









Department for Science, Innovation & Technology



# **Executive Summary**

This five-year review provides an overview of the impact achieved by the PostGraduate Institute for Measurement Science (PGI) over the period from 1 January 2020 to 31 December 2024

The National Physical Laboratory (NPL) is a trusted institution and our strategic partners, the University of Strathclyde and the University of Surrey, are leading academic institutions with vast expertise in industrial collaborations and doctoral training. All three organisations have extensive networks across the UK and overseas. Working within the framework of this strategic partnership, the PGI has developed its influence and convening power to shape new opportunities for PhD research in the UK.

Our fully funded doctoral researchers gain industrial experience, working in exciting and varied environments, with access to top innovators, and utilise cutting-edge equipment at national laboratories and universities. This combination enhances their PhD experience and makes our postgraduates highly sought-after employees, paving the way to rewarding careers.



Dr Richard Burguete Head of the PostGraduate Institute. National Physical Laboratory

The PGI is building research opportunities across sectors and disciplines, aligned with national and global challenges and research strategies, as demonstrated by the diversity of case studies presented in this review.

# **Mapping our Success**

Through NPL and our academic and industrial partners we provide access to over 1,000 scientists and engineers who are nationally and world leading in their fields, as well as providing links to business development and policy experts.

## **Building Future Leaders**

330

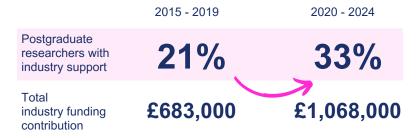
Students have been awarded a PhD through the program

Graduates have gone on to be employed at NPL



\*Current roles from 298 respondents in 2024

#### **Industry Readiness to Strengthen** the UK Workforce



The growth in our industrial engagement with 58 current industrial partners establishes a strong pipeline of highly skilled and industry-ready graduates. These graduates strengthen the UK and international workforce, and the PGI has had a considerable impact on National Measurement Strategy research and its application across the public sector, industry, and academia.



By building a community for our Postgraduate Researchers (PGRs), the cohort experience that the PGI provides transforms the research environment for PhD students associated with NPL. This enables our researchers to showcase their talents to a wide range of interested stakeholders, develop effective networks, and has enriched their appreciation for the relevance and need for measurement science to address global challenges.

# Sustainable Growth

200+

Current students: Leaders and innovators in the making



# Skill Development and **Knowledge Transfer**

PGI cohort events

Hours (yearly average) of training event touchpoints since 2020

1400

**507** 

**PGI** conference attendees across the last 5 years



# The PGI Story

The enduring and successful partnerships of NPL with the University of Strathclyde, the University of Surrey and the Department for Science Technology and Innovation (DSIT), are exemplified by the PGI and its cohorts of PGRs.

Working together the partners have combined complementary areas of expertise, building on experience and research via collaborations with industry to advance the impact from research and development in the UK. These partnerships have played a key role in helping NPL realise its vision to be:





PGI ambassadors and staff at the Value Proposition launch in 2024

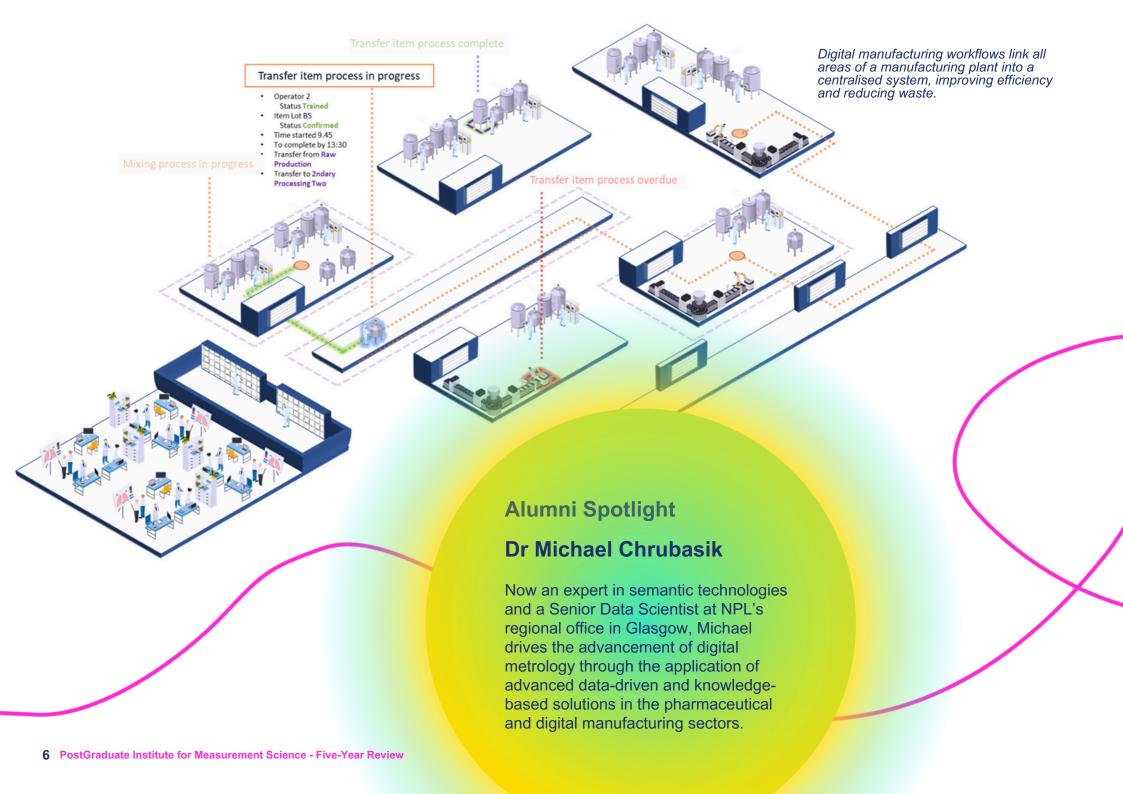
**An exemplary National Laboratory that** undertakes excellent science and engineering and uses this to deliver extraordinary impact for the UK.

The PGI is a recognised centre of excellence equipping the UK with an exceptionally skilled workforce ready to tackle real-world challenges. The development of flexible studentship funding streams that support projects aligned to partner strategic objectives has created a strong pipeline of cross-disciplinary PGRs. These PGRs benefit from the wider network of industrial and research organisations introduced by the partnership.

As an outcome of the previous five-year review, the PGI conducted a benchmarking exercise to evaluate its performance against similar organisations. This provided positive assurance that we successfully delivered our objectives, and highlighted opportunities to build on this with a much stronger articulation of the value and uniqueness of the PGI.

Through an extensive co-creation process with a diverse group of stakeholders, our newly crafted vision and remit was set out as follows:

'The PGI is the UK home for measurement science skills development. Nurturing a talented lifelong community, in partnership with academia and industry.'



# The Impact of Measurement Science



A Raman spectroscopy laser system

# The Impact of Measurement Science: Creating a Sustainable Environment

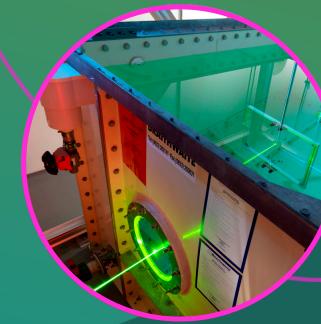
The need to decarbonise our economy whilst monitoring and adapting to climate change is driving significant transformation across all sectors. Balancing the sometimes conflicting needs of society and our environment is a complex challenge.



Top: Controls for a Repeater Laser at NPL.

Bottom: The large underwater acoustics tank

From transitioning the energy system from fossil fuels to ensuring net zero development, our students engage in providing the measurement solutions to identify and deliver action to eliminate environmental damage.





Kalyani Ramanan, University of Edinburgh Satellite-Derived Methane Emission Certification – A Trusted Source of Climate Information

The Paris Agreement initiated a progressive shift, driven by technological advancement and new regulations, towards using satellite observations to locate and estimate emissions of the potent greenhouse gas methane. Large plumes originating from fossil fuel extraction sites are particularly important. Despite these advances, the methods for estimating methane emissions and their associated uncertainties (stemming from factors like wind, surface features, and sensor characteristics) often lack transparency. This hinders the reliability of emissions data products.

#### Solution

This project is investigating the sources of uncertainty in satellite-derived methane emission estimates. By applying principles of metrology to the satellite retrieval of greenhouse gas data we ensure that all uncertainties are accurately reflected in the final emissions products.

