National Quantum Computing Centre

Annual Report 2023

From the
Director's desk

Dr Michael Cuthbert, NQCC

With the publication of the National Quantum Strategy, commitment to renewed and growing investments as well as a series of new research calls, 2023 has been a bridging year for the National Quantum Technologies Programme – one of growth, ambition and renewed energy.

A year ago, I reported we had broken ground on our new facility and were looking forward to completion this autumn with commissioning through the winter. 12 months on, progress has been more challenging than originally anticipated. Inflation, labour shortages and supply chain limitations have all played their part to slow our construction programme, with the building now expected to be finished early in 2024. This is counter-balanced by the early completion of our Innovation Hub on the Harwell Campus, which will be at the heart of our collaboration strategy as we expand our activities and technology programme to provide lab space for our growing roster of external collaborations. In parallel, our team has doubled in size in the year, further strengthening our technical capabilities as well as growing our Quantum Readiness, Applications and Project Management teams.

Under the combined heading of the UKRI Technology Missions Fund – a £250m programme across a variety of emerging technologies, including quantum computing – we have collaborated with EPSRC and Innovate UK to support a number of funding calls throughout the year. These have included £6m for "Software Enabled Quantum Computing", £8m for "Feasibility Studies in Quantum Computing Applications" and up to £30m to "Develop and Deliver Quantum Computing Testbeds in the UK". In combination, this programme seeks to drive the demonstration of quantum advantage, an important milestone in the development of quantum computing that will act as a driver for investors and a trigger for user adoption.

The testbed awards will be announced in the coming weeks and I eagerly await our reviewers' feedback. We have been heavily oversubscribed throughout the call, providing further evidence that quantum computing is maturing both as a technology and as an industry. The potential for the NQCC to host multiple state-of-the-art testbeds across a variety of qubit platforms so soon after commissioning our new facility has the team full of anticipation.

At the same time we have invested in classical compute resource to support quantum emulation, and we have secured third-party access to cloud resources to support our industry pilot projects and enable the adoption of quantum computing by the wider research community funded through UKRI. Alongside these initiatives we have continued to build on our SparQ user engagement programme, launched last year, in part through our new partnership with the University of Edinburgh's Quantum Software Lab. We have been working together to integrate our SparQ workflow as we explore new industrial sectors, build new end-user relationships, and explore a range of use cases and their suitability for Noisy Intermediate-Scale Quantum (NISQ)-era computation.

Building a highly skilled quantum workforce is at the heart of the National Quantum Strategy and we continue to play our part in supporting this effort through our technical training collaboration with University of Bristol and the provision of online learning tools, along with hosting summer internships, supporting PhD studentships and supervising STFC graduate placements. All have grown in scale and maturity in 2023.

It has also been a year to support our expanding ecosystem and quantum community with a series of workshops, conferences and hackathons. In January we collaborated with the Institute of Physics to run a Cold Atom Tweezer Array workshop, bringing together key stakeholders to identify how academic research and industry technology could combine to create a powerful roadmap for the UK that will steer the field and continue the rapid progress of recent years. In March we hosted a Scalability Conference that enabled technologists developing superconducting, trapped ions, cold atoms and photonic platforms to share progress and discuss challenges in scaling these technologies in the near-term and the future. In April we celebrated the launch of Quantum Software Lab in Edinburgh, and in July we held our second annual hackathon at the University of Birmingham. With more hackers, more industrial use cases, more third-party providers, and more applications support from the NQCC, we saw not only growth from 2022 but growing excitement at the future potential for quantum computing.

We welcome wholeheartedly the publication of the National Quantum Strategy, and we are clear on how the NQCC will contribute to the UK's vision. We look forward to welcoming the wider community to the NQCC as we open our doors to the new facility in 2024.

On behalf of the leadership team, I welcome this third annual report of the NQCC and thank our funders, our advisory boards, our collaboration partners and our growing team for their support and hard work throughout the year.

UKRI National Quantum Computing Centre

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Welcome to the NQCC

Building on the National Quantum Technologies Programme and the £1bn investment over the past decade, the UK's National Quantum Strategy was published in March. This commits £2.5bn of investment over the next 10 years, with a vision for the UK to be a world leading quantum-enabled economy.

Quantum computing has the potential to unlock unprecedented parallel processing, creating a step change in computing power, but our effort is part of a global race with significant international investment in hardware, software and skills. Recruiting and retaining top talent is of key importance. The long-term impact of quantum computing on society and the economy is potentially huge, with a projected global market of $450–850bn annually over the next 15 to 30 years.

Building on the investments made in enabling science, the National Quantum Computing Centre (NQCC) is being established on the Harwell Campus with an initial investment of £93m over five years by UK Research and Innovation (UKRI) and supplemented in 2023 with a further £41m of programme funding. The primary purpose of the NQCC is to fill a key gap in the research and innovation landscape, addressing the challenge of scaling quantum computing.

The NQCC's first five years will focus on demonstrating the capabilities of Noisy Intermediate Scale Quantum (NISQ) platforms. The initial technology focus of the NQCC has been to develop superconducting and trapped-ion hardware, with prototype projects underway since 2021, while we are also now assembling a technical team to develop cold-atom tweezer array quantum computing.

The NQCC will give assured and direct access to developers and promote the formation of a strong UK-based quantum computing supply chain, whilst driving efforts towards a universal fault-tolerant quantum computer.

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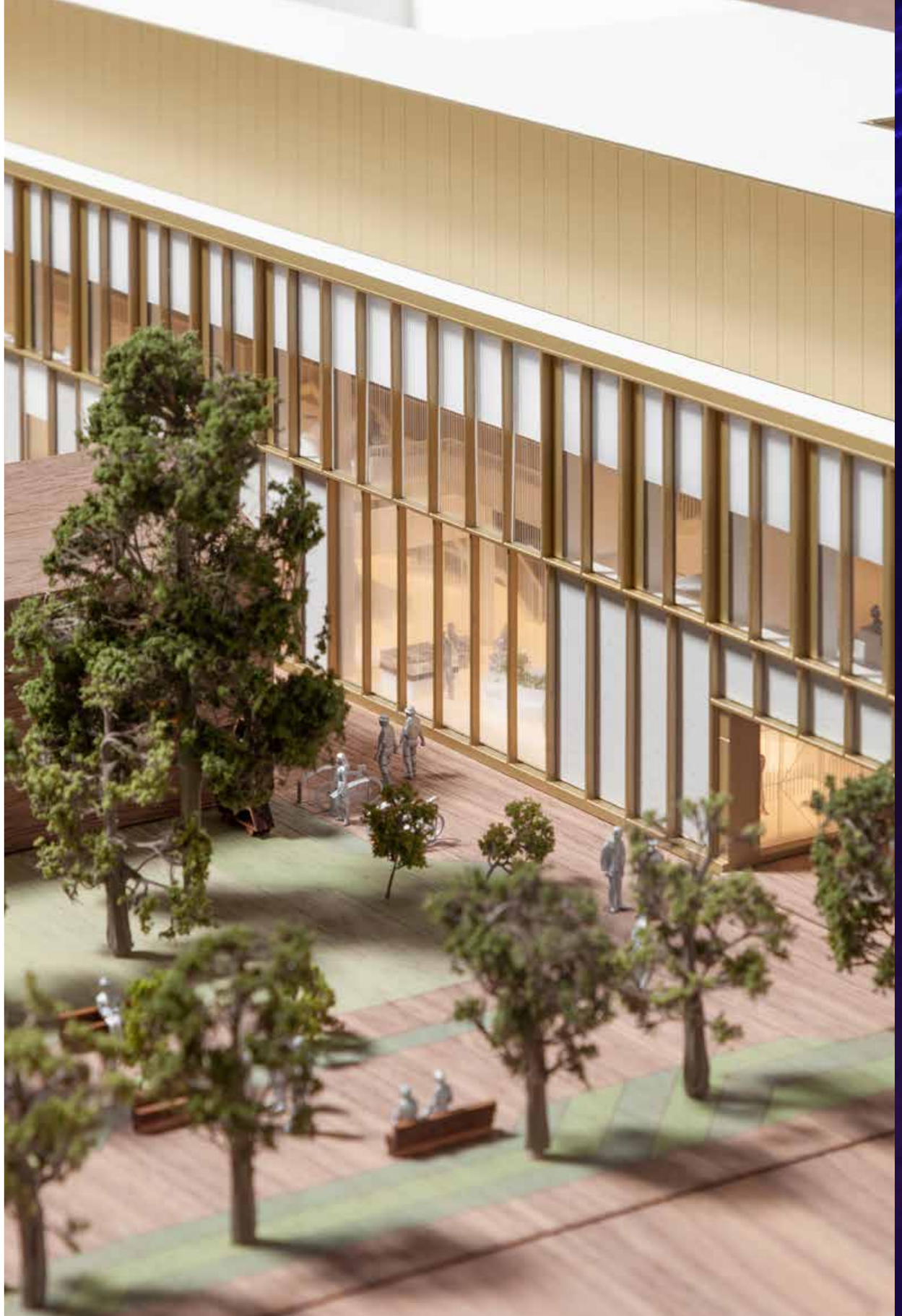

NQCC's Mission and Vision

Our Vision

As a trusted authority, our vision is to enable the UK to solve some of the most complex and challenging problems facing society by harnessing the potential of quantum computing.

Our Mission

In order to realise our vision, the NQCC is focusing on three key areas: technology development, quantum readiness, and establishing a state-of-the-art quantum computing infrastructure. We act responsibly, as an independent and objective trusted authority, both nationally and internationally, across these areas.

To drive effective technology development, we are building, testing and hosting first generation quantum computers, collaborating on innovative and diverse solutions to meet the key challenge of scaling. We address the whole quantum computing stack; hardware, software, and user applications. We own and are evolving the UK's quantum computing technology roadmap, which will guide our journey from the Noisy Intermediate-Scale Quantum (NISQ) computing era towards universal fault-tolerant quantum computing. To ensure the UK as a quantum-ready nation, we are facilitating the user journey from awareness to advocacy.

To establish a state-of-the-art quantum computing infrastructure we advocate for, and invest to build equipment and facilities to deliver an assured, secure, sovereign capability. We are creating the environment and space to inspire talented people to collaborate and innovate, ensuring UK leadership in this pioneering area. As the focal point of UK quantum computing, the NQCC anchors activities across the nation.

Meet the **Leadership Team**

Dr Michael Cuthbert, Director

With a background in superconductivity and cryogenic systems, Michael has had a number of technical and commercial leadership roles with Oxford Instruments in Japan, US and the UK, most recently as Head of Quantum Technologies. Michael is a member of the Institute of Physics, sits on several advisory panels, including the NQTP Programme Board and is an Aegis Professor in Quantum Technologies at the University of Bristol.

