut Laue-Langevin Director.

Neutron and Muon Science User Meeting

Muon Training School


Facility Development Studentship

ISIS Open Day

# Public and student engagement

**Throughout the history of ISIS, external engagement has been important, whether it be with school children or Prime Ministers, undergraduates or professors. Over the years, these interactions have developed into valuable programmes of engagement with school students and the public, university students and our user community. Often people journey through this engagement pipeline, going from interested student to user or staff member, even including our current director Roger Eccleston, who first worked at ISIS as a sandwich student in 1987.**

## Public engagement

**Over the years, ISIS has hosted hundreds of events, including open days, where members of the public and school students are invited to tour the facility and learn more about the wide variety of work that takes place. Every year, ISIS also offers work experience placements to school students, providing unique insights into the facility and roles in Science, Technology, Engineering and Maths (STEM).**

In 2024 alone, ISIS reached 5900 members of the public and school students, both in person and online, through its public engagement programme. On top of this, ISIS's 40$^{th}$ anniversary also coincided with Harwell Open Week, during which ISIS welcomed thousands of visitors into the experimental halls. Staff across ISIS volunteered to showcase the facility and the work that they do through hand-on activities, demonstrations, exhibits, tours and workshops to inspire the public, especially young people, who could make up the next generation of staff at Harwell.

ISIS scientist Terry Jones, demonstrating how a sample can be loaded to a visiting local mayor during the RAL VIP Open Day, July 1990.

ISIS was competitively selected as one of only 23 scientific institutions taking part in the four-day Royal Society Summer Science Exhibition in 2007; a year notable for being the 75th anniversary of James Chadwick's discovery of the neutron. Presenting under the banner, 'Matter Matters!', ISIS demonstrated the value of neutron scattering in our everyday lives to more than 5000 school students and members of the public. The exhibition, in fact, reached several million people via British national and regional newspapers alone, and significantly more as a result of broadcast coverage both in the U.K. and internationally.

Clockwise from top left: Beth Evans, Martyn Bull, Rowan White, Alan Soper, Jonny Ranner, Silvia Imberti, and Mark Telling.


An excited favourite toy accompanying its owner on the ISIS Friends and Family Day in 2017.

Children getting to grips with magnetic slime during the ISIS Friends and Family Day in 2017.

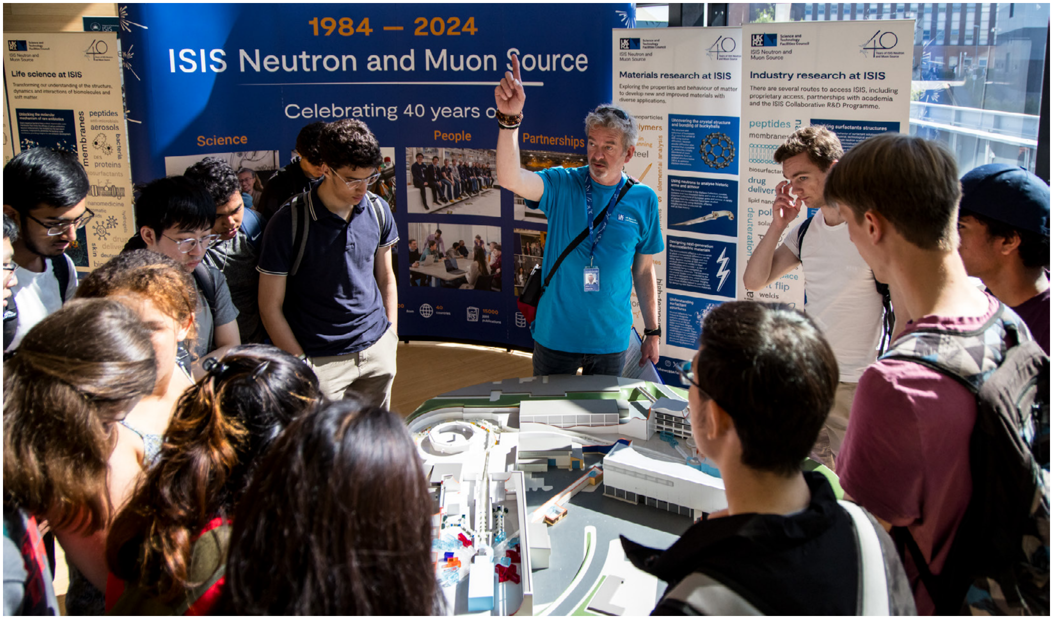
Chris Lawson running a cryogenic demonstration of a visitor's frozen breath at the ISIS Friends and Family event in 2022.

> "The work undertaken at ISIS and the discoveries it leads to are truly fascinating. It's a pleasure and a privilege to be able to share this fascination with our engaged and curious visitors. I especially hope to spark a sense of scientific wonder with our youngest guests, which will stay with them as they navigate the world."
>
> **Chris Lawson**
> *Sample Environment Group Leader*

Sarah Youngs demonstrates an experiment known as “jelly snakes” to her daughter at the ISIS Friends and Family event in 2022. The experiment is used to explain the concept of polymers.

ISIS opened its doors as part of the Harwell Open Week in June 2024. Here, a visitor tries to hook a rubber duck using the manipulator arms typically used by the Target Operations Team.

> "The open days create great memories. It is so much work to organise them, but the reward of seeing people of any age and background amazed by what we do and inspired to do science is incredibly hard to beat."
>
> **Antonella Scherillo**
> Ines Instrument Scientist




Nick Edwards introduces students to ISIS at the facility model during the one of the Schools Open Days of Harwell Open Week 2024.

> “The ISIS Neutron and Muon Source was my favourite bit. It was so interesting and fascinating to learn all about muons and see them being detected and also to learn about the experiments that were being carried out.”
>
> **Visitor feedback**
> Harwell Open Week 2024

> “ISIS was fantastic. The staff were brilliant. I learned so much about how it is used and for what purpose. Really impressed.”
>
> **Visitor feedback**
> Harwell Open Week 2024

## Student engagement

**ISIS recognises the importance of students to the facility, whether as undergraduate industrial placement students based at the facility for a year, or a PhD student using the facility for an experiment to support their research. In addition to students associated with many ISIS experiments, ISIS also co-funds PhD studentships with university partners through the Facility Development Scheme. ISIS is proactive in addressing the training needs of our student users, providing a broad range of practical and online training opportunities, as well as student-specific conferences and events.**

Alongside our student programme, we also play a key role in the STFC work experience, apprenticeship and graduate programmes, with many of those finishing the programmes joining the facility full time.

### Neutron training schools

Terry Willis, the founder of the UK Neutron Scattering Group at Harwell was instrumental in organising a 'School for Neutron Scattering', with the first school held at Harwell in 1966. A celebration of the School was held at The Cosener's House, Abingdon, 21 May 2009.

> “As far as we know, the school in 1966 was the first one in the world, and many famous neutron practitioners have attended the schools of the past 50 years, and hopefully it will run for many more. Many of those who attended the early schools, or played a role in their organisation, attended a celebration at The Cosener’s House in May 2009.”
>
> **Gerry Lander**
> at the 18th running of what is now the Oxford School for Neutron Scattering, September 2024

Delegates of the 2007 Oxford School of Neutron Scattering outside the newly-built Target Station 2.

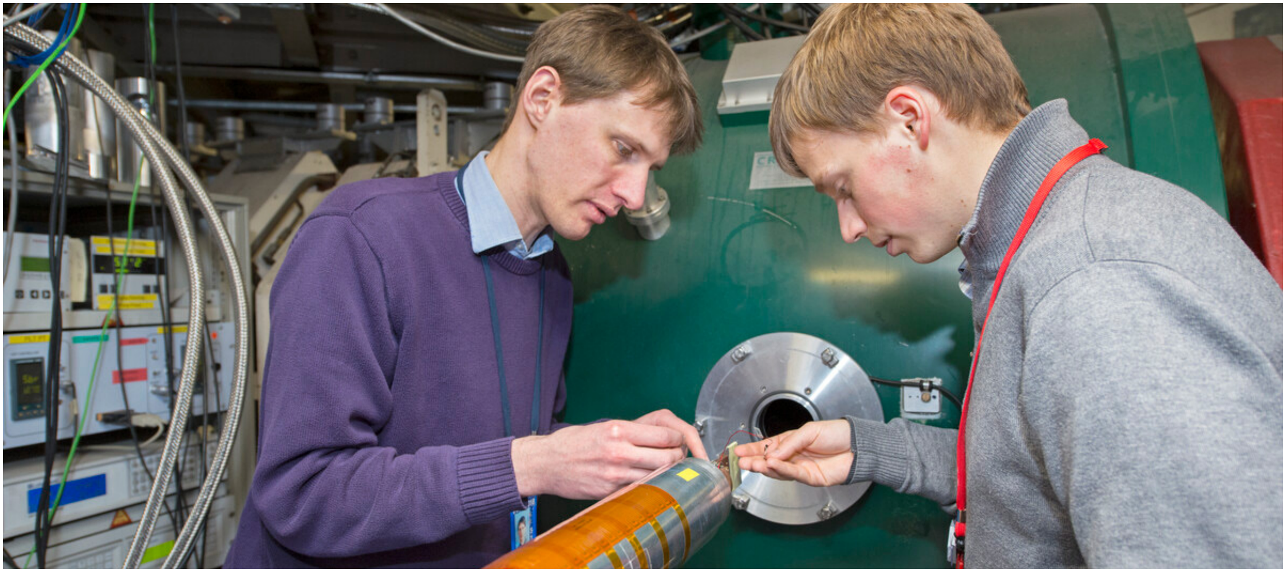
Gabriel Perez and Nicolò Paracini on the Neutron Training Course in 2016. Gabriel is now an Instrument Scientist in the Crystallography Group and Nicolò is an instrument data scientist for neutron reflectometry at the European Spallation Source.