#### **Impact**

This validation process is crucial for certifying that the data products are fit for purpose. Reliable emissions data are essential for informed decision-making and evaluating the effectiveness of climate mitigation strategies, ultimately supporting global efforts to combat climate change.

#### Challenge

Carbon capture and storage (CCS) is a way of reducing carbon dioxide (CO<sub>2</sub>) emissions, to help tackle global warming.

The Intergovernmental Panel on Climate Change (IPCC) stressed that to achieve the ambitions of the Paris Agreement, limiting future temperature increases to 1.5°C (2.7°F) and increasing efforts to reduce emissions is not enough. Deploying technologies to remove CO2 from the atmosphere is vital.

#### Solution

This project focuses on improving the selection and application of adsorption materials for Direct Air Capture (DAC) of CO<sub>2</sub> under realistic conditions. We use molecular simulations to predict how well materials like Metal-Organic Frameworks (MOFs) can capture CO<sub>2</sub> from air. We simulate how different force fields impact the accuracy of this prediction, a key to developing efficient carbon capture technologies.



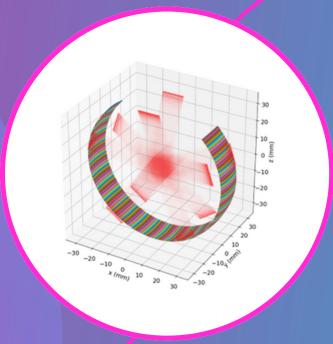
Khadija Asif, University of Strathclyde Tackling Global Warming

#### **Impact**

Refining the computational methods can better predict which materials can be most effective in real-world scenarios. These findings could significantly enhance the development of DAC technologies; providing a more reliable method for identifying high-performing materials, leading to more efficient carbon capture solutions, and helping industries reduce their carbon footprint - thus contributing to global climate goals.

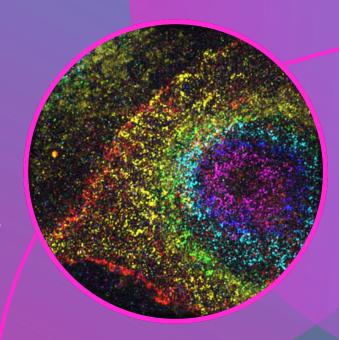
# The Impact of Measurement Science: Accelerating Cancer Research

In 2022, there were an estimated 20 million new cancer cases and 9.7 million deaths. The number of people living with cancer up to five years after a diagnosis was estimated at 53.5 million. About 1 in 5 people develop cancer in their lifetime, and approximately 1 in 9 men and 1 in 12 women die from the disease.



Billy Vale's 3D simulation of the NIR imaging detector, used to detect CAR-T cells.

3D distribution of protumorigenic receptor CCR5, with each colour representing CCR5 in a different layer of a hamster ovary cell, measured by Patrick Hunter.



**Ground-breaking research has** been undertaken by our PGRs to support innovative treatments which require novel approaches to measurement to ensure better outcome for cancer patients.



CAR-T cell immunotherapy is an emerging powerful technique for cancer treatment. While it is effective in treating haematological cancers, methods for quantifying the spatial concentration of CAR-T cells in vivo are necessary to better understand and improve its efficacy for solid tumours.



Billy Vale, University of Surrey Deep Learning for Improving Photoacoustic Imaging for CAR-T Cell Cancer Immunotherapy

#### Solution

One approach involves modifying the CAR-T cells, causing them to produce photochromic proteins that provide strong near-infrared (NIR) optical contrast. NIR photoacoustic (PA) imaging is then used to image these proteins which causes them to photoswitch and leads to a variation in the contrast between successive images. Thus, the time varying contrast provided by the proteins is distinguishable from the time-invariant background tissue signal.

We developed a forward simulation model to generate synthetic PA images of samples containing the photochromic proteins, which we then used in machine learning experiments. Results demonstrate that, using our dataset, convolutional and transformer neural networks can detect protein concentrations of 10-8 M with ~99% accuracy.

#### **Impact**

This multi-disciplinary research integrating physics simulations and artificial intelligence is part of the effort to advance non-invasive high-accuracy quantitative in vivo imaging of CAR-T cells in general, and to accelerate preclinical research in cancer immunotherapy for solid tumours.