Professor Elham Kashefi, Chief Scientist

Elham is Professor of Quantum Computing at the School of Informatics, University of Edinburgh, and Directeur de recherche au CNRS at LIP6 Sorbonne Universite. She co-founded the fields of quantum cloud computing and quantum computing verification and has pioneered a trans-disciplinary interaction of hybrid quantum-classical solutions from theoretical investigation to actual experimental and industrial commercialisation.

Ash Vadgama, Deputy Director for Operations

Ash has worked within High Performance Computing for almost 35 years for UK Government. Ash started his career as a computer scientist developing scientific software on early vector supercomputers, then led early developments in secure Linux clusters, various emerging technologies, Petascale HPC systems and resilient data centres, whilst also collaborating with US national laboratories and other international partners, later moving into Business Leadership, HPC programme and financial management.

Dr Simon Plant, Deputy Director for Innovation

Simon's technical background spans quantum nanomaterials, nanophysics and quantum sensors. He has led work across various roles in research, government and the public sector to drive the development and commercialisation of quantum technologies (QT) and support the growth of the industry. He was previously the technology lead at Innovate UK responsible for shaping and implementing the UK's innovation strategy for QT.

Anne-Claire Blet, Deputy Director for Programme Delivery

Anne-Claire has extensive experience in large-scale complex programmes across both the public and private sector, as well as having commercial experience in the UK quantum industry. Anne-Claire previously worked at the United Nations as part of its Sustainability Programme supporting strategy, policy and programme delivery. She went on to join the start-up what3words as Director of Strategic Partnerships before becoming the Chief Operating Officer at Oxford Quantum Circuits.

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NQCC programme: **At a glance**

"By adopting an evidence-based approach for evaluating the outcomes of our programme, we can celebrate our successes, ensure that the NQCC is accountable, and build trust in the organisation.

Dr Sushma Tiwari,
Programme Evaluation Manager

4
In-house QC technology platforms

High Performance Computing, Trapped Ion, Superconducting and Cold Atom Tweezer Array hardware capabilities in development at the Harwell Campus.

9
Proof-of-concept project funded under the Highlight Call on Quantum Computing.

Nine proof-of-concept projects funded with >100% match funding from participating organisations.

5
Facilities to house high-specification laboratories

State-of-the-art laboratories capable of hosting multiple quantum computing platforms across a variety of modalities.

2
NQCC-run technical conferences and workshops

The NQCC organised two technology-focussed events, engaging more than 150 participants on topics related to the roadmap for quantum computing.

>900
Outreach / public engagement

Over 900 individuals have interacted with the NQCC through our public engagement and outreach activities.

2
NQCC's UK Quantum Hackathons held annually

Over 100 hackers (primarily Masters, PhD and post-docs), 8 quantum computing providers and 13 user organisations have participated across the two Quantum Hackathons.

57
Team size

Includes 12 international hires, 60% are directly involved with development and deployment of quantum computing.

4
Memorandums of understanding signed so far

Memorandums of understanding signed with QCS Hub, Oxford Quantum Circuits, University of Edinburgh and NPL to enable quantum readiness and develop the UK eco-system.

An update on the NQCC's
Programme delivery

The NQCC is leading an ambitious programme of activities aimed at driving technical innovation and stimulating the growth of a quantum-ready economy, and over the last year we have made significant progress against all of our strategic objectives.

Key achievements have been made in workstreams spanning technology development, building quantum readiness across the public and private sectors, and the provision of state-of-the-art facilities to build, host and operate quantum computers. These range from establishing our first experimental system for ion trap quantum computing through to workshops with the financial and life-science sectors that have identified opportunities for collaboration. We have also explored use-cases where quantum solutions could offer a computational adavantage in future.

Other notable highlights include the launch of the Quantum Software Lab at the University of Edinburgh, a major call for proposals that will invest £30m to establish a series of quantum testbeds, and engagement with the wider community through our second quantum hackathon and other high-profile events. We are also excited to report that the construction of our main facility is nearly complete, with commissioning expected to be finished by spring 2024.

To support these diverse activities we have been building a team of talented individuals who are passionate about quantum computing and its potential to transform our world. We now have almost 60 people who are working to deliver our wide-ranging programme, and we are continuing our recruitment efforts with a focus on technical roles.

Technology

Demonstrate a practical quantum computer with more than 100 qubits, operating in the noisy intermediate-scale quantum (NISQ) regime

Infrastructure

Deliver a landmark facility that provides the infrastructure for researchers, technology providers and end-users to collaborate on the development of quantum computers and applications

Quantum readiness

Drive knowledge exchange between quantum developers, technology providers and end-users in both industry and academia

Workforce

Building a talented team of individuals who are passionate about quantum computing and its potential to transform our world

- **JAN. '23** — Signed MOU with the National Physical Laboratory to collaborate in the field of quantum computing.
- **FEB. '23** — Launched NQCC's online quantum skills course using Q-CTRL's Black Opal.
- **FEB. '23** — Announced £8m of funding for a competition to develop industrial applications of quantum computing.
- **MAR. '23** — The UK's National Quantum Strategy announced £2.5bn investment emphasising NQCC's role towards national efforts.
- **APR. '23** — Opened the Quantum Software Lab at the University of Edinburgh.
- **JUN. '23** — Announced £30m of investment to commission the development of quantum computing testbeds in the UK.
- **JUL. '23** — Appointed Anne-Claire Blet as the Deputy Director for Programme Delivery.
- **SEP. '23** — Launched a new website to better engage with the stakeholders and drive awareness.
- **OCT. '23** — Announced partners to provide secured quantum computing access for the UK users to drive R&D.
- **OCT. '23** — Opened a new Innovation Hub at Harwell campus as a dedicated facility for collaborative R&D.

Technology: Trapped ions

Dr Cameron Deans, Trapped Ions Hardware Development Manager

"Over the last year our team has greatly accelerated both our collaborative and internal work. We have designed, built, and tested several of the key subsystems for our first ion trap measurement and will soon begin testing the fully assembled system."

We have been designing and building our ion trap system, with a trap supplied by Ion Trapping Quantum Computing Research Group at the University of Oxford, and are ready to test the fully assembled hardware set-up.

Trapped ions are a focus for the NQCC because they offer a mature and well characterised platform for quantum computing. Their long-lived quantum states provide high fidelities and long coherence times, which make it possible to create high-quality qubits that perform accurate logical operations. Since atoms are identical and reproducible, they also offer the potential of all-to-all connectivity between large assemblies of identical qubits.

While we have been establishing our experimental programme we have been working with academic and industry partners to guide our technology development and to engage in a range of collaborative R&D projects. We have also grown our experimental team, with two new ion trap physicists joining us early in the year to bring our total to eight.

Our experimental efforts have been underpinned by the temporary lab space we have secured on the Harwell Campus. Cross-STFC collaborations have enabled access to specialist expertise and facilities on site, including cleanrooms and engineering support.

We have successfully bonded and mounted our first ion trap chip, while the team has procured and installed key pieces of experimental equipment such as optical tables, laser systems, and two cryogenic vacuum systems. Assembly of our first ion trap system is nearing completion.

Alongside our initial experimental work, we have been procuring the major items we will need for our dedicated laboratory space in the main NQCC building. This will allow us to expand our experimental programme, and we will shortly be fitting out the lab in partnership with our industry and academic collaborators. We are also continuing to contribute to the UK's wider quantum ecosystem via our ongoing collaborations exploring miniaturisation and ion trap packaging, ion-photon interfacing and device networking. We continue to build new connections, with a number of joint proposals submitted to expand our programme of R&D projects.

Key milestones achieved:

- Completed modular engineered rack assemblies for all in-lab-fibre laser light delivery
- Completed trapped ion interface and cryo-vac assembly with gate voltage electrode wiring and in-vacuum optics delivery.

NQCC's ion trap physicists setting up the lab.

Technology: Superconducting circuits

Dr Vivek Chidambaram, Superconducting Hardware Development Manager

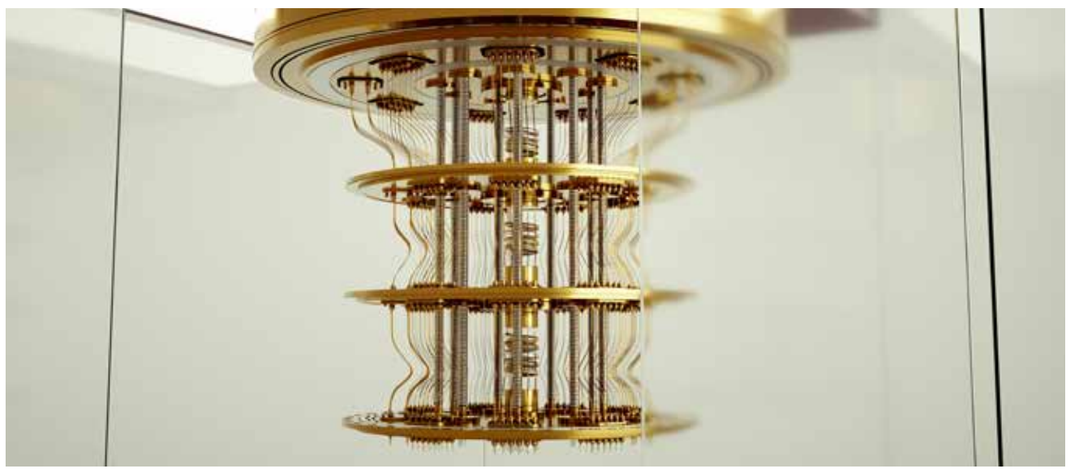
"Engaging with the community is really important for us, ensuring we are briefed on the latest research results and creating opportunities for collaborations to develop."

Superconducting circuits are one of the most mature qubit architectures, since they support long-lived quantum states, make use of established nanofabrication techniques, and can easily be connected together to create multi-qubit systems. At the NQCC our initial work has focused on building our core team, procuring key pieces of experimental equipment, and making connections within the wider research community.

One major activity over the last year has been to grow our technical team, with broad research experience across superconducting circuit experiment and theory. Recruitment is continuing, with the aim of doubling the team over the next six months or so.

As the team has become established our initial focus has been on laboratory and equipment specification as well as the necessary procurement activity to put this infrastructure in place. Our initial procurement has been dominated by dilution refrigerators, radio-frequency electronics, test equipment and commercially available qubit control systems. In parallel, we have been working to design and specify all of our signal conditioning input/output control architecture.

A key activity during this planning phase has been to develop connections with the wider research community, with team members visiting different labs to understand current best practice and discuss possible experimental approaches. That has helped us to make some flexible choices about the components and wiring in our initial set-up, which will allow the team to gain more experience of the equipment and the experiments before we make any decisions on further specialisation. We have also been attending and presenting at various conferences, which together with the lab visits has helped to raise the visibility of the NQCC as a centre for superconducting circuit research and innovation.



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Technology:
Cold atom tweezer arrays

Dr Nicholas Spong,
Hardware Engineer

"Cold atom tweezer arrays have been making substantial progress in the past 24 months. Having gathered comprehensive evidence, the NQCC is initiating a new programme of work to bring together a team of experts in support of ensuring this will be an important technology for the UK."