> "This was my first ever visit to ISIS. I remember being amazed by the complexity of the facility and its unique capabilities for tackling a wide range of scientific challenges. I thought to myself that it would be incredible to work at ISIS, and now I feel very lucky to have the opportunity to contribute to the world-class science that is carried out here."
>
> **Gabriel Perez**
> Instrument Scientist, Crystallography Group

## Muon training schools

MuSR Instrument Scientist, Peter Baker, has run ISIS's muon training schools for the last twelve years and gradually developed complementary online learning materials with the support of industrial placement students. The online learning platform was developed as part of the SINE2020 European project with a team in Copenhagen.

Peter Baker showing a student how to load a sample into HiFi in March 2016.



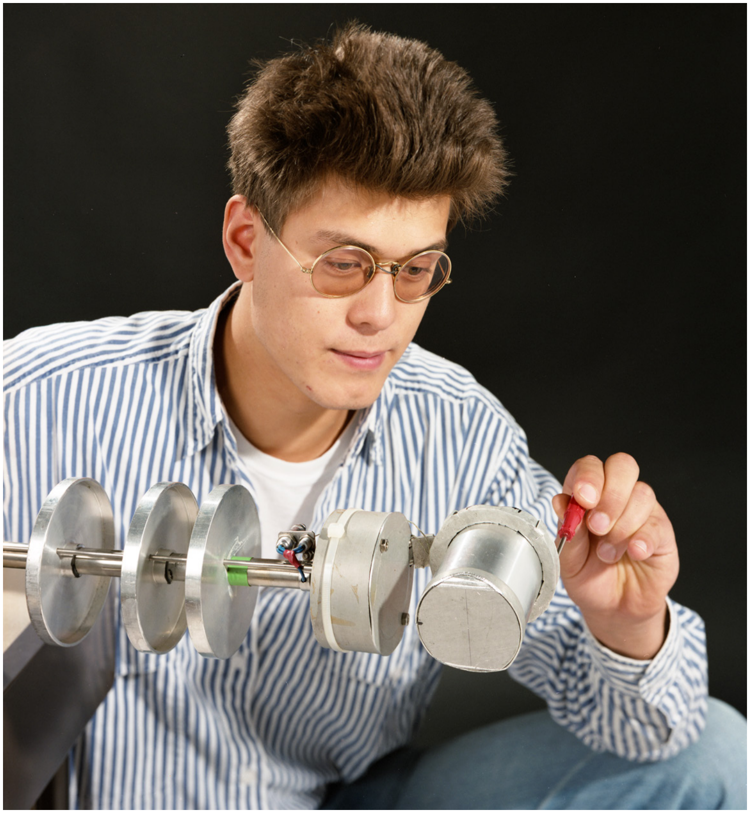
> "The online learning materials give users the opportunity to learn some of the techniques before attending in-person schools or experiments, and then they're able to reinforce what they have learnt afterwards. People rarely come across muon spectroscopy at undergraduate level so have little experience with the techniques when they come to do their PhDs. Bringing everyone up to a basic level of understanding is very important."
>
> **Peter Baker**
> MuSR Instrument Scientist

Saidah Sakinah Mohd Tajudin, University Sains, Malaysia and RIKEN, and Oana Ciubotariu, Babes-Bolyai University, Romania, working on Emu as part of the Muon Training School in 2014.

## Student placements at ISIS

Ken Andersen first arrived at ISIS as a PhD student at the University of Keele. He later joined ISIS as Osiris Instrument Scientist before moving on to senior roles at the Oak Ridge National Laboratory and European Spallation Source. He is now Director of the Institut Laue-Langevin.

Ken Andersen testing a high-pressure helium sample on Mari in October 1990.



> “I was this completely green PhD student and I had no idea what I was doing. Andrew Taylor and Zoë Bowden were so welcoming, respectful and inclusive. They really wanted me to have a good experience. I remember at the time being really impressed by that. I'll also never forget first walking into the main hall. I thought, ‘Wow! This is cool. I really want to work here one day. This is a place that's going places!’ It had and still has a buzz about it that is just exciting.”
>
> **Ken Andersen**
> former Osiris Instrument Scientist, now Director of Institut Laue-Langevin

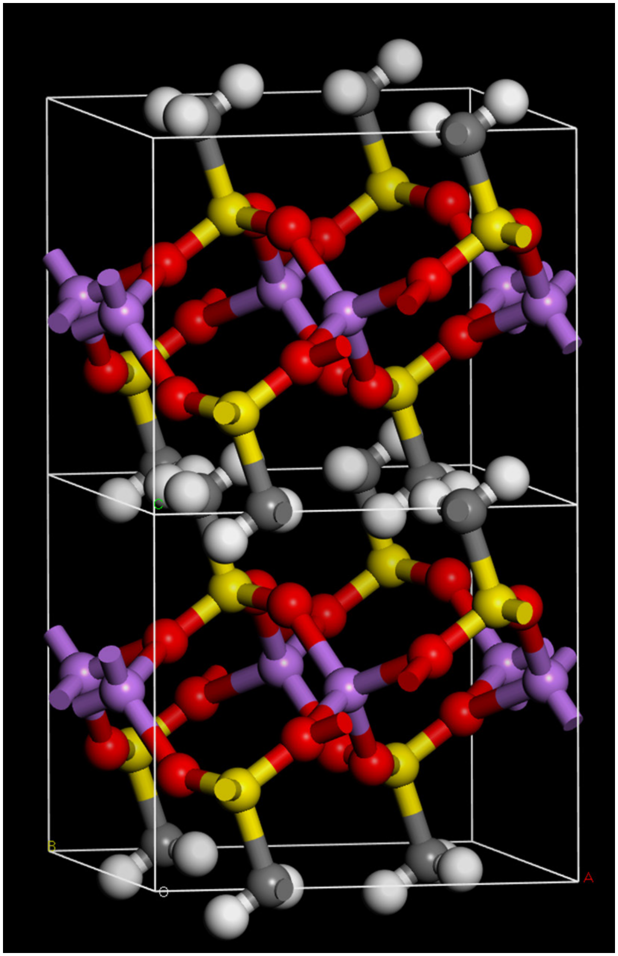
After an industrial placement year at ISIS with the newly formed Polarising Filters Team, Kathryn Baker worked elsewhere for a few years before returning to ISIS in a software engineer-style role, similar to her earlier placement.


Kathryn Baker checking installation of control programmes on the SANS2D beamline with Gareth Howells and then Head of Instrumentation, Debbie Greenfield, in August 2008.

> "I found that I really did love the problem-solving of computing, and I believe I provided some value to ISIS as well. My biggest gain from my placement year was finding this role that gives a sweet spot of doing what I enjoy doing and providing a service which betters the world."
>
> **Kathryn Baker**
> Senior Software Engineer, Experiment Controls

Between the third and fourth years of his Computer Science degree in 2004/5, Tom Griffin spent a year as part of the Data Analysis Group at ISIS. Upon graduating, he joined STFC as a Software Engineer and later moved to the Computing Group. He has remained at STFC ever since, working his way through a variety of roles including ISIS Computing Group Leader up to becoming Director of the STFC Scientific Computing Department in 2018.

> “ISIS was a great place to start my career as a student and then as a graduate. It gave me a solid grounding in the range of skills needed to deliver computing for science, as well as the opportunity to get involved in a variety of different projects.”
>
> **Tom Griffin**
> Director, STFC Scientific Computing Department



During a two-week work experience placement at ISIS, local school student Emilie Revill-Hivet made and characterised a new lithium compound using Tosca, leading to the publication of an article in Royal Society Open Science.

This figure shows the two cells, lithium methanesulfonate and potassium methanesulfonate.

DOI: 10.1098/rsos.200776

> “During my placement I was able to meet other students who were working in different facilities, as well as go along to talks and workshops that were happening. Although the impressive site was daunting at first, everyone was very welcoming and helpful.”
>
> **Emilie Revill-Hivet**
> Work Experience Student


Elisa Barzagli was a PhD student working with Antonella Scherillo on archeometallurgy. She was diagnosed with cancer during her studies and passed away shortly after completing her PhD. Elisa left a legacy in being the first to use elemental analysis methods that are now available to Ines users.

> “Elisa was very close to my heart. She decided to still perform experiments after her diagnosis. I remember her teaching me how to braid my daughter’s hair. I have tears in my eyes thinking about Elisa. Her legacy will live on in the memories of all of us who knew her well.”
>
> **Antonella Scherillo**
> Ines Instrument Scientist


Even during the COVID-19 pandemic, ISIS still welcomed placement students.