Patrick Hunter, University of York Shedding Light on the Onco-Immunogenic CCR5 Receptor, One Protein at a Time

## Challenge

With around 375,000 new cases of cancer reported across the UK annually, the advent of effective therapeutics would help to relieve crises within health services and amongst thousands of families across the UK. The ability of tumours to establish a protumorigenic microenvironment is an important point of investigation in the search for new therapeutics. Tumours form microenvironments in part by the 'education' of immune cells attracted via chemotactic axes such as that of the chemokine receptor CCR5 and its binding partner CCL5. Further, association with pro-tumorigenic features such as drug resistance and metastasis has suggested CCR5 as a therapeutic target. However, with several conformational 'pools' being reported, phenotypic investigations must be capable of unveiling conformational heterogeneity.

#### Solution

Addressing this challenge, we performed super-resolution structured illumination microscopy (SIM) alongside single-molecule partially TIRF-coupled HILO (PaTCH) microscopy of CCR5 in fixed cells. SIM data revealed a nonrandom spatial distribution of CCR5 assemblies, while intensity-tracking of CCR5 assemblies using PaTCH indicated dimeric subunits independent of CCL5 perturbation.

#### Impact

Extensions of this study to investigate the effect of CCR5 antagonists on the behaviour of CCR5 can provide important insights into the function of prospective therapeutics.

# The Impact of Measurement Science: Harnessing Nuclear Power

Radiation and radioactive isotopes have a variety of applications, and accurate measurement is fundamental to all of them. The National Physical Laboratory and the University of Surrey have a partnership that includes nuclear physics research.



Over the past 10 years jointly funded students researched the routine use of nuclear power and the decommissioning of redundant nuclear plant, safeguarding the public and the environment while increasing industry understanding of nuclear fusion and nuclear medicine.

The increase in usage of nuclear fission to generate electricity is likely to lead to an increased volume of radioactive waste and spent fuel storage in ponds, which must be carefully and safely handled. The spent fuel is likely to be stored in these ponds for at least half a century and therefore requires the development of measurement systems for the long-term monitoring of fuel condition.



Sifa Poulton. University of Surrey What's the Ratio? Enhanced Safety Monitoring for Nuclear Fuel and **Power Stations** 

#### **Solution**

One proposed monitoring system would measure the abundance of different xenon isotopes produced by nuclear fission. The conditions under which fission occurs affects the isotopic ratio of xenon produced and so changes in the ratio would indicate changes to reactions occurring within the fuel. This principle is currently being used as a fingerprint to detect illegal weapons tests, which has demonstrated its effectiveness. It requires adaptation, including in timescales of detection, before it can be deployed within the civil nuclear industry. The monitoring system would employ coincidence detection methods to increase sensitivity to weak xenon signals by reducing the background.

#### **Impact**

Xenon detection systems can be used for safety monitoring in a range of civil nuclear applications. As well as stored fuel, they could be used as an additional criticality monitoring tool for active nuclear power plants and provide a way of measuring an important reactor poison. They could be deployed during decommissioning activities to search for compromised fuel rods and monitor the condition of corium during clean-up operations.

Ed O'Sullivan. University of Surrey Tailored Therapeutic Solutions through Diagnostic Imaging



#### Challenge

Terbium-152 is an isotope with promising properties for nuclear medicine. Its radioactive decay releases positrons which can be used for PET imaging, and its chemical properties give it promise for theragnostics, an approach to cancer treatment that combines diagnostics and therapy. But the details of the radioactive decay are not well known, and improved nuclear data is vital for this substance to be used routinely in a clinical setting.

#### Solution

To study this decay, samples of Terbium-152 were created with a high-energy proton beam, using a particle accelerator and strong magnets to separate out impurities. We investigated the radioactive sources using a high-resolution detector array to carry out gamma-gamma coincidence spectroscopy of the decay. The array allows correlation of gamma rays emitted within nanoseconds of each other, filtering out background radiation to determine the energy of excited states in the daughter nucleus.

#### **Impact**

Ongoing analysis of the data revealed the identification of twelve previously unknown high-energy excited states and the placement of many gamma rays into the decay scheme. These high-energy states are populated by low-energy beta decays, revealing that the average decay energy has so far been overestimated. This research will revise radiation dose estimates for patients, supporting the medical field with traceable nuclear data, allowing doctors to tailor therapeutic doses to individual patients based on the results of diagnostic imaging.