This new initiative on cold atom tweezer array quantum computing (TAQC) was informed by extensive engagement with all UK stakeholders who have an interest in neutral atomic and molecular quantum computing. We started with some initial landscaping work with the research community and the commercial sector, which generated so much positive feedback that we took the opportunity to organise a high-profile workshop on TAQC in January 2023.

As well as bringing together the UK community, the workshop enabled international experts who had been invited from leading organisations in academia and industry to offer advice and share knowledge. The outcomes from the workshop highlighted the need to strengthen the UK's capability in TAQC, with a consensus among the attendees that the NQCC can provide a focal point for the development of tweezer array hardware platforms in the UK.

This programme will focus on five key themes:

Building, owning, and operating tweezer array quantum computers: The NQCC will take a leading role in the construction of a state-of-the-art platform for TAQC, and we are currently recruiting a team of highly qualified quantum physicists to drive this vision forward.

Third-party systems: The NQCC aims to accelerate the UK's endeavours by including TAQC platforms in the call for quantum testbeds being administered through the Small Business Research Initiative (SBRI). Further, the NQCC is securing access to commercial cloud-based quantum computers to enable near-term applications development on TAQC platforms.

Dedicated benchmarking and applications development: We have recruited two new team members who are working across our innovation and hardware teams. These two new roles support cross-functional applications development and benchmarking for analogue quantum computers, with a special focus on tweezer arrays.

Community support and roadmapping: We will continue to engage with the quantum computing community to enable knowledge sharing, collaboration and innovation, and to help define the NQCC roadmap for the development of TAQC.

Collaborative projects: The delivery of the roadmap will be supported through joint projects aimed at stimulating the quantum computing supply chain, driving innovation, and creating a robust ecosystem.

Technology:
Software & control systems

Dr Tim Boyle,
Software and Control Systems Development Manager

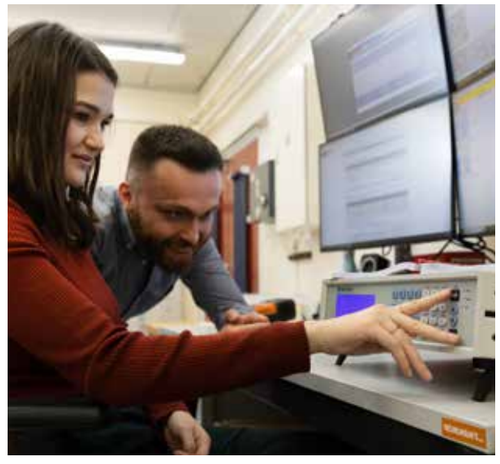
"This year we have focused on building both the size and capabilities of the team, and I am really impressed with the progress we have made. We have been exploring and proving the software elements required to implement a full quantum stack, and I can't wait to make the complete system available to internal users."

The software and control systems group maintains and develops software that ranges from the control of quantum computing hardware through to providing quantum programming platforms for application engineers. Our current focus is on building real-time control systems for the hardware platforms being built by our internal teams, and on establishing a quantum emulation system that will run on the in-house high-performance compute cluster.

This year we have been working to build up our software stack, in particular to establish the architecture needed to link the applications layer down to the hardware platform now being built by the ion trap team. After developing a proof-of-concept, we created a front-end portal that is linked into our benchmarking tool as well as to Qiskit, an open-source development kit for running applications on quantum platforms. This core software provides a flexible architecture that allows us to access a wide range of middleware, enabling us to interface with different systems and hardware platforms.

Over the last year we have also engineered a complete control system for the ion trap team, with the racks of equipment now installed in the lab and starting to be used for everything from data collection and monitoring through to qubit control. Our solution is based on ARTIQ, an open-source framework that to date has mostly been used in academic environments to run experiments from a single computer.

Our aim was to create a cloud-based infrastructure that can be accessed by everyone in the team, which has required us to develop a more robust framework and to set up additional processes to enable the system to operate on a secure network. Now that we have a working solution in place, we have commissioned an external audit by a consultancy that specialises in cloud-native environments. As well as providing some external validation for our solution, we hope that they will provide some advice and feedback to help us to refine our approach and identify other technology options that could be deployed on the system.



Physicists at the NQCC's first quantum computing lab.

People:

A day in the life of a researcher

"In my opinion the most difficult challenge we face is producing entangled states between arbitrary qubits while still maintaining high fidelities."

Dr Jessica Powell,
Superconducting Qubit Physicist

As a new member of the superconducting circuits team, I am working to translate my knowledge of spin qubits and high frequency readout control mechanisms to superconducting devices.

My initial focus has been on identification and procurement of control electronics and developing the necessary software scripts in preparation for our first qubit measurement.

I'm excited for the year ahead, particularly the prospect of moving into the new NQCC building and working with my colleagues and external collaborators to tackle the challenge of scaling up quantum processors. In my opinion, the most difficult challenge we face is producing entangled states between arbitrary qubits while still maintaining high fidelities.

Overcoming this technical challenge will open up some exciting opportunities for quantum computing, and I hope to be a part of a team that produces a scalable and workable solution.

"As a researcher in quantum control systems, each day unfolds as a captivating journey in the realm of cutting-edge technology. I enjoy implementation and testing of control algorithms, delving into experimental designs and intriguing topics."

Manish Chowdhary,
Software Engineer

I design and optimise control algorithms for quantum systems, working closely with experimentalists, analysing results, and advancing control methodologies. Interdisciplinary collaboration with physicists, engineers, and computer scientists is a pivotal part of my work.

My journey from contributing to the IBM Summit supercomputer project to pursuing an MS in physics at UW-Madison led me to the captivating world of quantum computing. The boundless potential, coupled with a thirst for continuous learning, keeps me deeply engrossed.

In my view quantum computing is brimming with promise and challenges. While it remains uncertain when we'll achieve quantum computers capable of solving complex problems, the human ingenuity that fuels progress will yield remarkable outcomes in physics and computing.

I think that decoherence poses the paramount challenge in realising quantum computers. Addressing error correction and developing materials that can support stable qubits with prolonged coherence and high-fidelity operations will be critical for success.

The coming year promises intense R&D dedicated to the pursuit of efficient control strategies for quantum systems.

People:

A day in the life of a researcher

"These remaining challenges will need engineering innovation rather than the discovery or implementation of new physics."

Dr Scott Thomas,
Ion Trap Physicist

As an ion trap physicist, my key responsibilities are to assemble and operate our first hardware system, as well as any future ion trap systems that our team will build. My main focus is on the laser systems that are needed to control and cool the ions, initialise and read out the quantum states, and in certain schemes to perform qubit gates.

I am currently working to characterise the lasers and configure them for frequency locking, and soon I will take part in a collaborative R&D project with the National Physical Laboratory's Ion Microtrap team.

In trapped ion quantum computing, the fundamental issues of addressing and controlling the individual qubits in traps with small numbers of ions have largely been solved. In my opinion, the main challenge now is to increase the number of qubits to achieve useful levels of computation or simulation. Once scaled up, we will also need to devise new ways to address individual qubits or specific subsets of them.

I enjoy working with ion trap systems because they require a great diversity of skills and knowledge to assemble and operate, including lasers and optics, electronic systems, and atomic physics. Interesting challenges and opportunities emerge from the intersection of these fields when attempting to use them for quantum computing.

"To scale the number of qubits we will need to look beyond the device and rethink the way we operate superconducting quantum processors".

Dr Kitti Ratter,
Superconducting Qubit Physicist

I joined the NQCC's superconducting circuits team in May 2023, bringing the experimental and technical expertise I have gained from working on various superconducting devices over the last decade.

My immediate focus is to help preparations for moving into our dedicated laboratory space. Specifically, I am responsible for designing and procuring the low-temperature equipment for the experimental setup of our dilution fridges. For the longer term, I am learning simulation techniques that will enable me to design bespoke superconducting qubit devices for future experiments.

The year ahead is going to be exciting for the superconducting circuits team. Once we have our own experimental space we will be able to start characterising our first quantum bits. I am very much looking forward to reaching this first milestone with my colleagues and collaborators.

In my opinion the biggest challenge we face in our field is scaling the number of qubits. Overcoming this challenge will require much more than a clever, modular device architecture. We will need to look beyond the device itself and rethink the way we currently operate superconducting quantum processors. I believe we are well placed at NQCC to tackle such a challenge, and I am excited to be part of this endeavour.

Infrastructure:

Facility – progress and milestones

Following the construction of the NQCC facility's structural frame during 2022, progress is now firmly focused on the internal fit out of plant, office space and laboratories. The experimental spaces are well advanced with optical tables and fume cupboards recently installed, to enable connection into the building mechanical ventilation systems.

Plant commissioning of the building and laboratory mechanical and electrical systems has commenced. Integration of the new building with the campus power and data networks is also well underway.

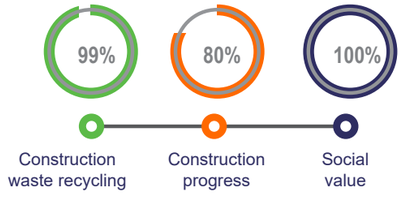
Handover of the completed building is planned for early 2024, with scientific commissioning of the laboratory spaces to follow.

To date, the NQCC construction works have delivered £1.22m of social value benefit. Employment and skills initiatives associated with the project during construction have directly benefitted 54 people from the local community. 29 people have been employed as a result of the construction project, which includes 7 apprentices.

Recycling during the building project remains high, achieving 99% recycling of all construction waste produced.

The NQCC building is on target to achieve its primary sustainability objectives:

- Achieve a BREEAM rating of "Excellent" for the completed building
- Achieve a 40% reduction in regulated CO_2 emissions during operation
- Support UKRI and EPSRC in meeting the government's Net Zero policy objectives.



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NQCC facility construction, opening in 2024.

Infrastucture:

NQCC Innovation Hub opened for collaborative research

"Over the past year we have been focussing on plant commissioning and systems infrastructure to help the NQCC drive our technology goals"

Ash Vadgama,
Deputy Director for Operations

Delivering the infrastructure that enables our technologists to create amazing science is at the core of the Operations team's purpose. We have enjoyed incredible support from STFC Estates, Procurement and Legal colleagues as well as our construction partners to support the delivery of our new facilities and the capabilities housed therein.

Our laboratory space has been designed to give us flexibility over time as the technology develops and scales. This design intent has created challenges throughout the construction process, particularly on air handling, ambient temperature control and power management.

Alongside, the main facility we have fitted out and brought temporary lab space online within existing STFC laboratories for both the Trapped Ions and Control Systems teams. This has been instrumental to ensuring our technology programmes have been able to ramp up ahead of the facility being completed. Furthermore we have completed our Innovation Hub accelerating lab and collaboration space in support of the testbed call and our numerous collaboration projects.

The Operations team have also been procuring and installing classical HPC compute resources enabling simulation and emulation tools development as well as ensuring long-term software and control system capabilities across all our technology platforms.