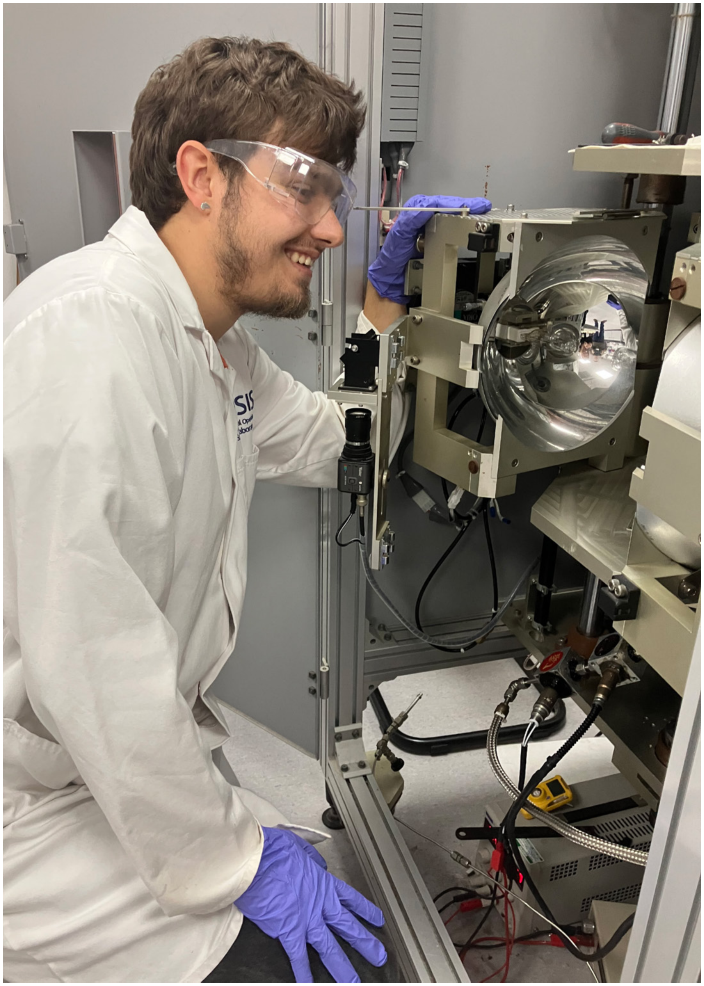
Toluwalase Agoro worked on the RIKEN muon beamline and is now studying for his PhD at Cambridge.

> "My time at ISIS was marvellous! I was able to meet amazing people and learn exciting things."
>
> **Toluwalase Agoro**
> University of Cambridge

Olivia Tindle was placement student with the Neutronics Group.

Despite struggling at college and being told she should try something else, learning at university suited Olivia more; after being diagnosed with ADHD and dyslexia, open book exams allowed her to focus on applying her knowledge. During her placement, she investigated the effect of neutron energy on radiolysis of liquid methane and took work from previous research to build a code to model the moderator and feed in data from ISIS.

> "I knew there would be a place for me in physics and, whilst it's been an uphill battle, I've finally found it."
>
> **Olivia Tindle**
> Sheffield Hallam University




Benji Moore did an industrial placement, jointly supervised by WISH Instrument Scientist Pascal Manuel and Robin Perry, University College London. He used a new technique to synthesise single crystals, using X-ray diffraction in the ISIS Materials Characterisation Laboratory and neutron diffraction on SXD.

Benji's work was published as a first-author paper in CrystEngComm and he is now a PhD student at the University of Manchester, returning to ISIS as a user to build on the experience gained during his placement.

> "I don't think I would have been considered if I did not have the experience from my year in industry. Learning all the fundamentals and foundations set me up well for my PhD and my return to university. It enabled me to perform better than my colleagues, which was good for my grades!"
>
> **Benji Moore**
> University of Manchester


Katie Burke, a biochemistry undergraduate at the University of Warwick, did her placement with the Communications and Impact Team. Here, Katie reports on the FAMU experiment at the RIKEN beamline, which used infrared spectroscopy to study an exotic form of hydrogen. Katie has recently graduated with first class honours and has just joined Diamond Light Source in their Public Engagement Team.

> "The women at ISIS are truly incredible and inspiring for all young women starting out in STEM. From a 70-year-old engineering retiree who fought her way up the management ladder, to the female scientists currently running and supporting experiments equipped with their PhDs, passion for work and a genuine life at home. It is wonderful to see that any uncertainty (subconscious or otherwise) is entirely unfounded."
>
> **Katie Burke**
> Science Communications placement student

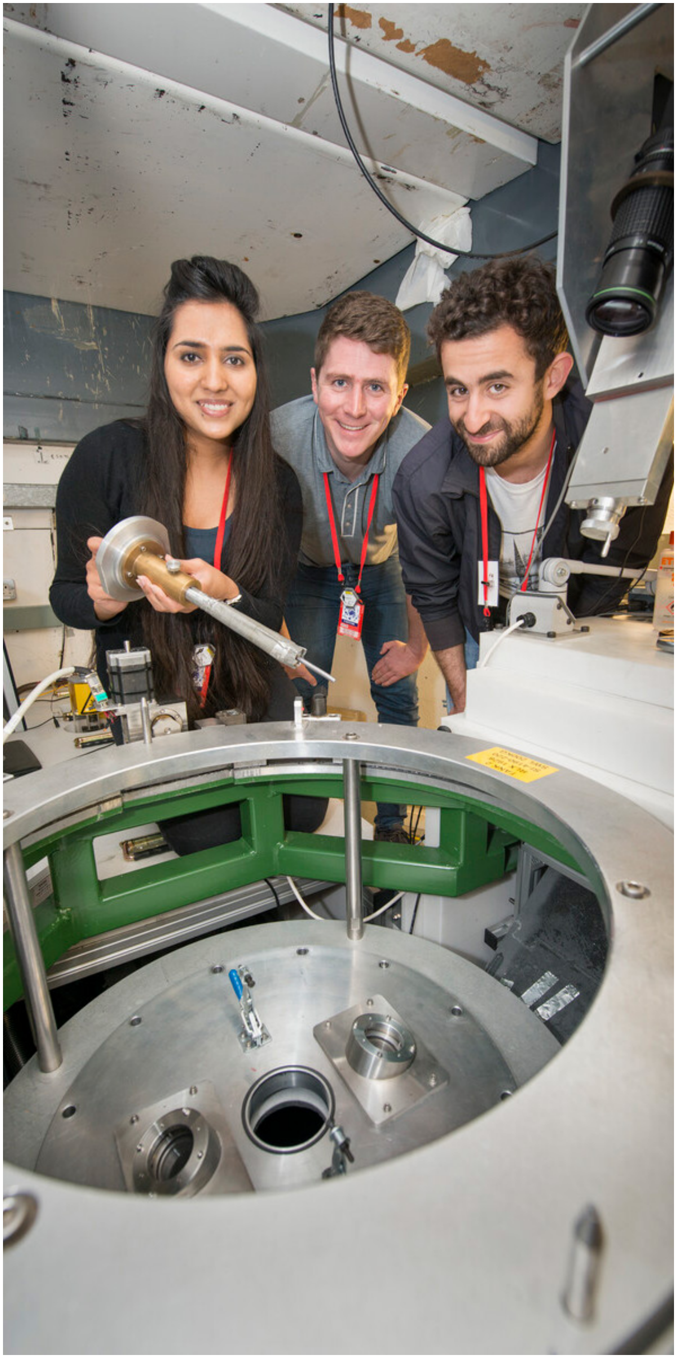

© British Omani Society

Aziza al Mugheiry, a Physics and Astronomy undergraduate at Cardiff University did her placement in Development of Online Scientific Training for Neutron and Muon Experiments during 2023/4. At 19 years old, she was the first GCC national to be employed by UKRI and her role at ISIS was a milestone for gulf Arab representation in science. In February 2024, Aziza became the youngest ever speaker at the British-Omani Society since its inception in 1976.

> “I’ve only ever done 15-minute presentations at university so an hour’s lecture at a society representing my birth country, and the country I am having these amazing opportunities in felt very daunting! But it was a unique opportunity and a fantastic challenge.”
>
> **Aziza al Mugheiry**
> Cardiff University

## ISIS Facility Development Studentships

After an undergraduate degree in biomedical sciences, Anthony Reid worked as a physics teacher for six years. At 27, he completed a MSc at the University of Sheffield before obtaining a PhD through the ISIS studentship programme. He investigated the time-resolved strain of dynamic engineering components using X-ray and neutron diffraction and imaging. He has since joined Frazer Nash Consultancy as a Data Scientist in Strategic Modelling, where he works on a range of projects across the energy system.



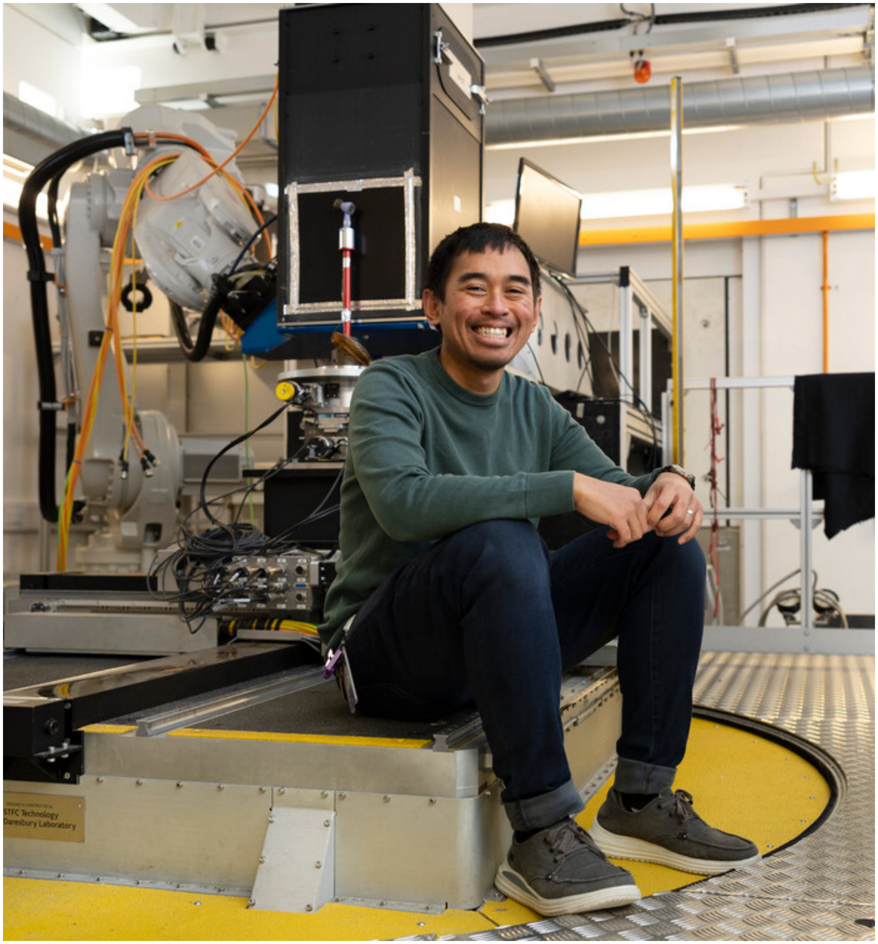
Tavleen Attari, University of Durham, Anthony Reid, University of Sheffield, and Amane Abdoun, University of St Andrews, working on Pearl during the 2016 Neutron Training School.