The Impact of Measurement Science: Revolutionising Quantum Technologies

Quantum technologies are revolutionising many aspects of our lives and bringing enormous benefits to the economy, society, and the way we can protect our planet. The PGI is developing a next generation of scientists and engineers who can leverage the unique quantum behaviours of matter to build more efficient, powerful, and sustainable technologies.

> Part of an atomic clock system – a magneto-optical trap chamber - showing fluorescence.



Atomic fountain clocks are currently the best microwavebased clocks available to humankind: they laser-cool atoms down to the single microkelvin regime to define the SI second with 16 digits of accuracy and precision. However, they are large, expensive apparatus whose use is limited to well-funded research laboratories. As the ultimate source of the long-term stability of national timescales, wider access to accurate, drift-free clocks would improve society's resilience to loss of Global Navigation Satellite System (GNSS) coverage, which is currently the workhorse of precise time distribution.

#### **Impact**

The result is a clock that is less than half of the height, and approximately 20x smaller in volume, than the Primary Frequency Standards, while achieving a similar linewidth on the clock transition. The aim now is to optimise the short-term stability via the signal-to-noise ratio of the compact detection method, such that the longerterm stability and systematic effects can be fully evaluated.



Samuel Walby. University of Oxford Designing, Building and Testing a Mini-Fountain Cold Atom Clock

#### Solution

To effect wider adoption of atomic fountain clock technology, we have been working on designing, building, and testing a minifountain, which aims to achieve similar stability and accuracy to the full-sized Primary Frequency Standards, but at a fraction of the cost and with reduced complexity and size. By only accepting even a slight reduction in performance, many parts of the traditional apparatus become overkill, and can be replaced with more efficient solutions. Particular attention has been paid in the design to improving the design in three areas. Temperature stability was improved by updating the microwave cavity used for interrogating the clock transition. The overall robustness of the laser system was increased by using all-in-fibre optics for generating the light for laser cooling and detection. We reduced the size by carrying out stateselection and detection in the same chamber as the cooling.

"Doing a PhD through the PGI has been fantastic, it's great to have a community of inspiring, like-minded people going through the same experience. I love seeing my hard work translate into real-world progress."

# The Impact of Measurement Science: Advancing New Materials

Materials that can endure the harshest conditions are needed to allow us to dig at the bottom of the ocean and to transport the fuels of tomorrow. Learning to manufacture these materials at scale and incorporating safety and sustainability into their design and innovation is as important as their discovery and development.



The effort is essential to unlocking innovation across all major industrial sectors which could not be achieved without measurement science.

Discoveries of new materials and improvements to old ones all depends on a deeper understanding of the relations between the processing, composition, and structure of materials as well their properties and function.

#### Solution

This project is developing a methodology allowing for in-situ verification of materials. In practice, this would utilise a Scanning Electron Microscope (SEM) and a custom biaxial deformation rig which could deform material within the confines of the SEM, allowing the use of real-time imaging and Differential Interference Contrast Microscopy (DIC) to understand how materials behave under complicated loading conditions. These conditions are more indicative of the conditions seen in sheet-metal manufacture which is used throughout the aerospace and automotive industries.



John Catterson. University of Strathclyde Improved Metallurgical Manufacture via Multi-axial Testing.

#### **Impact**

The closer the ability to characterise materials aligns with their actual performance, the better their selection and utilisation for their intended purpose. Developing a novel means of characterising materials and subsequently characterising previously unknown materials presents new opportunities for industry to better fit their requirements.



Jacopo del Gaudio, University of Manchester Large Volume 3D Imaging of SSC Crack in Nickel Superalloy 600 Using fs-Laser Serial Sectioning Technique.

## Challenge

Stress corrosion cracking (SCC) occurs when a susceptible material is subjected to stress in a corrosive environment. SCC is a major failure mechanism in the primary circuit of pressurized water reactors and a significant threat to the performance of nuclear power plants with significant economic impact.