"We will be populating this space in the coming weeks with supporting hardware. This is an exciting stepping stone ahead of the NQCC opening in 2024."

Chris Pulker,
Facilities Manager

Our first facility, the NQCC Innovation Hub, is complete, which will extend our footprint for hosting the development and operation of quantum computing testbeds. This will provide a base for driving our collaborations with industries and businesses, and accelerating our programme delivery, ahead of the completion of our main facility in 2024. The Innovation Hub comprises lab space, collaborative offices, and meeting space.

Optics and Cryogenics lab spaces at NQCC Innovation Hub.

Infrastucture:

Quantum simulator

"We have created and tested a transpiler that converts an input written in Quantum Assembly Language into a QuEST script, while we also plan to extend the capability to run simulations using GPUs"

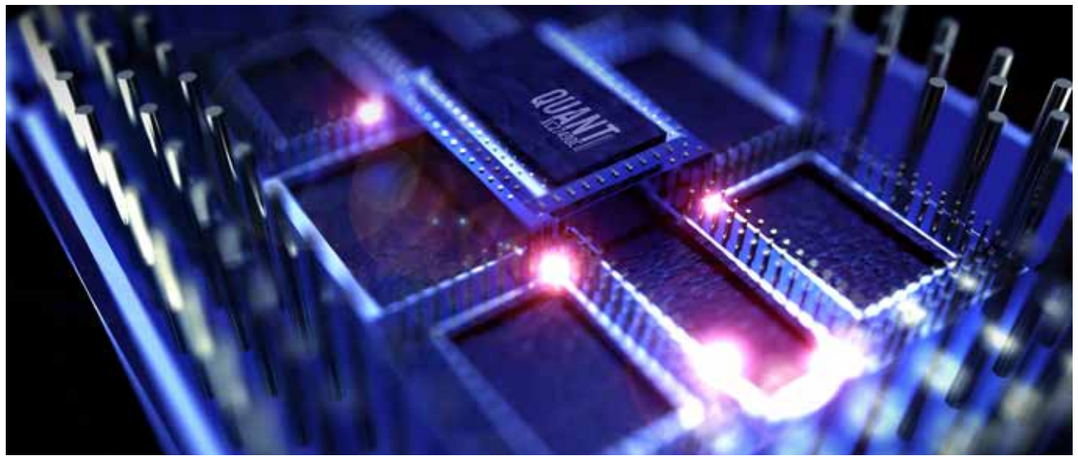
Dr Aneirin Baker.
Hardware Engineer

We are currently working to implement a software package for simulating quantum circuits on our own high-performance compute cluster on the Harwell Campus. These quantum simulators enable a classical computer to run quantum circuits in the same way as a quantum machine, providing a valuable tool for developing quantum algorithms, debugging circuits, and analysing the quantum processes that take place during a computational task.

We are developing the Quantum Exact Simulation Toolkit (QuEST), a distributed software program developed at the University of Oxford that leverages the power of GPUs to simulate quantum circuits quickly and efficiently. While most simulations of quantum computers require a significant amount of memory and processing power, the use of GPUs enables QuEST to produce results more rapidly while requiring less compute resource than comparable packages.

We plan to use QuEST to build noise models for our hardware platforms, allowing us to better understand their performance and to scale more efficiently from small-qubit machines to processors with more than 100 qubits. Having an accurate noise model will also enable external collaborators to simulate business cases and algorithms using a classical computer, providing a better understanding of the challenges faced by early-stage hardware platforms.

A number of objectives have been identified to optimise QuEST for use within the NQCC and by external partners. We have already created and tested a transpiler that converts an input written in Quantum Assembly Language (QASM) into a QuEST script, while we also plan to add the capability to run simulations using GPUs.



Quantum readiness:

SparQ user engagement programme

SparQ is the NQCC's flagship programme for user engagement, providing the entry point for organisations to explore and exploit the emerging capabilities of quantum computers. The NQCC is engaging with users in government, business and the research community to build awareness, provide networking opportunities to build a strong user community within the UK, and identify applications where quantum computing can offer most value for industry and society.

SparQ builds quantum readiness by supporting the pathway from "awareness to advocacy", allowing end users in academia and industry to build familiarity, evaluate the technology, and make the case for quantum computing within their organisations.

Access	Expertise	Networking	Skills
Access to quantum computing resources	Technical expertise and applications support	Networking, workshops and hackathons	Skills development and learning resources

Access to quantum computing resources

Access to quantum compute resources is a key enabler to support proof-of-concept projects, collaborative R&D, quantum hackathons, and more. In 2022, Oxford Quantum Circuits was announced as the first principle provider of quantum compute resource to the **SparQ** programme, while the 2023 quantum hackathon involved seven different technology providers.

Technical expertise and applications support

SparQ provides end users with opportunities to work with emerging quantum algorithms and hardware, allowing them to build their skill-sets and gain an understanding of the current and future capabilities of quantum computers. Through collaborative R&D and proof-of-concept projects, the NQCC provides access to applications expertise and quantum computing resources to help UK organisations explore and develop relevant use cases. Demand for support in this area continues to grow, and this year the NQCC is pleased to be supporting seven collaborative Innovate UK projects to deliver feasibility studies for industrial applications.

Networking, workshops and hackathons

By connecting developers, technology providers and end users, **SparQ** aims to facilitate knowledge exchange and accelerate the adoption of quantum computing in both the public and private sectors. As part of this activity the NQCC organises an annual quantum hackathon, which in 2023 was held at the University of Birmingham (see page 24).

Skills development and learning resources

The **SparQ** programme provides education and training resources to help the quantum professionals of the future to build and develop their skill sets. These include a self-paced online course for students and professionals to gain an understanding of the key concepts of quantum computing and continuing professional development courses that have been developed and delivered in collaboration with universities (see page 34).

UKRI National Quantum Computing Centre

Quantum readiness:

Collaborative R&D projects

Near-term quantum computing techniques addressing operational healthcare use-cases important to NHS health and care provision

This project investigated the application of near-term quantum computing techniques to address various operational challenges within the NHS, with a focus on operating theatre planning and urgent-care patient allocation. The team created a small-scale demonstration for theatre planning that could be encoded onto a quantum computer, with even a 1% efficiency improvement.

Lead: Applied Quantum Computing
Partners: The Public Service Consultants Limited, NHS, NQCC

Data-driven reactivity prediction using computed quantum features for drug discovery

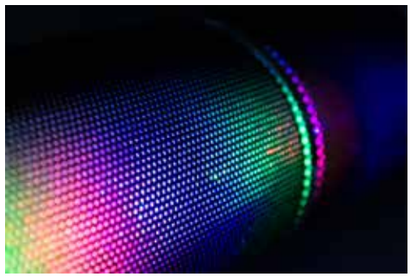
This project devised a general approach in which rich quantum-derived features can be exploited to predicting the reactivity of a chemical series of sulfonyl fluoride compounds. The project created a robust software pipeline to provide a data-driven workflow for exploiting the quantum features of molecules to make predictions using a machine-learning model. The project concluded that the quantum-enhanced approach has the potential to significantly accelerate the molecular design process, and eventually to reduce costs and allow for higher throughput.

Lead: Capgemini UK
Partners: GSK, NQCC

Quantum Monte Carlo radiation transport simulation

Modelling radiation transport is fundamentally important for the nuclear industry, as well as for medical radiotherapy, the space industry, food irradiation, and oil well logging. Monte Carlo techniques provide the most accurate way to solve the equations for radiation transport, but they are slow to run on classical computers. This project investigated the potential of quantum computing to speed up the simulations and ultimately to provide improved tools for the design and operation of radiation facilities in the nuclear, medical, and space industries.

Lead: The ANSWERS Software Service, part of Jacobs UK
Partners: National Nuclear Laboratory, Sellafield Ltd, University of Cambridge, NQCC



Federated quantum machine learning for genomics data

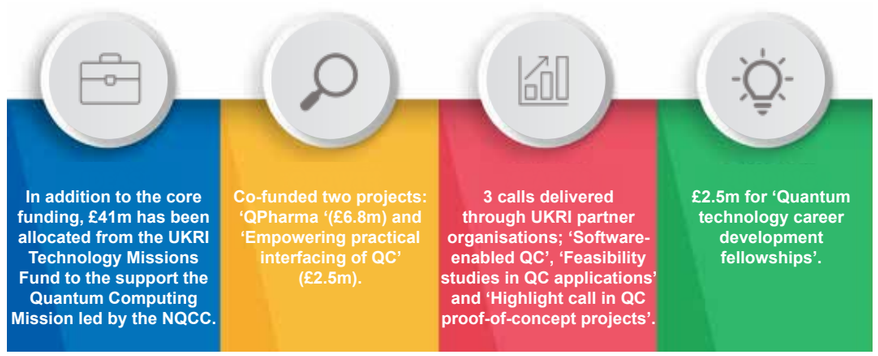
Biomedical data is an essential resource for developing machine-learning models that are used in the diagnosis, treatment, and the prevention of diseases, but healthcare data is subject to strict regulations and privacy laws. This project exploited quantum computing to achieve federated learning in genomics data, which allows multiple organizations to collaboratively train machine learning models without directly sharing the data, and created a cloud-based proof-of-concept platform that enables hybrid quantum machine-learning models to be trained on genomics datasets.

Lead: Zaiku Group
Partners: North East Yorkshire Genomics Lab Hub, NQCC

Driving innovation:

Funding and opportunities

We participate in collaborative R&D projects with UK businesses and research groups, and commission external projects to support the growth of the UK's technology supply chain.



February 2023

Feasibility studies in quantum computing applications

Through the UKRI Technology Missions Fund, the NQCC is collaborating with Innovate UK to deliver £8m of funding for a series of Feasibility studies in quantum computing. The call was open to any UK-registered business that wants to develop innovative quantum solutions that address industry-relevant problems.

The projects target industrial problems, with the aim of exploring the impact and feasibility of using quantum computing for specific applications.

By bringing together end-users from different industry sectors with experts in quantum computing, the projects aim to identify and develop use cases that demonstrate the potential and commercial benefits of the this technology for the UK.

April 2023

Quantum technology career development fellowships

The NQCC sponsored a number of awards through EPSRC's programme of Quantum Technology Career Development Fellowships. The objective has been to support talented post-doctoral researchers who have the potential to lead their own research programmes and develop their research profiles within quantum computing. The funding is available for between three and five years.

Twelve fellows are being supported through the EPSRC programme, representing an overall investment of £10m, while an additional £2.5m for three fellows has been provided by the NQCC. Overall the programme is supporting 15 researchers at institutions across the UK, helping them develop an independent research career in quantum technology and to accelerate their personal and professional career development.

A spotlight on:

Delivery and development of quantum testbeds in the UK

Dr Simon Plant, Deputy Director for Innovation

"This key initiative is a great example of how we aim to work with partners to build the UK's quantum computing capabilities, enabling the technology to be demonstrated and showcased."