> "I had so much fun doing my PhD. I got to work with some amazing people from around the world and learnt so much, even joining in with experiments that had nothing to do with my own work."
>
> **Anthony Reid**
> University of Sheffield

Matilda Rhodes came to ISIS for her industrial placement year as part of an integrated Masters in chemistry at the University of Southampton. She was part of the team in the Materials Characterisation Laboratory, developing techniques for investigating the magnetic properties of thin films at different conditions.


After completing her masters, Matilda began her ISIS Facility Development PhD at the University of Edinburgh, characterising lithium ores using negative muons. Here, Matilda is presenting her research at the ISIS Student Meeting 2022.

> “I enjoyed my project and researching, which I hadn’t previously thought of pursuing. It made me realise that I could do a PhD.”
>
> **Matilda Rhodes**
> University of Southampton



Ranggi Ramadhan did a PhD through the ISIS Facility Development scheme and, after a post-doctoral position at the Institut Laue-Langevin, is now an instrument scientist on IMAT.

During his studentship, Ranggi spent most of his time at Coventry University, but with one week every month at ISIS.

Ranggi at IMAT in November 2023.

> “This [the ISIS Facility Development Studentship] worked well as I was doing an engineering PhD, so all of my colleagues at Coventry were engineers, and my time at ISIS gave me the opportunity to learn more about the science.”
>
> **Ranggi Ramadhan**
> Coventry University

ISIS also hosts annual meetings for PhD students using neutrons and muons in their work.

PhD Student Zac Amato presents his research at the 2021 meeting.

The future of ISIS

SANDALS-2

Ines

Computing away day

# Looking ahead

**Materials – whether they be in the form of the products we buy, our sources of energy or our healthcare – are continuously in demand by society. The key to understanding and optimising materials is a detailed knowledge of atomic structure and dynamics. ISIS's success has been built on its ability to provide this unique and valuable information.**

It is inherently difficult to predict future scientific directions but this is a reality that large scale facilities have to engage with. There are two immutable principles that can help us. Firstly, society will continue to have a fundamental need to understand matter at a basic and profound level. Secondly, society requires products and systems that have enhanced functionality, can be readily recycled, and make smaller demands on the planet's finite materials and energy resources. It is in this space, where the unique insight provided by neutrons and muons is essential and where the facility must evolve to meet these challenges.

To keep ISIS at the forefront of materials research, we need to continue to innovate and develop: in our source, our instrumentation, our enabling technologies and most importantly with our skilled staff and user communities.

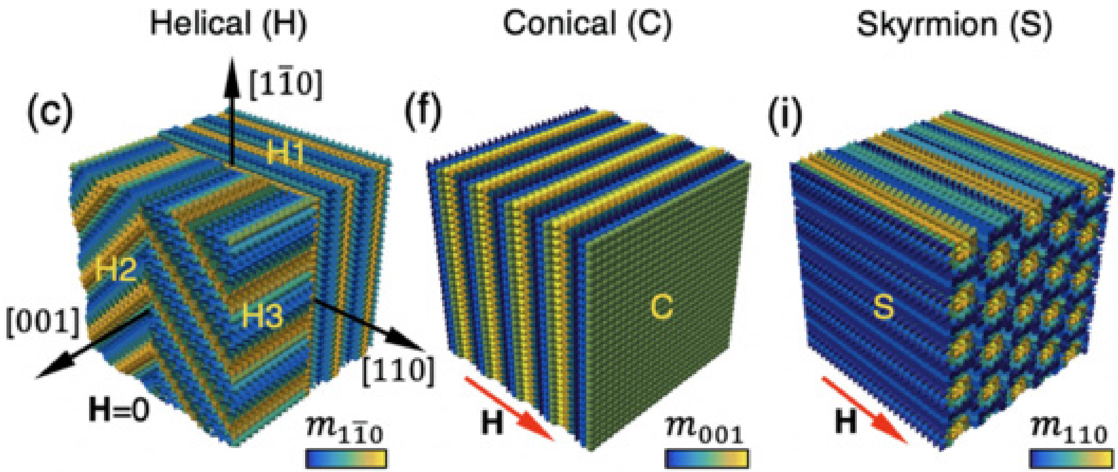
We continue to be committed to equity, diversity and inclusion – a working environment, promoting dignity and respect for all, and where individual differences and the contributions of all staff are recognised and valued.

The Pride flag flying outside Target Station 1 in 2022.

## Science

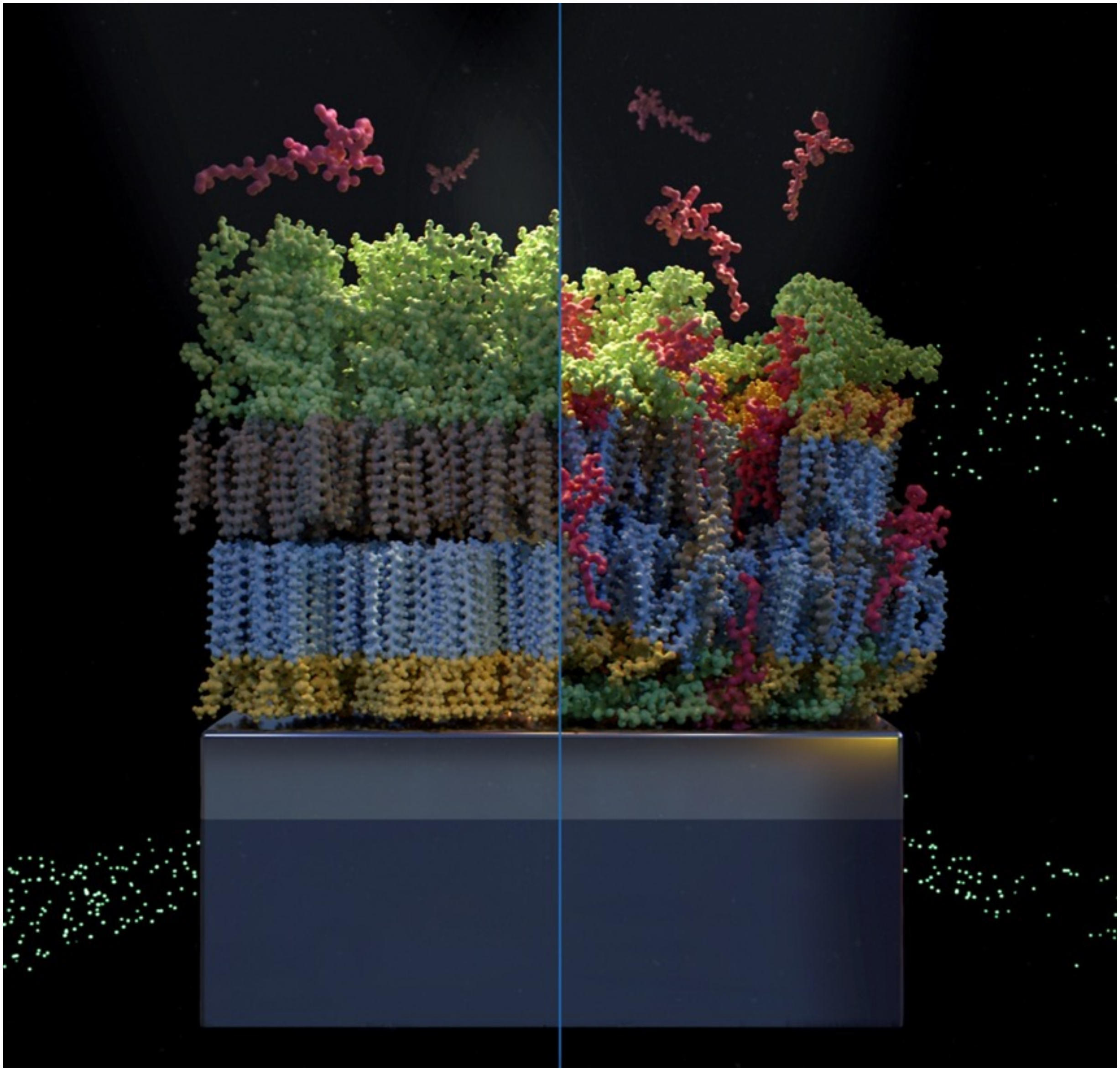
**The scientific research performed at ISIS by the academic and industrial communities alongside ISIS scientists is breathtaking. Not only in the new understanding of materials that is gained, but also in its diversity, spanning across all the physical and life sciences. Neutrons and muons will continue to occupy a central role in materials discovery for the benefit of society – they will be used to optimise the electrochemical storage of energy, allow us to improve the efficiency and effectiveness of smart pharmaceuticals and vaccines, and enable us to optimise the performance of quantum sensors and technologies. This is only a tiny fraction of the future impact of neutron and muon science. When combined, this makes a transformative impact on societal challenges, such as an ageing population, the transition to clean energy and a circular economy more sensitive to the needs of our planet.**

Exotic magnetic textures that are topologically protected[1] have enormous potential for highly energy efficient computation. Neutrons can image this emergent behaviour to describe both their atomic structure and their dynamics, which is ideal for the next generation of quantum technologies.