#### Solution

This project aims to measure the crack path in three dimensions (3D) in space in relation to the microstructure of the material, which will help to design alloys to inhibit crack initiation and growth. The aim is to measure the crack propagation across hundreds of microns with sufficient accuracy to measure the microstructural properties that may affect crack development on a large scale. The images from an X-ray computed tomography (XCT) and fslaser serial sectioning (fs-laser SST) of the slices must be accurately aligned to provide a true representation of the 3D volume. The process included a new guideline for minimizing and quantifying the misalignment of the slices by milling a set of reference marks of known position and orientation on the sample surfaces.

#### **Impact**

The process can be reconstructed during the post-measurement rendering analysis to estimate the bias due to the slice shape and position. The errors and uncertainties in lengths and angles will be calculated to measure the crack path and microstructure properties. Calculating these with sufficient confidences to reliably describe the parameters that determine material performance under SSC can prevent equipment failure without warning and minimize the risk of SCC.

# The Impact of Measurement Science: **National Reach of the PGI**

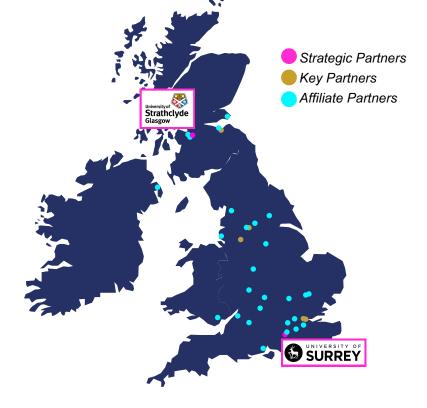
As the UK's National Metrology Institute, NPL delivers national impact by leveraging expertise in measurement science across the UK, using its status as a national laboratory to advance economic, social, and environmental benefits tailored to the unique needs of local industries and communities. The PGI and NPL's regional focus are at the heart of this mission connecting local actors to NPL's research goals, enabling co-funded PhDs with 41 separate universities and over 50 industry partners across the UK in this five-year period.

The PGI is integral to the success of NPL's national ambition by building relationships with local and regional academic and industry partners. The impact generated is evident in the more than 189 co-funded studentships across the UK initiated since January 2020. Local knowledge and relationships are vital to building communities and capabilities with partners across the UK, supporting the development of a highly skilled workforce for initiatives such as the National Quantum Technology Programme.

In key regions, the PGI population has grown significantly with cohorts reaching a critical mass that enables local support amongst PGRs and supervisors. This network is proving invaluable for organising and hosting the PGI conferences in Strathclyde (2023) and Manchester (2024).