Back in June the NQCC announced that, as part of a wider Quantum Computing Mission, we are investing £30m to commission the development of quantum computing testbeds (prototype quantum computers) in the UK. The NQCC is partnering with Innovate UK to deliver the competition.

The Quantum Computing Mission aims to:

- Accelerate the UK's strategic advantage and capabilities
- Accelerate the growth in user adoption of quantum computing and associated essential skills
- Uncover critical bottlenecks in understanding technology readiness and systems performance on the pathway to delivering fully fault-tolerant error-corrected quantum computing for the UK.

The NQCC is coordinating with partners across the UKRI in support of this initiative. The mission seeks to drive the development of testbeds and applications to underpin further growth of a UK quantum computing sector capable of delivering quantum advantage in 2025.

The funding through the mission supports:

- **£6m Software-Enabled Quantum Computation call with EPSRC** – launched 12 Dec 2022, closed 1 February 2023
- **£8m Feasibility Studies in Quantum Computing Applications call with Innovate UK** – launched 13 Feb 2023, closed 29 March 2023
- **Up to £30m for the Quantum Computing Testbed Development call with Innovate UK** – EOI launched 30 May
- **£6m investments directly through the NQCC:**
  - Innovation Hub at Harwell Campus
  - **SparQ** user engagement programme, and quantum readiness training
  - Quantum computing as a service (QCaaS).

The expected outcome of the mission is to drive end-user adoption of quantum computing through access to resources and skills development, and by demonstrating the value that quantum computing can provide for improving the prosperity, security, and productivity of the UK.

Details of the testbed competition can be found here. Please note that the call for proposals has now closed and applicants will be notified of the outcome in mid-November.

Quantum readiness:

Quantum hackathon in the UK

Hackathon offers glimpse of quantum potential

The NQCC held its second UK quantum hackathon at the University of Birmingham.

The hackathon is part of the NQCC's user engagement programme – SparQ (see page 20), which builds awareness of the current capabilities and limitations of quantum computing technology, nurtures the talent pipeline and convenes stakeholders to build a strong user community.

We were joined by Master's and PhD students, researchers, quantum providers, and industry professionals from across the quantum community for an exciting two days of technical problem-solving at our second quantum hackathon in the UK.

Download a full article here.

One of the hackathon teams with their mentor.

National Quantum Computing Centre

UK Quantum Hackathon 2023:

Winning use cases

1st place – Rolls Royce team: Near-term quantum linear solver algorithms

The state-of-the art computational methods used to simulate modern power systems present a bottleneck for existing supercomputers. To overcome this challenge, the team investigated the performance of near-term quantum linear solver algorithms on the IonQ trapped ion quantum computer, which was accessed via the Classiq software platform.

The team constructed quantum circuits that could be tested on the quantum hardware, producing results with good agreement between the target values and those calculated using a quantum approach. These results demonstrated that quantum computing could improve the simulation of power systems compared to current classical methods.

2nd place – Jacobs team: 1-D Monte Carlo particle transport

Understanding the transport of subatomic particles is critical in designing radiation shields to protect both people and equipment from the radiation produced in environments such as nuclear reactors and hospital radiotherapy suites. One of the most accurate ways to model this subatomic transport is provided by Monte Carlo techniques, but these models are slow to run on classical computers.

To see whether a quantum approach might offer an advantage, the team simulated 1D particle transport in a slab of material using Quantinuum's ion-trap hardware. They constructed quantum circuits to understand particle distribution in a variety of materials, including concrete and steel, with the results indicating that quantum computing could be used to speed up Monte Carlo simulations of particle transport in various materials.

3rd place – Applied Quantum Computing team: Vaccination centre location

The UK NHS faces many operational challenges, one of which is where to locate vaccination centres during a pandemic to maximise vaccination rates. This problem requires a huge range of variables to be considered, including travel distance, the capacity of each vaccination centre, demographics, population density, and many others. Such a complete analysis is extremely difficult due to limitations in computational power, but quantum computing may offer a solution. The team investigated two hybrid quantum algorithms to optimise this logistical problem and tested them on a simulated environment. With further investigation, they found that a quantum approach could find an optimal solution for a variety of test cases using Qiskit's quantum computer emulator.

Supporting the National Quantum Strategy:

NQCC's role and outlook

Dr Michael Cuthbert, Director

"The UK is well positioned, with leading quantum computing companies sitting alongside world-class research excellence in quantum computing from our universities and research labs. The increased investment will further bolster the UK's position as a home for quantum computing innovation, creating the right environment in which to start and grow companies as part of a rapidly developing, high-tech industry."

Strategic framework

The UK's National Quantum Strategy, which was announced in March 2023, will invest £2.5bn in quantum research, innovation and skills development over the next ten years. Building on the success of the National Quantum Technologies Programme, this long-term commitment aims to establish the UK as a leading quantum-enabled economy in which quantum technologies are embedded within the country's digital infrastructure to ensure resilience and drive growth in both the private and public sectors.

The NQCC will play a leading role in the expanded 10-year framework, with a key focus on the development and commercialisation of quantum computing in the UK. It will continue to work alongside its partners in research, industry and government to address the challenges of scaling and to boost the adoption of quantum computers, with the strategy identifying a number of specific activities for the centre:

- To provide access to quantum computing resources across a range of platforms for wider research and the quantum industry, providing an entry point for businesses looking to engage with the quantum community and explore use cases. As part of this activity the NQCC is investing £30m to develop a series of quantum testbeds over the next two years, as highlighted on page 23
- To bridge the gap between nascent technology development and end-user applications, with the potential for ambitious missions to drive large-scale testing across selected sectors. The NQCC will achieve this by accelerating its SparQ user engagement programme, with specific workstreams dedicated to use-case exploration, testing, and upskilling within the public, defence, aerospace, and healthcare sectors
- To dedicate at least a quarter of the NQCC's access to computing platforms and associated research programmes towards exploring critical applications of societal benefit, such as realising the advantages from personalised medicine, understanding the causes of dementia, or improving battery efficiency. The NQCC already has a dedicated initiative on responsible and ethical quantum computing, as described on page 32
- To work with the National Physical Laboratory to develop open standards based on benchmarking and verification tools currently being developed to enable comparisons to be made between different quantum computing platforms.

The National Quantum Strategy can be read in full here.

Aligning with the NQCC's vision:

Quantum Software Lab in Edinburgh

In April 2023, a dedicated Quantum Software Lab (QSL) was launched at the University of Edinburgh, in partnership with the NQCC. It is based in the School of Informatics and aims to overcome key challenges to accelerate the development of quantum computing and investigate new ways in which quantum computers can provide benefits, beyond the reach of traditional computers.

Prof. Iain Gordon, Prof. Elham Kashefi and Dr Michael Cuthbert.

Research at the QSL will provide the foundational knowledge for the NQCC's development programme in quantum software and applications, and will also pave the way for the UK's first secure and verifiable distributed cloud platform for quantum computing.

Under the leadership of the NQCC Chief Scientist, Professor Elham Kashefi, the Lab will conduct key research into the development of new quantum software, based on a core programme of research called the Quantum Advantage Pathfinder.

Researchers from the Lab will work closely with industry partners to understand how quantum computers might help address their problems. The Lab will be able to offer expertise and education, in addition to undertaking pioneering research.

The Lab represents a core research capability in quantum software that can attract talent, help to train the next-generation workforce, provide scientific expertise, and build the capability to solve the key scientific challenges facing quantum computing.

Advancements in science may enable new applications, and new applications may inspire new research directions, the team says.

The Lab's theoretical research pillars will develop the necessary tools for identifying and demonstrating any quantum advantage that one might obtain in a provable and reproducible way for specific practical applications.

The work of the Lab will be delivered in support of the NQCC's vision of exploring the potential of quantum computing to address some of the most complex computational challenges, enabling the UK to realise its full benefits, as the technology is further developed.

Sir Peter Knight and Professor Jane Hillston.

Establishing the Lab aligns with the ambitions of the NQCC's user engagement programme, SparQ, which seeks to grow the UK's developer and user communities, by supporting potential users of quantum computing on their journey from awareness to advocacy.

QSL opening dinner at the Signet Library, Edinburgh.

Read a full article here.

Quantum readiness:

Developing use cases with industry

"The Quantum Software Lab can play a vital role in translating end-user needs into quantum solutions, while also working with key vendors to test and validate applications on near-term hardware."

Prof. Elham Kashefi,
NQCC Chief Scientist and Head of QSL

Since the Quantum Software Lab (QSL) was launched in April 2023, we have been working with industry partners to identify and develop relevant use cases. In April we hosted the AIMday for Quantum Computing Applications, which featured workshops with 13 industry partners. We are now working on the delivery of two use-case projects that emerged from the day, one in the life sciences and one in the aerospace sector.

The first project, which is a collaboration with Advanced Medicals and Quantum Base Alpha (QBA), aims to exploit quantum machine learning to encode genomic data into quantum state vectors. The approach will consider geometric principles and compression methods to improve the predictive functionality of non-coding DNA, which is important for understanding complex medical conditions.

The second project is focused on the optimisation of flight path and traffic management in the aerospace sector, and involves National Air Traffic Services (NATS) as well as QBA and QSL. In both projects, QSL and QBA are leading on the development of quantum machine-learning techniques.

At the same time the QSL team is continuing to make progress against its key pillars of theoretical research, which will provide novel tools that we will use in our industry-focused investigations. As well as publishing a series of research articles and contributing to academic workshops, a number of QSL researchers participated in the NQCC's annual hackathon. We have also taken advantage of our location at the University of Edinburgh to engage with the wider scientific community, recently holding a workshop with the School of Chemistry to understand how quantum computing can support research in drug discovery and materials.

QSL has also organised an online workshop with the Financial Conduct Authority (FCA) to understand how quantum techniques might lead to the creation of higher quality synthetic data in the financial sector, and we are supporting a workshop focused on quantum-enhanced blockchain technology. To boost collaboration within the academic sector, it is helping to organise research seminars through the Quantum Computing Application Cluster. This brings together expertise across quantum hardware and software at the Universities at Strathclyde, Edinburgh and Glasgow.

Over the next 12 months, our efforts will focus on bringing together industry partners in hardware and software with end-users in financial services, chemistry, logistics, life sciences, defence and security, and energy. This remains challenging, however, and we envisage that early-stage results will emerge in the second quarter of 2024.

The School of Informatics building that hosts QSL.

National Quantum Computing Centre

Quantum readiness:

Pharmaceuticals and advanced materials

"In this project, we tackled predictive modelling challenges within the constraints of current hardware platforms, but with a view to future scaling."

Dr Phalgun Lolur,
Quantum Applications Engineer

The NQCC has been working with partners in the pharmaceutical industry to develop and test a quantum-enhanced approach for predicting the performance of chemical compounds that could lead to the discovery of new drugs. The project focused on targeted covalent drugs, which have become increasingly popular in the pharmaceuticals sector because they operate through a two-step action that can boost their potency and offer a higher selectivity than traditional small-molecule inhibitors.