DOI: 10.1103/PhysRevB.102.104424

[1] Put a twist in your trouser belt before you fasten it and then try to remove the twist without undoing or cutting your belt. This is a form of the protection that electrons experience and which makes their properties very robust: ideal for applications.

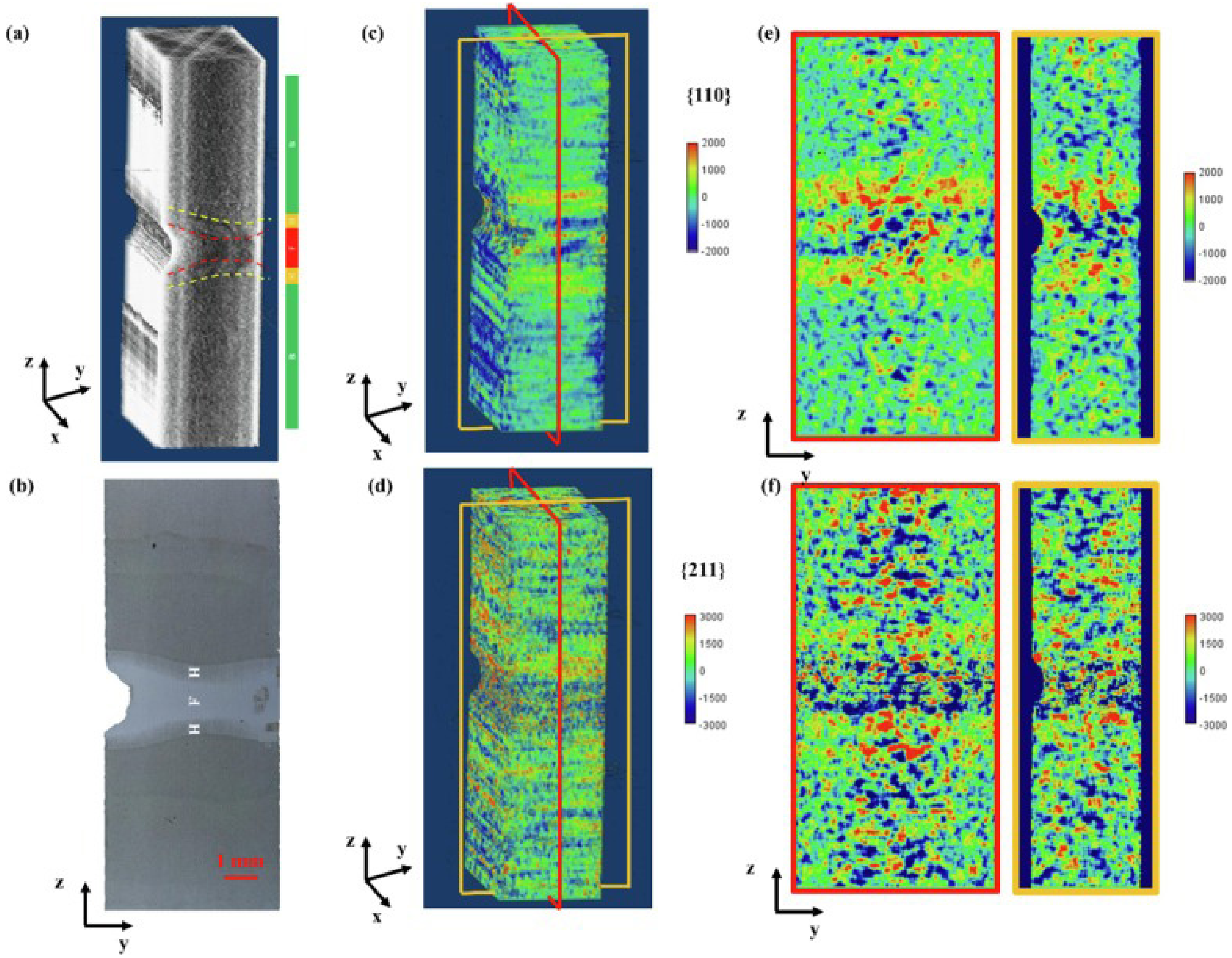


The molecular level understanding of membranes has important possibilities for future targeted therapeutics. The bacterial models used to undertake this work in antibiotics were developed at ISIS.

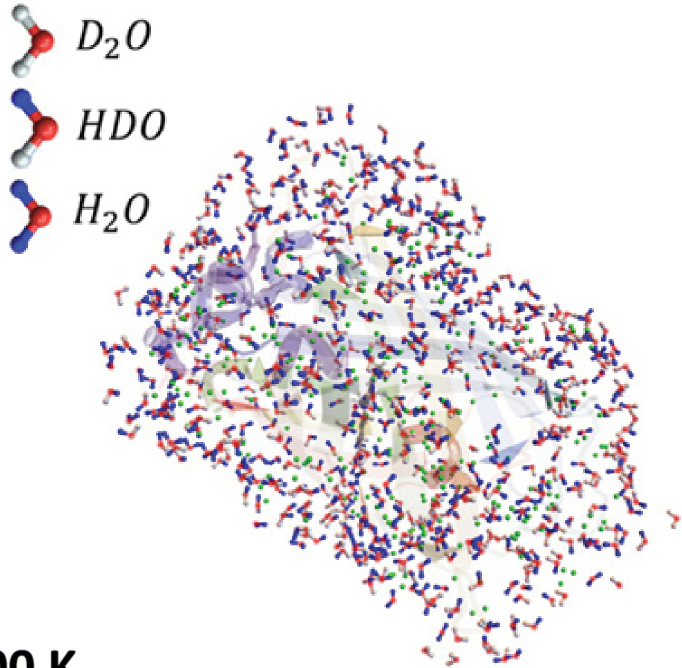
Image courtesy of Luke Clifton.

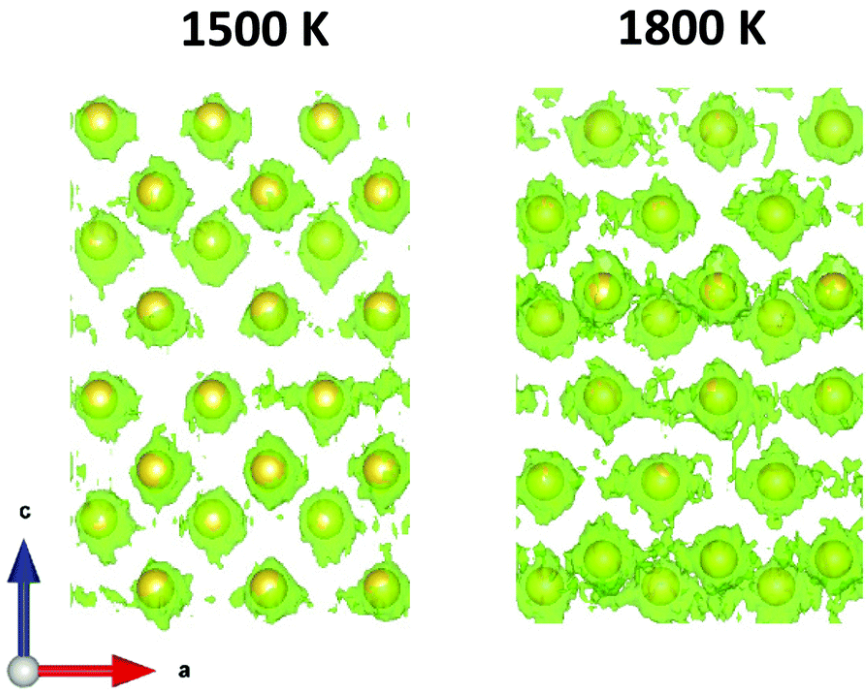
Neutrons can see inside complex engineering components and spatially resolve the strain within. Nuclear fusion reactors rely on joining techniques: in this case the strain present in the laser welded region can be quantified and imaged. The images on the top left and centre are neutron tomographic reconstructions of a laser welded joint. The technique is non-destructive and can reveal the residual strain for particular orientations of grains within the component (centre column of figure). From these rich datasets slices in any orientation of interest can be digitally extracted.

DOI: 10.1016/j.nme.2023.101462



Exploiting the quantum nature of the neutron beam, we are able to separate out the structure and motion of complex materials. In this case, a light oil confined in a molecular cage offers insight into the storage of energy materials.