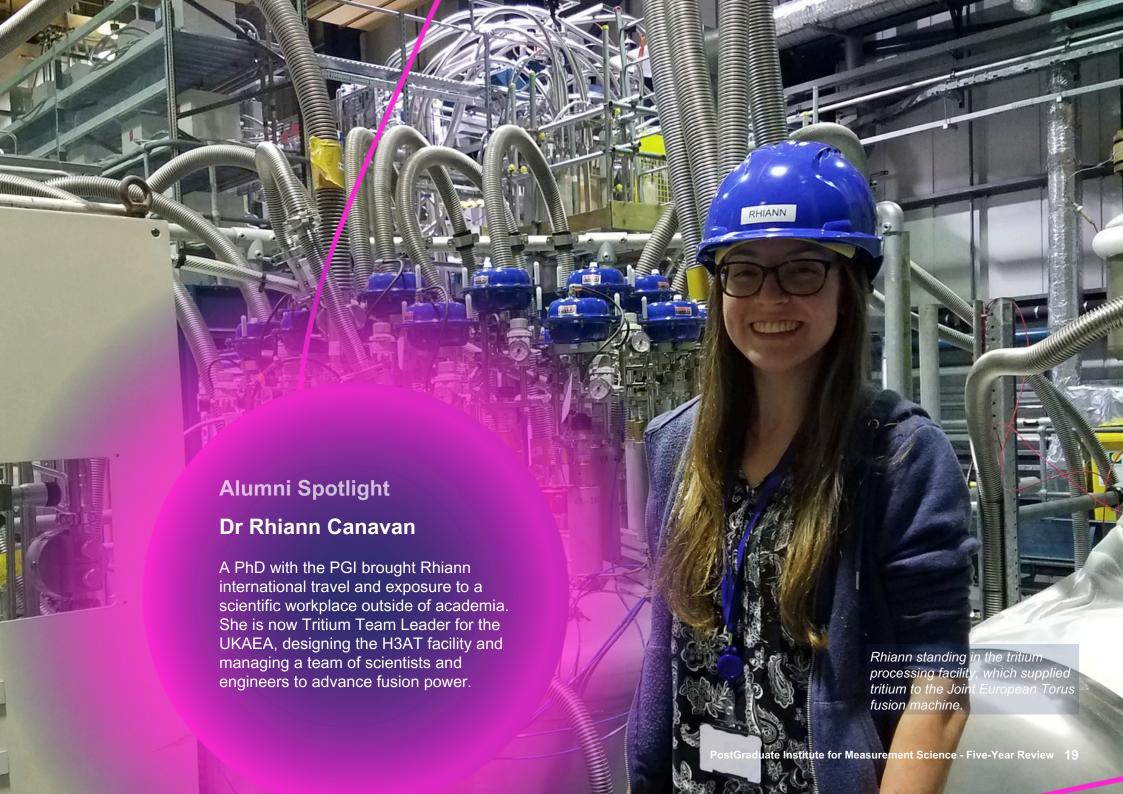


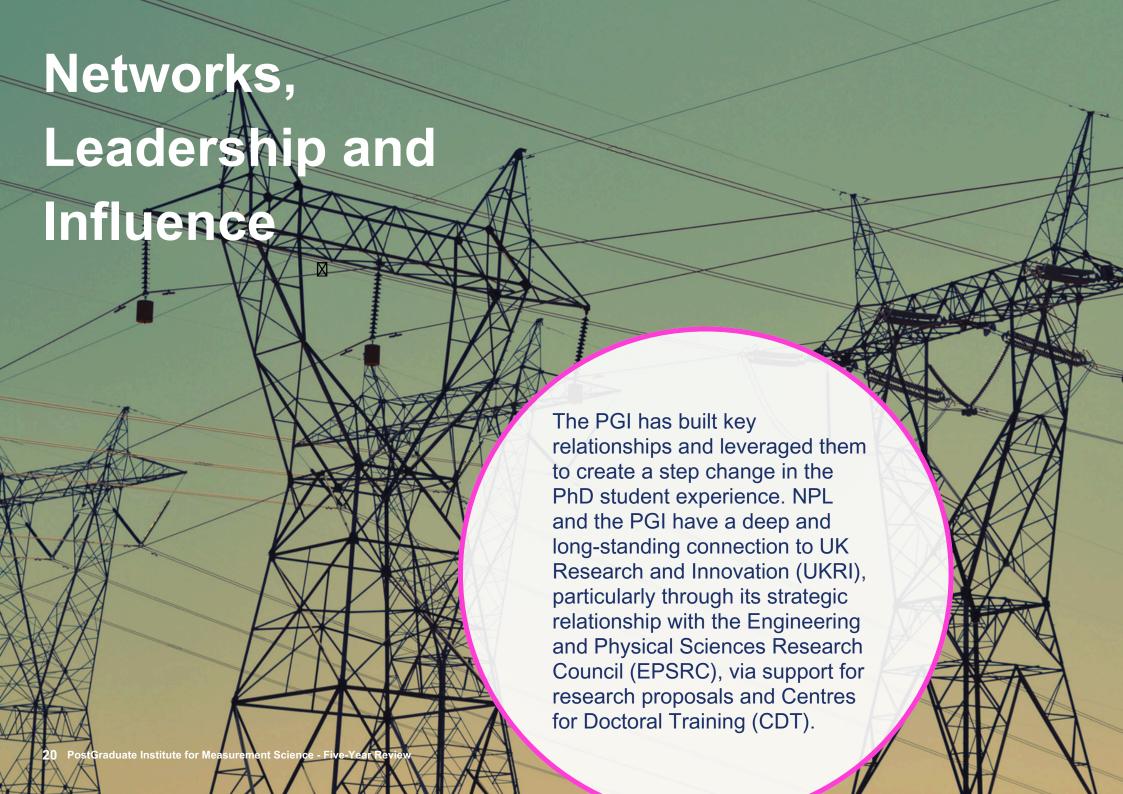
Dr Jingjing Wang on the PGI as a platform for growth