The central challenge in the project was to predict the reactivity of a series of candidate molecules, in this case sulfonyl fluoride compounds, since this is the key parameter for balancing key properties such as potency and selectivity. Our approach creates a data-driven pipeline that combines experimental data with quantum simulations of the molecules to establish a machine-learning model for reactivity.

Through the use of embedding methods, we extracted the quantum features of the molecules from a reactive molecular fragment by simulating the many-body fragment Hamiltonian. This allowed us to tackle predictive modelling challenges within the constraints of current hardware platforms, but with a view to future scaling.

As an outcome of this research, we have identified the following next steps:

- Explore a wider pool of applications beyond the sulfonyl fluoride chemistry – both in drug discovery and consumer products R&D
- Understand how we might extend the approach to problems where there are no common reaction centres or substructures, and how the fragmentation and active space transformations could be automated for wider applicability
- Optimise the algorithmic approaches by combining the embedding strategy with the initial state preparation and unitary transformations and measurements, with the aim of maximising the predictive performance of the available quantum computational resource
- Extend the pipeline to facilitate the use of quantum machine-learning algorithms, creating a scalable end-to-end pipeline that does not require intermediate measurement readouts between the quantum simulation and machine-learning steps
- Explore the robustness of the pipeline to hardware errors, which is one of the key advantages that we hope to realise from the proposed approach, and how this will scale
- Identify the minimum scale of quantum resource required to deliver quantum advantage, and further navigate the space of algorithms at larger scales by combining error suppression and mitigation techniques with the longer-term vision for a fault-tolerant era.

Quantum readiness: **Financial services**

"I believe that quantum computing has great potential to help us solve problems that we never thought we could, to view the world in a different way, and to enhance and accelerate our ability to innovate."

Dr Konstantinos Georgopoulos,
Quantum Applications Engineer

One of the most advanced sectors and potential early adopters of quantum computing is the financial technologies (fintech) sector. It is rich in use-cases anchored around optimising a solution given a large number of constraints, forecasting a scenario based on a set of inputs, decision making based on analysing enormous datasets, or securing the vast amounts of data and transactions that are held or carried out by financial institutions.

Overall, a strong driver for applications R&D is the opportunity to advance quantum readiness within the sector, defined as the ability of financial institutions to be ready to take advantage of the opportunities of quantum computing and mitigate and manage the potential disruption. The use of quantum computing technologies in these domains has the potential to offer a number of benefits, such as:

- Operational improvements to cut costs, accelerate timelines and reduce energy consumption
- Better risk management by adopting more resilient and accurate models based on quantum computing
- Improved cybersecurity by adopting protocols that will strengthen security systems and mitigate the potential risks posed by quantum computing.

The NQCC has been actively engaging with the fintech sector for more than two years. We have run a series of workshops and participated in bilateral conversations that have given us an insight into how institutions within the fintech sector view quantum computing and its applications. In parallel, the applications team has been undertaking deep technical work in algorithms and applications that could provide solutions to specific use cases in the sector.

The main outcomes from our work so far has been to:

- Build an understanding of the critical use cases for the fintech sector that quantum computing has the potential to solve. Leading examples include fraud detection, modelling pricing and cybersecurity
- Gain exposure to the sector's priorities and the potential impact of quantum computing on the financial services organisations' business models
- Develop a comprehensive use-case library for the fintech sector and, through our technical work, map potential solutions for those use cases
- Make progress towards answering the critical question: "What are the potential quantum applications in fintech and when will we be able to implement them?"

As we continue with this work our priorities will be to:

- Further focus on algorithms that provide solutions to use-cases, understanding their technical requirements and the necessary capabilities needed to execute them
- Undertake more deep dives on the applications of quantum computing in the fintech sector
- Continue nurturing the ecosystem and offering thought leadership and technical expertise
- Inform roadmaps and our strategic planning in response to the sector's journey towards quantum readiness.

National Quantum Computing Centre

Quantum readiness: **Healthcare**

"Quantum computing ushers in an exciting new era of healthcare possibilities. With strategic collaboration, the UK can lead the charge in developing quantum-enhanced solutions that tangibly improve patient outcomes worldwide."

Dr Sonali Mohapatra,
Quantum Innovation Sector Lead

The NQCC has funded a number of pioneering projects in key application areas across the healthcare, pharma and life sciences sector where quantum computing (QC) could offer a crucial advantage over classical computing. These include:

Drug discovery

- The NQCC has ongoing partnerships with pharma companies to explore and build hybrid quantum-classical computing platforms for rapid molecular screening and accelerating the identification of candidate drugs. Projects aim to reduce the time and costs required for the current trial-and-error discovery processes and develop policy frameworks for responsible and ethical QC innovation
- The NQCC is part of a consortium investigating quantum computing approaches for assessing quantum dynamic properties of complex chemical systems for enzyme-targeted drug discovery, currently inaccessible using classical methods. Led by Kuano, a company developing artificial intelligence and other novel techniques for drug discovery, this project will also perform benchmark analysis of commercially relevant systems.

Logistics: The NQCC is collaborating with Applied Quantum Computing and the NHS to explore how QC could help optimise operational healthcare functions such as theatre allocation, patient scheduling in urgent care and nurse routing. Improving the efficiency of these logistical problems will optimise the allocation of resource and has the potential to improve the quality of care.

Data security: A project led by Zaiku, involving the NQCC and the University of Malta is exploring how advances in QC could support a federated machine-learning approach that will enable secure data sharing across healthcare networks for collaborative diagnosis and treatment. This project aims to create an easy-to-use platform-as-a-service (PaaS) that enables healthcare and genomic organisations to perform computations on encrypted healthcare data without needing to decrypt it.

Reactivity prediction: The NQCC collaborated with Capgemini and GSK to investigate the benefits of using QC for in-silico predictions of reactivity, a problem that has broad industry relevance because conventional machine-learning techniques are challenging to apply. In this application a quantum approach is expected to offer better generalisation from fewer measured examples.

Medical irradiation and radiation transport: In another project, led by the ANSWERS Software Service team at Jacobs, the NQCC was part of a consortia investigating potential advantages offered by QC to radiation modelling. While the project sat primarily within the nuclear sector, radiation modelling is also key to medical irradiation e.g., in shielding, dose planning, dose verification, medical isotope production, etc.

Other interesting use-cases include disease modelling, population health management, pricing optimisation, etc. As quantum hardware and algorithms mature, the NQCC will work to strengthen the UK's leadership position in quantum-enabled healthcare through strategic collaborations.

Key focus areas of activity will include:

- Driving adoption by raising quantum awareness among healthcare professionals
- Fostering cross-sectoral R&D partnerships to identify high-potential healthcare use cases
- Supporting proof-of-concept projects and feasibility studies to explore and develop quantum-enhanced solutions
- Enabling experimentation by providing access to real quantum systems
- Convening key sectoral stakeholders in roundtables and workshops to understand sectoral quantum readiness and collaboratively shape the strategy and roadmap.

Responsible and ethical quantum computing (REQC):

NQCC's initiatives and impact

Dr Natasha Oughton, Engagement Officer

"A highlight for me was having a REQC component included as part of the hackathon, showcasing our commitment to thread REQC through everything we do. It was wonderful to see the level of engagement from both hackers and mentors, and we've even inspired others to include REQC elements into their own hackathons!"

The NQCC has been championing a responsible and forward-looking approach to understanding the societal, ethical and policy implications of quantum computing research and innovation, leveraging our expertise and position to ensure that quantum computing is used responsibly, safely, and for the benefit of society. Our aim is to maximise the benefits of the technology while minimising the potential for harm, driving the adoption of quantum computing to make the world a better place for everyone.

Our work in this area has intensified over the last year, spanning three key components:

Research-informed thought leadership
Our research on REQC informs our own approach and our contribution to thought leadership. We have been sharing our insights and expertise through a number of opportunities, including co-organising a workshop as part of IEEE Quantum Week on Responsible and Ethical Quantum Computing, and the Quantum Summit of London Tech Week.

We are also engaging with academic research on the wider implications of quantum computing, collaborating with other experts to co-author papers on topics including epistemic access and the barriers faced in engaging with quantum computing, and explainability for quantum algorithms.

As part of the QuPharma project, investigating hybrid quantum–classical computing to accelerate drug discovery, we created a framework for trusted, responsible and ethical use in the pharmaceuticals sector that was shared with the project partners.

Our research also informs our contributions to policy discussions, including co-drafting the World Economic Forum's Quantum Blueprint for the responsible development of a quantum ecosystem, and providing input into the Regulatory Horizons Council (RHC), a committee that identifies the implications of technological innovation.

Ecosystem enabling
We aim to champion REQC throughout the UK quantum computing ecosystem. To identify next steps and priorities, we held a workshop to understand how organisations are currently engaging with REQC, best practices, and common enablers and barriers, to inform the NQCC's future strategy for supporting the ecosystem in developing and using quantum computing responsibly and ethically.

We are also working to thread REQC throughout our external engagements. At our annual hackathon in July, we set teams the additional challenge of building societal benefit into their solution, building awareness for both the industry mentors and the early-career researchers taking part (see page 24).

Developing our own responsible approach
We are developing a framework that will guide research and innovation at the NQCC, ensuring that we take a responsible and ethical approach in all our operations.

Roadmapping:

Scalability Conference 2023

Dr Klara Burlamaqui Theophilo, Ion Trap Physicist

"The conference enabled both the delegates and the NQCC to gain a broader understanding of the quantum computing landscape, and to identify which key challenges are shared across hardware platforms."

The Scalability Conference was organised by the NQCC in March 2023 to bring together experts in different hardware platforms to understand the progress made so far in scaling up quantum computers and the challenges that still remain. 130 people from more than 60 companies attended the event, offering a unique opportunity for delegates to compare the current performance and future prospects for a range of hardware approaches.

The presentations focused on qubit architectures that exploit trapped ions, superconducting circuits, photonics and cold atoms (tweezer arrays), although some of the attendees were working on other hardware platforms, such as diamonds, as well as enabling technologies.

The conference included 12 invited presentations, with speakers coming from across the UK and overseas, as well as three presentations that introduced the activities and approach of the NQCC's hardware development teams. One panel discussion enabled representatives from industry and academia to debate emerging strategies for benchmarking and verification, while another focused on enabling technologies that underpin the development of quantum computing, such as nanofabrication.

Unlike other conferences in the field, the event enabled hardware developers to compare the current capabilities of their hardware platforms and scalability challenges they are working to solve.

Photonics is not only a platform for quantum computing, but an important enabling technology for other hardware platforms, particularly those based on ions and atoms. As such, other hardware platforms would benefit from the development of integrated photonics, as well as performance improvements in photonics devices. The same is true for cryo-engineering and efficient control-system development, which would represent an important step forward for most, if not all, platforms.