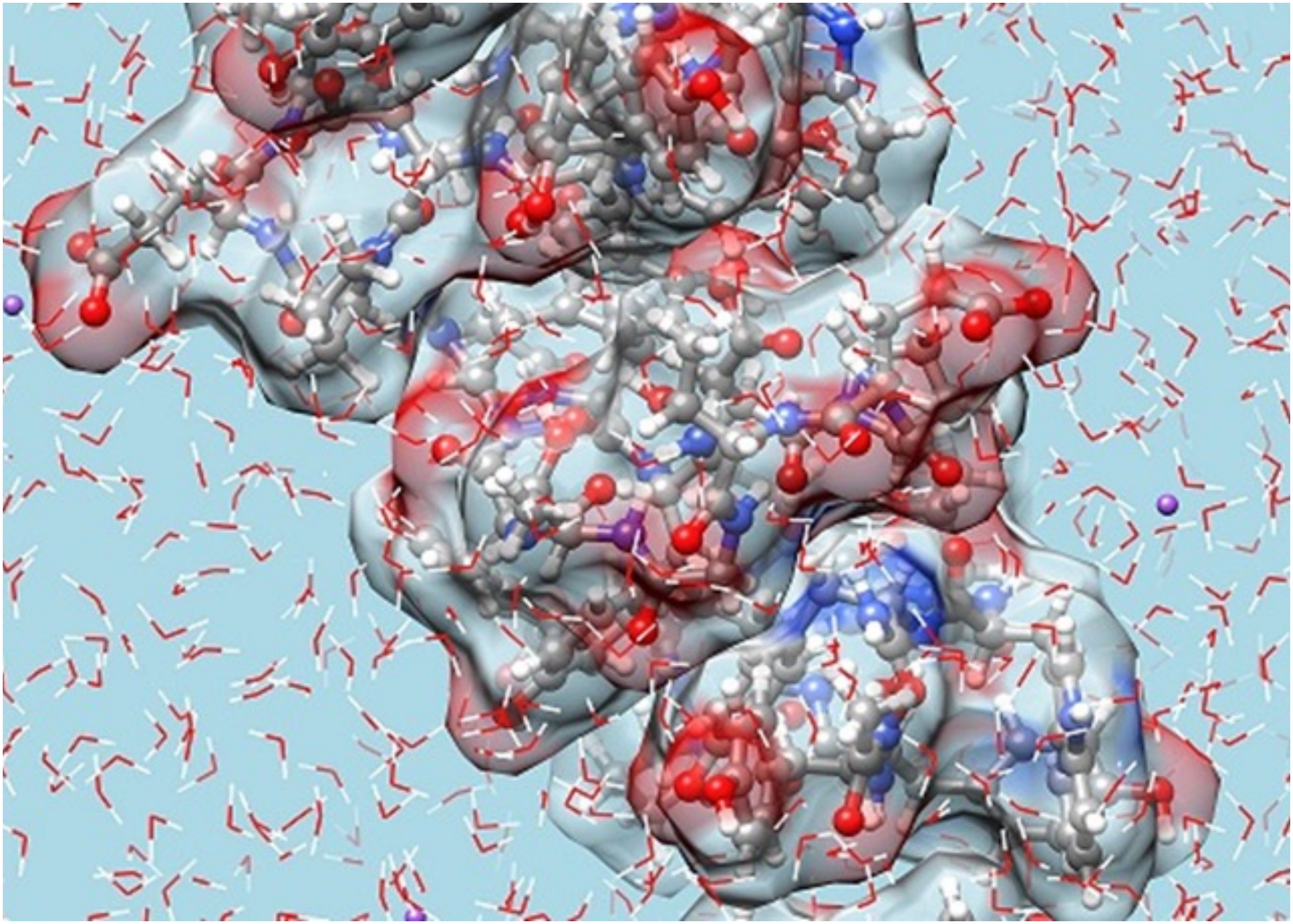




Combining the structural and dynamical information from neutron measurements with high performance computing modelling allows researchers to understand and engineer the performance of new battery technologies: essential for the clean energy transition.

DOI: 10.1039/D1MA00963J

Our ability to study materials at the nanoscale offers great potential for the future engineered design of biomaterials. Here, the multiscale structure of the nanoscale β-hairpin, also known as the 'mini-protein,' CLN025 is visible, with surrounding water molecules represented as wireframes, and sodium ions represented as spheres. Atoms coloured according to elements (carbon – grey, oxygen – red, nitrogen – blue, hydrogen – white, sodium – purple).

Image courtesy of Lorna Dougan, University of Leeds.



Our state-of-the-art technology can be used to understand some of our oldest materials. Here, PhD student Alex Rodzinka uses the Ines instrument to non-destructively study the manufacturing techniques of a 3000-year-old Iranian sword.

## User engagement

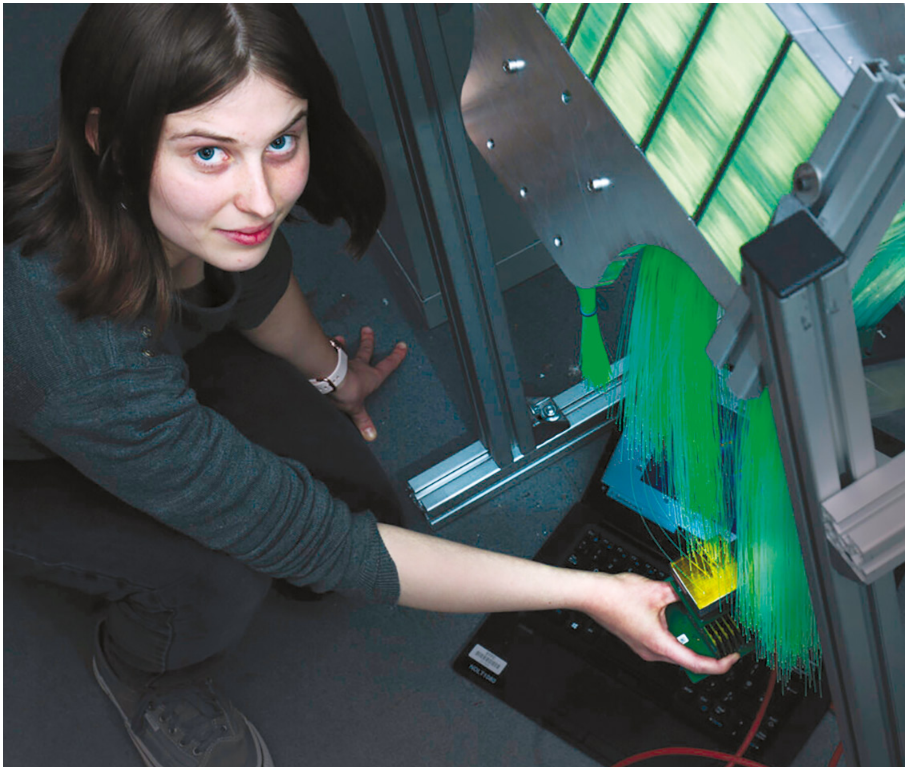
**The impact of the user community has been invaluable towards shaping ISIS to be the facility that it is today. The user community is a driving force, enabling us to push the boundaries of science and we look forward to realising new opportunities and possibilities in the future.**


The 2024 Neutron and Muon Science User Meeting, best known as NMSUM, ISIS's user meeting held annually at the University of Warwick.

> "Our annual user meeting (NMSUM) attracts a significant number of users and provides a valuable forum for sharing scientific advances, consulting, and using the opportunity to engage the user community, providing feedback and consulting them on plans to continually develop ISIS."
>
> **Roger Eccleston**
> Director of ISIS

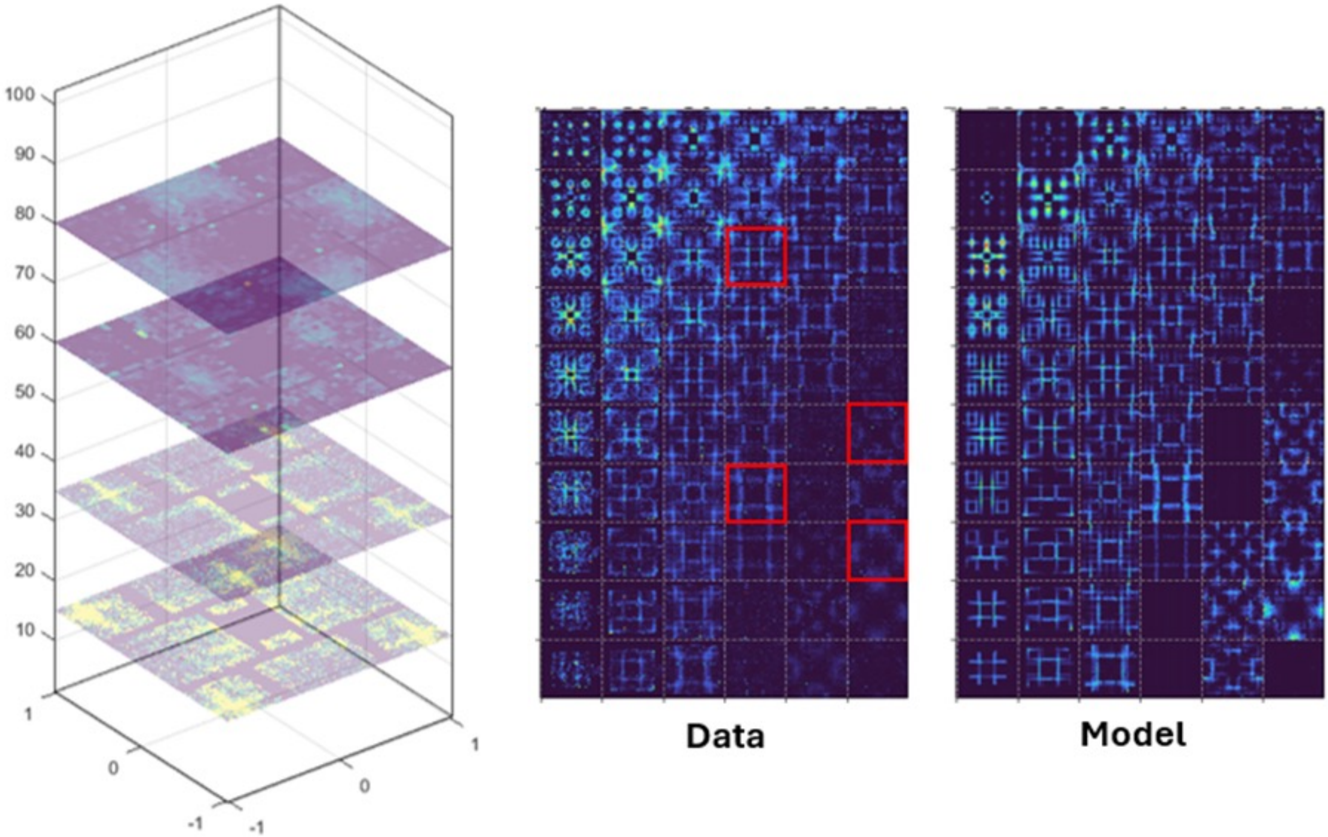
## Instrumentation and enabling technologies

**ISIS has an international reputation as a centre of excellence in the design, construction and operation of advanced instrumentation. We innovate in all areas to provide the research community with the correct tools and the enhanced understanding that follows. To respond to the evolving research challenges, we optimise our instruments alongside all the supporting infrastructure. This includes complex equipment that can place a sample at the very extremes of the physical universe in terms of variables such as pressure, temperature and magnetic field. ISIS continues to benefit tremendously from its location on the Harwell Campus: this proximity to other departments and facilities allows the exchange of ideas and technologies. Future instruments, sources and associated infrastructure have sustainable practices as a key requirement for their design, operation and decommissioning. Reducing the energy consumption of large-scale facilities is a global challenge requiring technology and partnerships across research institutes.**



To advance our capabilities for the user community, we continually develop our technologies. New technologies to more efficiently detect neutrons are an incredibly effective route to higher performance.