"During my PhD with the PGI, at the University of Manchester, my research centred on the characterisation of solution-processed graphene and organic molecules, primarily through Raman spectroscopy. I now work as a **Higher Scientist at NPL in the Surface Technology Group** based at Manchester University. I chose to work for NPL not only because of NPL's reputation for cutting-edge research in surface technology but also for its commitment to innovation. This aligns perfectly with my

career aspirations and the unique opportunity to collaborate within a world-class research environment that spans academia and industry. Being in Manchester allows me to remain connected to the scientific community that has supported my growth from my PhD to my current role. Looking ahead, I want to further develop my expertise in nanomaterial characterization and lead impactful projects. My goal is to bridge fundamental research and practical applications."





The PGI's support has concentrated on developing new PhD models and funding structures. These address priorities such as equality, diversity and inclusion and the growth of the doctoral talent pipeline needed to underpin the UK's ambition of leading global research and innovation.

Ongoing collaborations with the Association for Innovation, Research and Technology Organisations (AIRTO), and the Campaign for Science and Engineering have established our relevance in the UK research landscape. NPL is the Chair of the Academic Working Group for the National Laboratories Alliance (NLA) and through this the PGI takes a leading role in positioning Public Sector Research Establishments (PSRE) as key players in the UK's research and innovation ecosystem. One of NLAs main objectives is to increase visibility and understanding of the value of PSREs in the Research Development and Innovation landscape. Collectively, NLA organisations currently sponsor over 1,000 PhD students, with support and funding from UKRI Research Councils, working with them to deliver effective doctoral research and training.

The PGI engages directly with the UK government via the Government Science and Engineering (GSE) Profession network that sits within the Government Office for Science (GO-Science) and participates in the STEM Futures Programme which supports mobility and knowledge exchange between organisations from across industry, academia, and the public sector.

Capitalising on the strategic partnership between NPL, its regional centres, the University of Strathclyde and the University of Surrey, the PGI is well positioned to engage with and influence research agendas amongst a wide range of academic institutions, business interests, and major funding agencies. Through these links, the PGI identified and implemented collaborations that add value to the UK.

At an international scale, the PGI has been engaging with partners in Europe and further afield including Brazil, Singapore and Japan. We also interact with university-industry knowledge transfer organisations such as the University Industry Innovation Network (UIIN) and the University Industry Demonstration Partnership (UIDP) bringing the impact of PSRE research to a wide audience.



#### What the Future Holds

The PGI will continue to deliver the agile and responsive talent and skills development system needed to support a world-class workforce in STEM and drive economic growth for the UK. Equally, we will advocate for better outcomes for doctoral research linked to the evolving research landscape and industrial needs of the UK. Through our engagement activities with bodies such as the Association for Innovation, Research and Technology Organisations, the UK's National Laboratories Alliance, and the Campaign for Science and Engineering, we will ensure that we are playing a pivotal role in influencing the PGR landscape and future funding for PhD research.

# The values of the PGI underpin how we will continue to engage with our community:

#### We Connect

The sustainable relationships we create between our students and partners are everything. Being approachable, respectful, and inclusive means our extraordinary students can go further than they dreamed possible by being part of world class teams.

#### We Elevate

We nurture curiosity and talent during the PhD journey and beyond. Equipping our people with the technical and holistic skills UK businesses need to thrive. Identifying the insight and research that will take global measurement science to the next level.

# We Inspire

Our experts are at the vanguard of collaborative science and engineering that changes the world. We unlock potential to give our past, present, and future postgraduates the confidence to lead and innovate.



# The PGI's ambition is to excel and deliver against the following objectives:

- → Shape training in metrology, technical and research skills to develop future leaders in science and engineering.
- → Create enduring academicindustrial partnerships that focus on research impact delivered by postgraduate researchers.
- → Influence policy and strategies impacting PhD research and skills development.

- → Promote the PGI model of collaborative PhD delivery highlighting the benefit of working in an agile and creative way.
- → Increase the diversity of partnerships to enhance the impact generated by the PGR community at a local, national and international level.

Join us as the PGI champions PGR development and leads on addressing national and global needs, whilst being flexible and building resilience for the future.

Given the success of the last ten years, the PGI is ideally placed to transform this ambition into reality!



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PGI Conference attendees at NPI

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m www.linkedin.com/company/pgimetrology

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