While the conference was mostly focused on hardware, one of the panel sessions provided a focal point for discussions about benchmarking, from which it was clear that more debate will be needed to reach a consensus. These discussions once again highlighted the role that the NQCC can play in providing the UK's quantum community with an independent way to regulate and evaluate the quality of quantum computers.

For the NQCC, these discussions will help to support the UK's quantum ecosystem by identifying avenues for future technology development.

The feedback from the attendees was overwhelmingly positive, and we aim to run similar events in the future.

Scalability Conference 2023 attendees.

Building a strong community:

Training and skills development

"Our training and skills activities have begun to ramp up over the past year as we develop a portfolio of activities for learners at different stages of their quantum careers."

Daisy Shearer,
Outreach Officer

A crucial priority for the NQCC is to expand the UK's quantum workforce by enabling more people to gain the knowledge and skills needed to work with quantum computers. We offer training courses to enable students, researchers and industry professionals to understand and use quantum computers, provide support and learning opportunities for postgraduate students and early career researchers, and enable people who are considering their future careers to gain first-hand experience of quantum computing.

Professional development
In February 2023 we launched an online training course that enables graduate students and technical professionals to understand key concepts in quantum computing. The interactive course, which is provided through Q-CTRL's Black Opal learning platform, includes a series of training modules to allow users to learn at their own pace. The NQCC provides funding for two individuals per organisation to complete the training. Find out more at nqcc.ac.uk/learn/professional-development/online-quantum-skills-course/.

We have also partnered with the University of Bristol to create and deliver two six-week online courses aimed at researchers or professionals who want to move into the field of quantum computing and have a background in mathematics, physics or computer science. Delivered once per year, the first course describes key concepts and mathematical techniques in quantum information theory, while the second builds on that knowledge to enable participants to learn how to use quantum computing tools and algorithms.

Students and early career researchers
Our annual hackathon provides an opportunity for postgraduate students and early career scientists to gain hands-on experience writing quantum algorithms and testing them on real quantum computers. See page 24 for more details.

As part of EPSRC's Quantum Technology Career Development Fellowships, the NQCC is funding three fellowships for early career researchers at the University of Oxford, Royal Holloway, University of London and the University of Bath.

Placements and internships
For the first time this year, the NQCC offered a placement to an STFC-supported graduate student within the software team. During the placement, the student helped to design test systems for the ARTIQ-based control hardware, and also investigated open-source control systems for superconducting qubits based on field programmable gate arrays (FPGA).

The innovation team also hosted four interns over the summer: two focused on public engagement, one on business development, and one on sectoral engagement. These internships, aimed at undergraduate students and recent graduates, aim to build skills while also supporting our outreach objective of inspiring and engaging the next generation to consider a future in quantum computing.

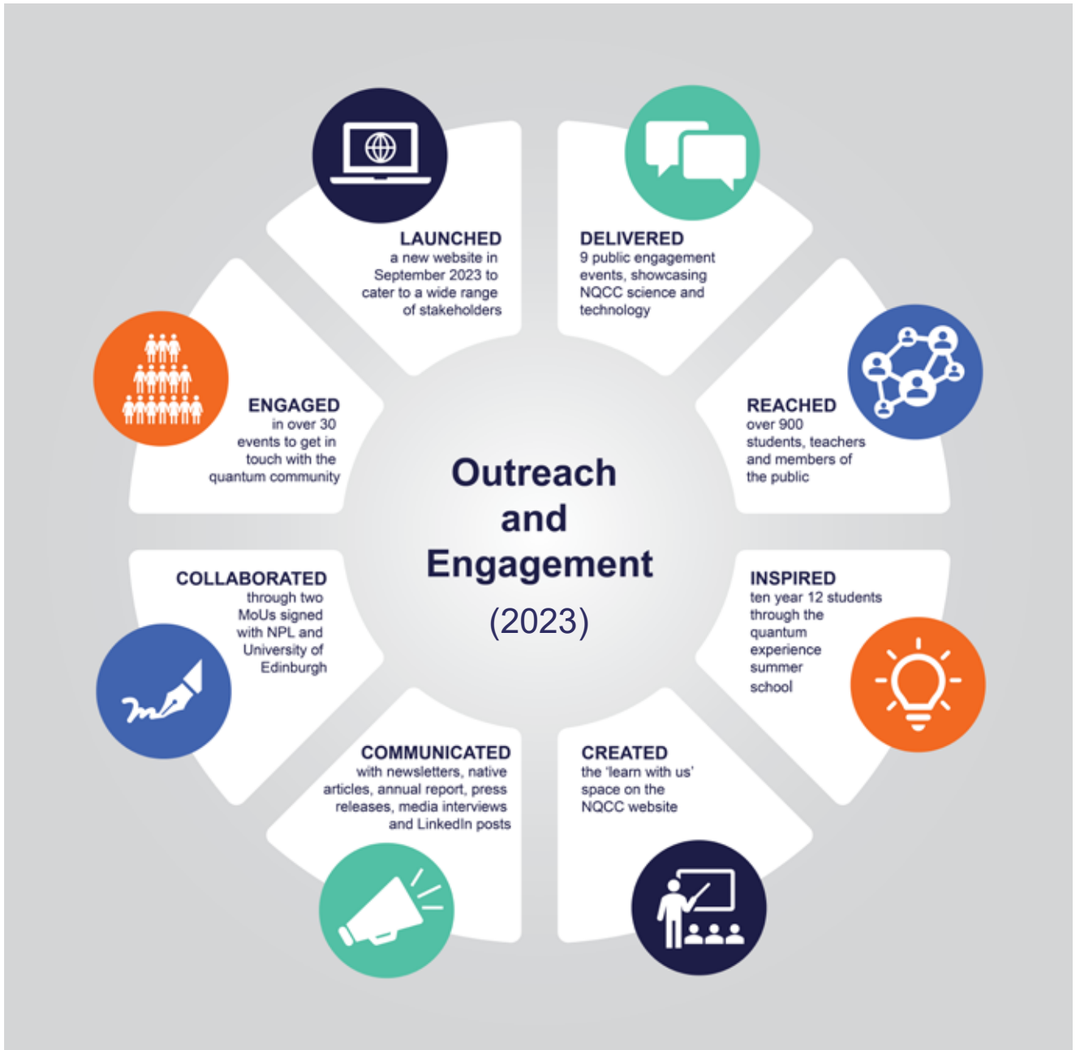
Learning resources
We are developing a library of learning resources to provide an introduction to quantum computing for school students and educators. The resources will be available through the NQCC's new website as they are released.

Learn with us:

NQCC's outreach pathways

Our science outreach efforts bring quantum computing to many different audiences, including school students and members of the public. We aim to inspire and encourage the next generation of quantum professionals by participating in public engagement activities aimed at young people and their families.

We engage and stay connected with all key stakeholders across the UK's quantum ecosystem, ranging from companies and university researchers to government departments, investors and end users. We provide regular updates and insights through a variety of communications channels, and organise networking events to facilitate discussion and collaboration.



Engage with us:

NQCC’s outreach and networking events

Networking events

Last year, the NQCC participated in over 30 networking events to stay connected with a wide variety of audiences and stakeholders.

Industry events

NQCC supported and participated several industry events in 2023, through panel discussions, workshops, presentations and having a NQCC booth for face-to-face interactions.

Quantum hackathons

NQCC holds quantum hackathons annually. Over 100 hackers (primarily Masters, PhD and postdocs), 8 QC providers and 13 user organisations have participated across the two quantum hackathons.

Public events

The NQCC has developed a pop-up exhibit with demos and resources exploring quantum computing that everyone can understand. This year, we have taken the exhibit to a variety of events, including STEM in the Park, Daresbury Open Week, the Institute of Physics’ Celebration of Physics, New Scientist Live, and Oxford Ideas Festival.

Quantum Experience Summer School

In partnership with the University of Oxford, the NQCC supported a summer school for year 12 students, which gave the students a taste of life as a quantum physicist.

Careers fairs and talks

As well as public science festivals and events, we have given careers talks and attended various careers fairs to show students and teachers the variety of different job opportunities and pathways in quantum computing.

Equality, diversity and inclusion

Dr Georgina Croft,
Chair of the ED&I
Working Group

"***We want to provide the right environment and facilities for all staff within the NQCC, as well as ensuring that our recruitment processes treat all candidates with fairness and respect.***"

The NQCC is committed to developing a sustainable approach to equality, diversity and inclusion (ED&I) across all of its activities and practices. In February 2023, an ED&I Working Group was set up to translate wider UKRI policies into practical measures that can be implemented at the Centre. Our 12-strong group of volunteers is currently being chaired by ion trap physicist Georgina Croft, and is working with the support of the Leadership Team, to embed a culture that drives equality, values diversity, and has inclusion at the heart of every activity.

Within the Working Group, our activities so far have focused on:

- Establishing a clear framework and terms of reference for the group
- Developing connections with broader ED&I initiatives within UKRI and STFC to ensure consistency and to access support for wider-ranging policy issues
- Engaging with NQCC staff to identify three areas where a focus on ED&I could have a meaningful impact within the NQCC. The topics chosen were recruitment, workplace culture and ED&I training across all of our activities and practices
- Exploring current best practices and policies for each of those three focus areas at similar organisations and national labs.

Smaller teams within the Working Group are now comparing the existing approaches at the NQCC with best practice in these focus areas. This will inform an action plan that we are developing to identify and then implement practical changes within the organisation. As part of a review of the plans for the new building, we also identified the need for a wellbeing room, and have secured a space that can be used flexibly as, for example, a prayer room or a quiet room.

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Employee away days and fun-clubs

Away days

On away days, the NQCC members get together to discuss our progress and plans. With a fast-growing organisation it's also important to build time in to get to know each other and improve our soft skills like communication and teamwork. Interspersed between sessions, we have team building activites to engage with members from different teams, pub-style quiz and maze-type games to challenge how we prioritise tasks.

Quantum coffee day

The NQCC team regularly get together to look back at the progress made in establishing the NQCC and discuss how its strategy and organisation will evolve in the coming months.

Quantum journal club

As a quantum centre, we aim to keep abreast of all quantum-based news. Each week we hold technical talks or discuss important changes in the quantum landscape, to ensure we have a good understanding and a wide view of our specialist topic. This can range from funding reports and company roadmaps to discussing quantum in the media and the importance of public outreach.

Rounders' club

With a lot of us having not played since school, and some never having heard of the game (it's very British), Emma put on a fierce training regime. Our first few games were tough – playing the reigning two-time champions and their main competition, but we came alive in the second half of the season.

Tuesday cake club

Each week we take a short breather to socialise with colleagues around a sweet treat. Many people have taken to the challenge of home-baking with excellent results, and several others have taken the opportunity to showcase foods from their cultures. Social cohesion is important to us, especially as we grow in number, giving us time to chat to each other about our interests outside of NQCC.