Sarah Mann, Detector Systems Group, undertaking quality checks of wavelength shifting fibre detectors.



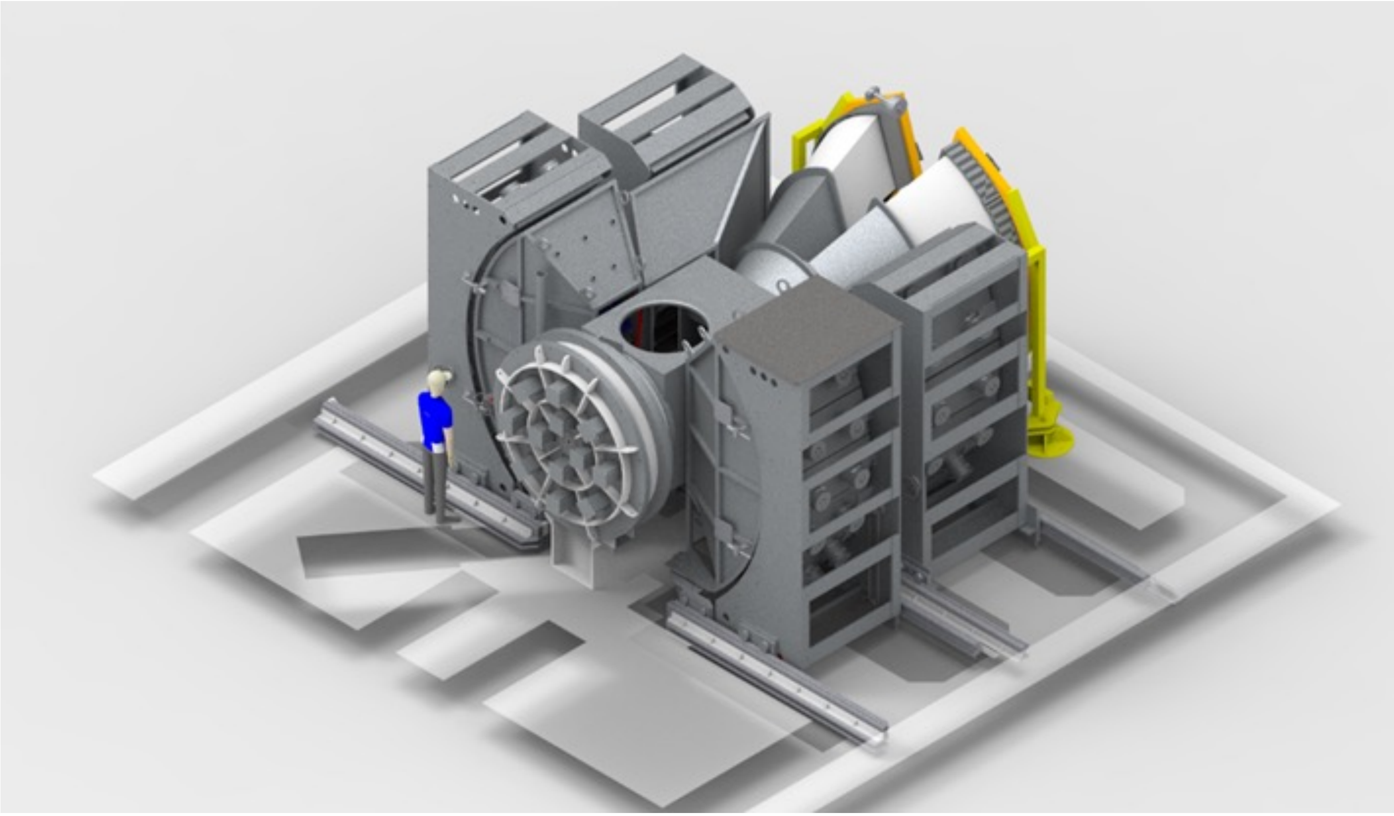

The data volume generated by our instruments continues to grow significantly. To extract the maximum information from these data requires advanced computational techniques. The richness of these data can be used to train the machine learning networks that are so prevalent in society and, in a virtuous circle, help drive the development of new technologies such as quantum computers to analyse the systems we study.

DOI: 10.1088/1361-648X/abea1c

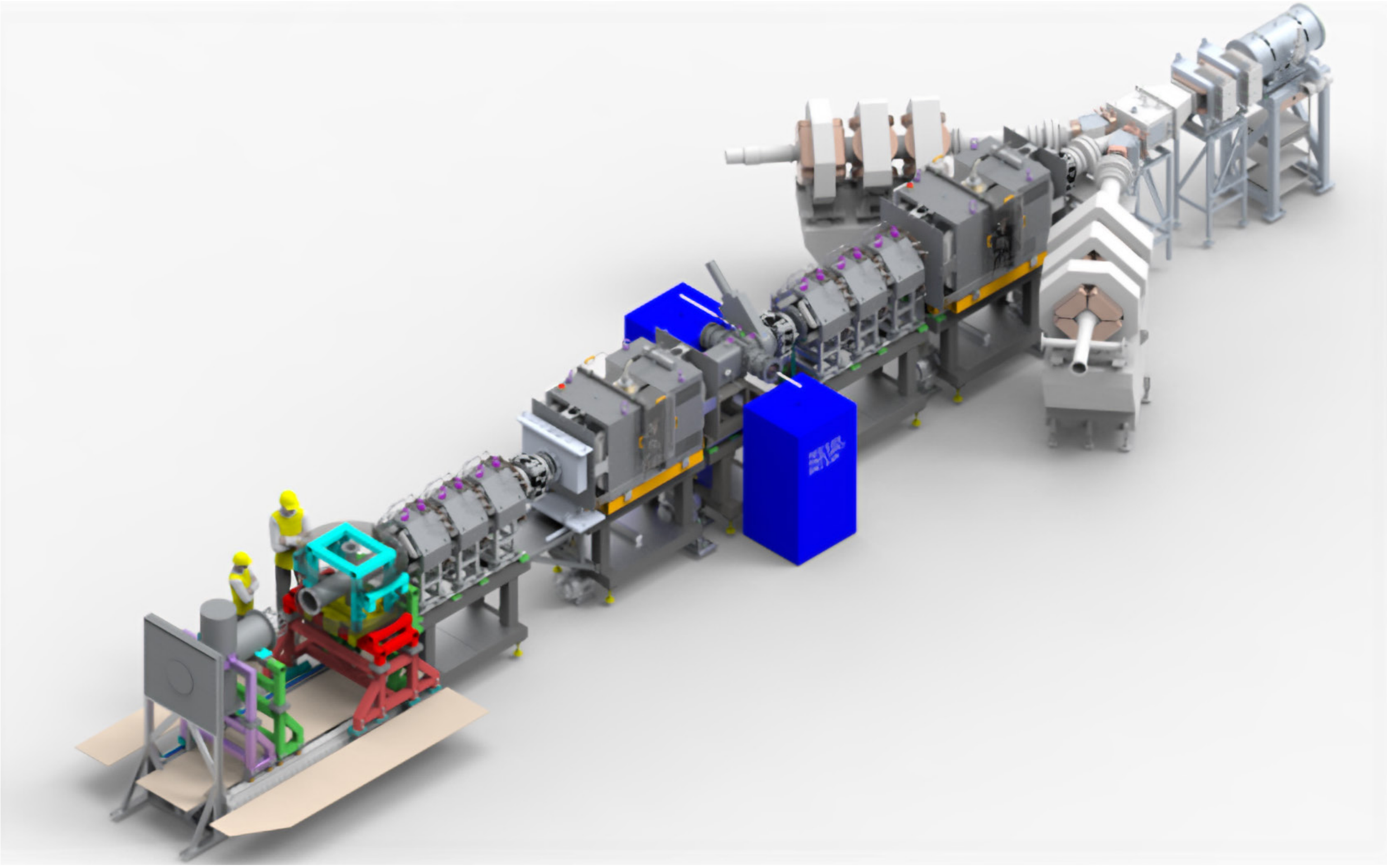
Generating the scientific insight from ISIS requires a very broad range of skills and expertise. This is particularly true as we move through the fourth industrial revolution where machine learning and big data are becoming more significant. At the ISIS Computing Away Day in February 2024, colleagues had the opportunity to discuss ideas and challenges together.