Governance

The NQCC is governed by a Programme Delivery Board that ensures regular monitoring and evaluation to EPSRC and STFC, the two research councils that are jointly responsible for delivering the NQCC's programme. Oversight is maintained through the Programme Advisory Committee and Technical Advisory Group, both comprised of external advisors who provide support and expertise to guide the development of the NQCC and its programme.

Programme Advisory Committee

The Programme Advisory Committee (PAC) provides advice, support and challenge on the activities and programme of the NQCC. With complementary expertise across quantum technologies research, programme delivery and technical innovation, this group of external advisors offers informed opinion to the Programme Delivery Board and the NQCC leadership team on the development of the Centre within the wider context of quantum computing in the UK and internationally.

Meeting once a quarter, the PAC ensures that the NQCC links to related activities within the UK's National Quantum Technologies Programme, helps to manage any external risks that might affect the NQCC's programme delivery, and liaises with senior sponsors and external stakeholders across academia, government and industry.

Professor Sheila Rowan, Chair
Professor Rowan holds the Chair of Natural Philosophy and is the Director of the Institute for Gravitational Research in the University of Glasgow. She received the Hoyle Medal and Prize of the UK Institute of Physics in 2016, was elected to Fellowship of the Royal Society of London and received a CBE for services to science in the Queen's New Year Honours list in 2021. In 2023, she was awarded the inaugural Lifetime Achievement Award of the Philip Leverhulme Trust.

Professor Sir Peter Knight
Sir Peter Knight is Emeritus Professor at Imperial College, a past President of both the Institute of Physics and Optical Society of America, chairs the National Quantum Technology Programme Strategy Advisory Board and the Quantum Metrology Institute at the National Physical Laboratory.

Professor Tom Rodden
Professor Rodden is Chief Scientific Advisor for the Department for Digital Culture Media and Sport (DCMS) and a Professor of Computing at the University of Nottingham. His research is highly interdisciplinary, bringing together a range of disciplines as computing becomes a ubiquitous feature of our world and we increasingly use personal data and AI technologies.

Roger McKinlay
Roger McKinlay is the Challenge Director – Quantum Technologies for UK Research and Innovation. He has been involved in the National Quantum Technologies Programme since 2015, and was a panel member of the 2016 Quantum Technologies Blackett Review. Roger is a Chartered Engineer and a past president of the Royal Institute of Navigation.

Michael Groves
Michael is Head of the Heilbronn Institute for Mathematical Research. He has worked as a security researcher at Government Communications Headquarters (GCHQ) for over 25 years and served as Vice Chair of the ETSI quantum-safe cryptography working group from 2015 to 2019.

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"Having strong governance structures in place is important for us to demonstrate the effectiveness and efficiency of our activities and keep confidence of stakeholders. The PDB, PAC and TAG provide us with assurance and advice, as well as the challenge required for accountability and compliance."

Dr Rebecca How,
Programme Manager

Programme Delivery Board

The Programme Delivery Board (PDB) provides strategic direction and control of the NQCC's programme and activities. The PDB is chaired by the Centre's senior responsible owner – currently Liam Blackwell, Deputy Director of Cross Council Programmes at EPSRC – and includes the NQCC's leadership team, senior sponsors from EPSRC and STFC, and both finance and HR partners. The PDB takes a strategic role in identifying and developing initiatives to aid the delivery of the NQCC's programme, and in monitoring, managing, and addressing any risks or barriers that might affect progress. The PDB also ensures that the NQCC programme aligns with the wider activities of the research councils and the UK's National Quantum Technologies Programme, provides challenge and assistance on the implementation of the programme, and works to secure the confidence of senior sponsors and stakeholders within UKRI and the external community. The PDB typically meets once every two months, aligned where possible to key milestones in the programme or project delivery.

Technology Advisory Group

The Technical Advisory Group (TAG) provides impartial expertise and insight to help shape the technical roadmap and delivery programme of the NQCC. With extensive experience of quantum computing technologies and adjacent fields, this group of expert advisors offers an informed and independent view on the current state of progress both at the NQCC and the wider quantum computing ecosystem in the UK and internationally. Chaired by the NQCC's Chief Scientist, the TAG works with the NQCC leadership team to review and update the technology roadmap and the centre's technical programme, milestones and objectives. The TAG provides advice and challenge on technical initiatives, informs and reviews the acceptance or quality criteria for the centre's key deliverables, and maintains the technical integrity of the NQCC's programme and projects. The TAG meets twice a year, aligned with the approval process and lifecycle of the technical programme.

TAG Chairperson:
Professor Elham Kashefi, Chief Scientist, NQCC

TAG Members:

- **Dr Carmen Palacios Berraquero**, Founder & Chief Executive, Nu Quantum
- **Mr Jonathan Legh-Smith**, Executive Director, UKQuantum
- **Dr Leonie Mueck**, VP of Product, nPlan
- **Mandy Birch,** CSE, TreQ
- **Professor Martin Dawson**, Director of Research at Institute of Photonics, University of Strathclyde, and Head & Scientific Director, Fraunhofer Centre for Applied Photonics
- **Professor Simon Benjamin**, Professor of Quantum Technologies, University of Oxford, and Co-Founder/CSO, Quantum Motion
- **Dr Tobias Lindstrom**, Principal Scientist in Department of Quantum Technology, NPL
- **Professor Viv Kendon**, Professor of Quantum Technology in Department of Physics, University of Strathclyde.

Sponsors and Partners

The NQCC is a flagship programme of UK Research and Innovation (UKRI) that seeks to drive the development and exploitation of quantum computers in the UK. It builds on the strengths in quantum computing established during the first phase of the National Quantum Technologies Programme (NQTP), and operates within a wider landscape for quantum development in the UK that includes the Quantum Technologies Research Hubs, the quantum challenges and programmes within the Industrial Strategy Challenge Fund, doctoral training programmes, and the activities of the emerging quantum industrial sector.

The NQCC partners with academia, government and industry to solve technology challenges and realise the benefits of quantum computers for social and economic development. The centre aims to provide research institutions and companies with early access to emerging quantum computing resources, enabling organisations in different industry sectors to explore its potential for addressing relevant use-cases and applications. In supporting the government's ambition to establish the UK as the world's first quantum-ready nation, the NQCC seeks to accelerate the technology roadmap towards the commercialisation of quantum computing.

The NQCC's programme is jointly delivered by two UKRI research councils – the Engineering and Physical Sciences Research Council (EPSRC) and the Science and Technology Facilities Council (STFC).

Located within STFC's Harwell campus, the NQCC is well connected to a growing community of technology suppliers, start-up companies and industrial end users, as well as major research institutions across the UK. The NQCC also has access to the wide range of facilities on the Harwell site, such as engineering and fabrication facilities, business incubators and collaborative spaces.

UK Research and Innovation

Engineering and Physical Sciences Research Council

Science and Technology Facilities Council

UK National Quantum Technologies Programme

NPL National Physical Laboratory

Department for Science, Innovation & Technology

GCHQ

Innovate UK

dstl The Science Inside

Ministry of Defence

National Quantum Computing Centre

Memorandum of understanding signed with NPL

In January 2023, the National Quantum Computing Centre (NQCC) and National Physical Laboratory (NPL) announced the signing of a memorandum of understanding (MOU) that reflects their commitment to collaborate in the field of quantum computing.

Quantum computing has the potential to speed up the discovery of new materials and medicines, offer new designs for batteries in electric vehicles, and lead to the more efficient use of transport networks through improved traffic routing. In the UK the National Quantum Technologies Programme (NQTP), a £1bn partnership between industry, academia and government has been delivering ground-breaking products and services for the new quantum era since 2014. Both NPL and the NQCC are key partners in the NQTP, which supports ideas, innovation and investment to secure UK advantage and opportunities in the globally competitive quantum landscape.

Both organisations commit to working collaboratively to accelerate the development of quantum computing for the benefit of the UK. Over the next five years, the institutes plan to explore future collaborations to:

- Enable the independent testing, benchmarking and validation of quantum computing technologies
- Explore the co-ordinated development and delivery of technical roadmaps related to quantum computing
- Enable the exchange of knowledge and expertise related to the research on quantum computing
- Support the development of industry standards for quantum computing
- Support UK efforts in training and developing talent to contribute to a skilled and diverse workforce in quantum computing.

Dr Michael Cuthbert and Dr Peter Thompson.

Aligned with the shared vision of the MOU, the NQCC and NPL endeavour to support the UK's efforts in delivering positive societal impact and significant economic growth through quantum computing.

NQCC Director, Dr Michael Cuthbert said, "*Through this MOU we are bringing our shared expertise in quantum computing hardware, software and applications together to support the development of industry standards. Our early focus is on testing, benchmarking and validation of quantum computing technologies and marks an important step, shaping our collaboration towards our shared goal of making the UK a quantum-ready economy.*"

"*Signing this MOU will accelerate the close collaboration between NPL and NQCC. We will ensure that metrology, measurement standards and independent test and validation can enable strategic advantage from quantum computing under the leadership of NQCC, engaging with the many academic and industry organisations contributing to this national effort*", Dr Peter Thompson, CEO of NPL commented.

The year ahead

2023 saw several key milestones for the NQCC. Our Innovation Hub is complete, the main facility has reached its final fit out, our partnership with Quantum Software Lab (QSL) in Edinburgh has been established, and our temporary labs for trapped ions and control systems development have been fully commissioned. We have also hosted multiple community events, delivered a series of funding calls – including the £30m investment we are making in state-of-the-art quantum testbeds – and negotiated cloud access to third-party quantum compute resource. At the same time our team has grown to 60 outstanding technologists, scientists and professionals.

As we approach the spring of 2024, we look forward to taking ownership of the new facility, with a huge amount of work to follow in commissioning the laboratory spaces and the IT infrastructure. Key activities planned for 2024 include device and nanofabrication work package procurement, the continued expansion of our technical programme to include cold-atom tweezer array platforms, and continued growth in SparQ and our quantum readiness efforts. As part of the testbed initiative we will also be deploying a series of quantum-computing platforms into our new facility.

Throughout 2024, we will be supporting colleagues across the National Quantum Technologies Programme (NQTP) and the Department for Science, Innovation and Technology to develop clear delivery plans in support of the National Quantum Strategy, and we will be working with new partners as the next round of Doctoral Training Centres are awarded and the Phase 3 Hub refresh is concluded. We seek to play a key role with new and existing collaborators to further extend the immense strides the UK has made in the first 10 years of the NQTP.

Through the testbed initiative we will gain access to a range of platforms to evaluate and benchmark performance, and to enable us to follow a twin-track approach: pursuing in-house development in parallel with the evaluation of external platforms. Over time this will enable us to develop new processes, methodologies and expertise to learn what can be delivered within time, cost and performance limitations, and to help de-risk technical milestones on the development and deployment of quantum computing. For industry providers this will establish the NQCC as an early customer, while the ability to engage with QSL super-users will deliver new capabilities and insight for the UK ecosystem.

Finally, 2024 will be a pivotal year for us to bring our people, our community and our technical programmes together in our world-class facility on the Harwell Campus.

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