# Endeavour

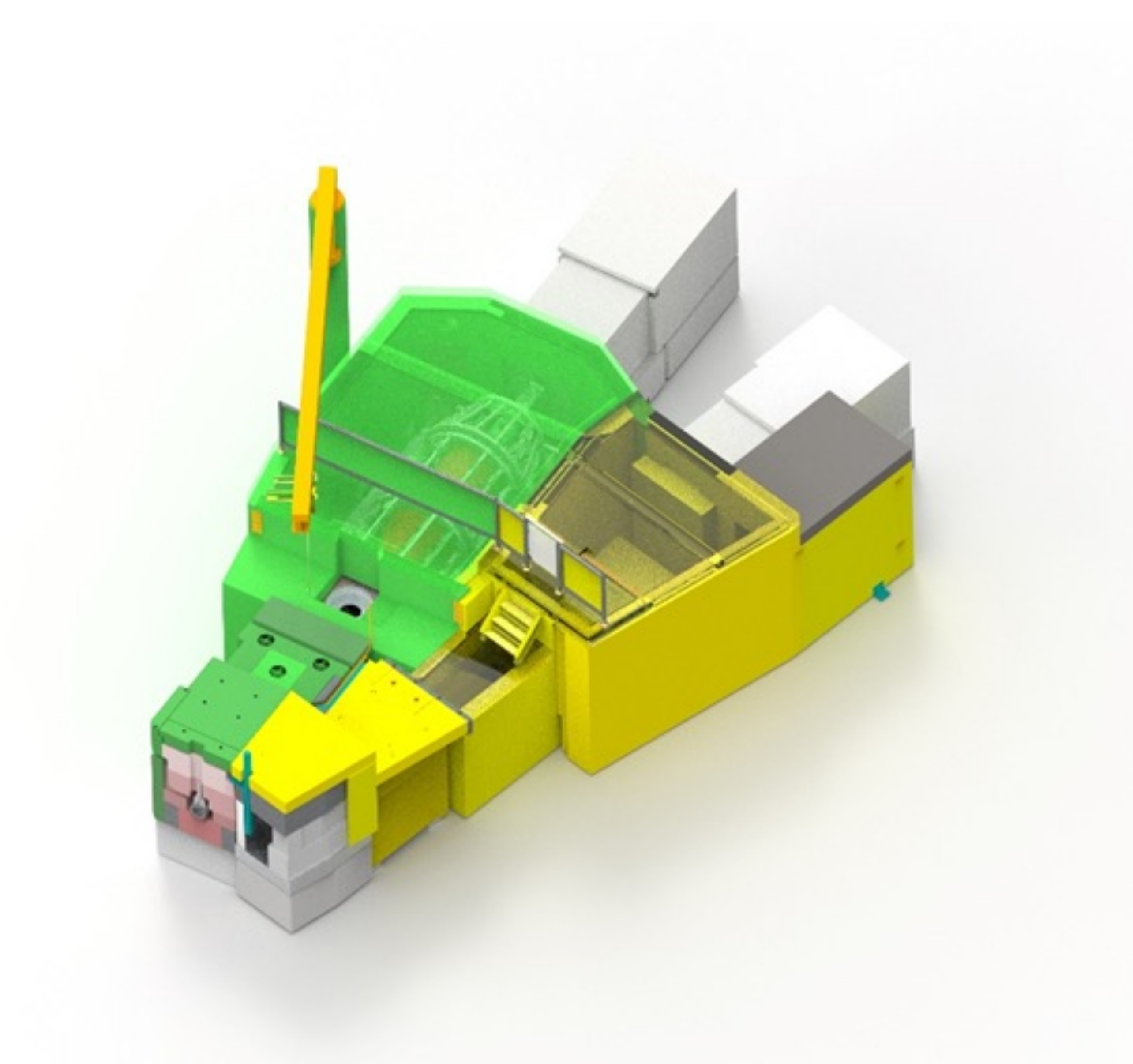
**To match the contemporary demands of discovery science and applied research, a continuous programme of facility instrumentation development is required. Endeavour is a funded ten-year programme of new and significantly upgraded instrumentation that will maintain and extend ISIS's ability to contribute to the most demanding research challenges.**



HRPD-X will keep ISIS at the forefront of high-resolution powder diffraction. This new instrument will provide unparalleled access to smaller and increasingly complex materials, where absolute and precise information is required in order to fully understand their properties driven by subtle changes in their structure.



Super-MuSR will be a major upgrade to the existing instrument as part of Endeavour. Super-MuSR will raise significant technical challenges in areas such as data rate and pulse slicing but promises to transform our ability to study complex materials directly relevant to quantum and battery technologies.

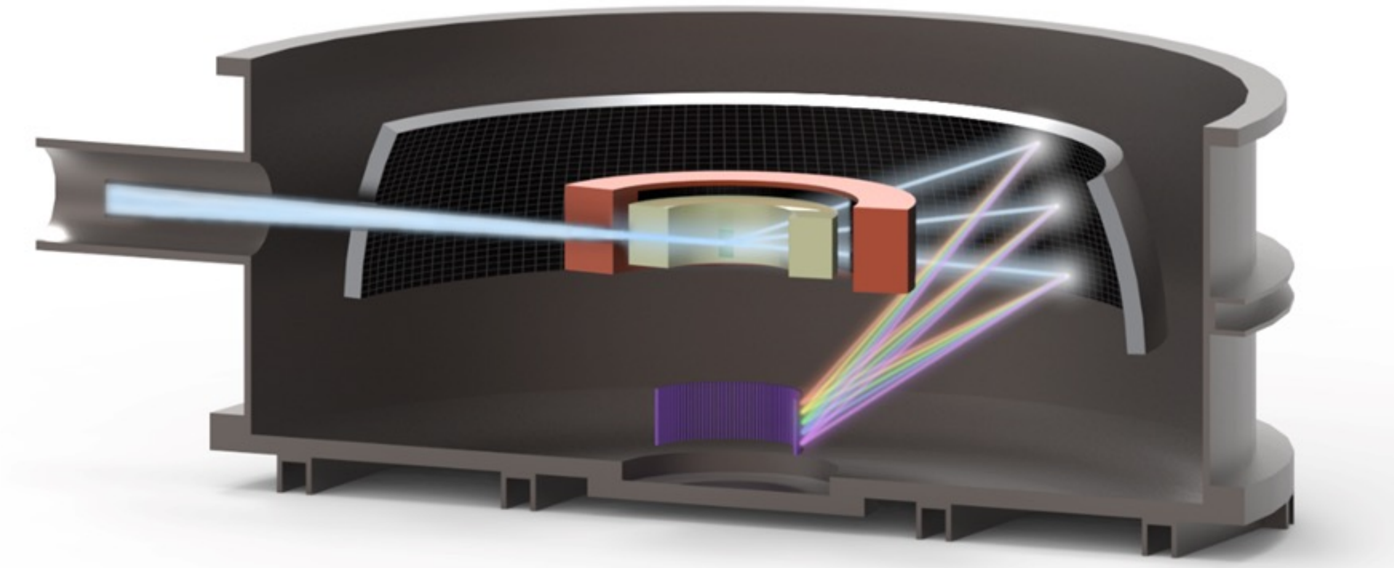


SANDALS-2 will significantly enhance the capability of the existing SANDALS instrument. Increased detector coverage will reduce counting times and allow studies of more complex materials – particularly those that will play an important role in green chemistry.

# Endeavour +

**As Endeavour progresses through to completion, there is still scope to enhance the capacity and capability of the two neutron target stations. Endeavour+ is our next tranche of instrument development that will ensure that the UK community has contiguous access to leading edge neutron and muon research infrastructure. This will fully exploit existing assets and allow them to operate to their full scientific capability.**

Endeavour+ instrumentation builds on technology developments drawn from across STFC and the experience of forty years of instrumentation at ISIS. Innovative designs leverage the digitisation of data and highly efficient parallelised techniques to explore the position and energy of the scattered neutrons.



A schematic of SHERPA, a polarised high-resolution backscattering spectrometer proposed for Endeavour+.

## ISIS-II

**ISIS-II is envisaged as the eventual replacement for ISIS. It will be a MW-class short-pulse spallation source with two target stations providing neutron, muon and proton irradiation facilities.**

Plans are being developed which will mean that, subject to funding, ISIS-II will be ready for construction sometime after 2030 and then operational in the 2040s. This will maintain and enhance the UK's neutron and muon provision, complementary to the other European neutron sources, and continue to provide the UK research community and international partners with world-class capability.

The two target stations will follow the current ISIS model to ensure that a broad range of beam characteristics are available to meet diverse research needs. Gain factors of up to two orders of magnitude will be possible.

## The future of neutron and muon science at ISIS

**Maintaining and expanding the value of ISIS science and technology for the present and future research communities is core to our strategy and requires that we innovate in all areas of our activities: from the source of neutrons and muons through to generating the resultant understanding of our materials world. Within ISIS, we have established a clear roadmap that brings together our skills, source, instruments and enabling technologies to optimise our current facility and to deliver the UK's next generation source.**

An artist's impression of a possible location of the ISIS-II facility, subject to planning permission. Credit: Dominic Fortes and Paul Dobson.

# References

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## Editorial Board



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The 40th anniversary of the first neutrons at the ISIS Neutron and Muon Source provides an opportunity to look back on the remarkable achievements that accompanied the inception, construction and development of ISIS, and look forward to future opportunities and successes. ISIS has a tremendous history of technical innovation and scientific productivity, enabled by strong partnerships and collaborations. Forty years on, ISIS remains in the vanguard of global neutron and muon facilities.

We reflect on these achievements, looking at our origins, development of the machine and target, science, the evolution of computing and data analysis, technical excellence, partnerships and engagement. We also look forward to what the future holds for ISIS, whilst paying tribute to the incredible talent that has made ISIS what is today, sharing stories and memories of all we have achieved together.

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40 Years