



ANNUAL REVIEW

2018/2019

National Physical Laboratory

The National Physical Laboratory (NPL) is the UK's National Metrology Institute. At the heart of our mission is delivering impact by disseminating research and measurement best practice and traceability for the economic and social benefit of the nation.

National Physical Laboratory

Hampton Road
Teddington
Middlesex
TW11 0LW
Switchboard **020 8977 3222**
www.npl.co.uk/contact

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CEO'S INTRODUCTION



Our vision is to deliver extraordinary impact from excellent science and engineering as an exemplary national laboratory. I have been delighted with our many achievements that show how we are making progress towards this vision.

It was an honour to witness the revision of the International System of Units (SI), so that all SI units are now defined in terms of constants that describe the natural world. This was a historic, once in a lifetime change; with scientists working at NPL over many decades making pivotal scientific contributions as part of this worldwide collaboration. The late Bryan Kibble, who developed the Watt balance while working at NPL, was internationally recognised as a critical contributor to the revision, and in recognition of this, the SI community renamed the Watt balance as the Kibble balance.

Our people are our greatest asset and continue to demonstrate leadership in a wide range of scientific fields. Helen Margolis,

Martin Seah and Andrew Hanson were recognised with MBEs in the Queens Honours list, while Graham Machin, Gareth Hinds and I became Fellows of the Royal Academy of Engineering. Martyn Sené, NPL's Deputy CEO, became President of the International Committee for Weights and Measures (CIPM) Consultative Committee on Ionizing Radiation, the first person from NPL to hold such a position in 25 years. Perdi Williams was selected as one of the UK's Top 50 Women in Engineering for her work on helping to redefine the kilogram. We also recognised three of our own scientists as new NPL Fellows: Josephine Bunch, Olga Kazakova and Paul Brewer, for their expertise in Biomolecular Analysis, Quantum Materials and Sensors, and Chemical Metrology, respectively.

We are a values-led national laboratory and I am very proud that our diverse and international workforce continues to deliver impact that is global in nature. NPL is the first non-university to achieve the Institute of Physics' Juno Practitioner status, for addressing gender equality, and recently offered 4 Daphne Jackson fellowships to support and mentor researchers back into STEM careers after breaks. Our outreach activities, involving many of our staff as STEM ambassadors, take science and measurement out to the community to promote STEM careers and increase public engagement with science. Annually we organise over 300 activities and engage with over 70,000 people.

Recent scientific highlights include a publication in *Science* magazine describing laser-based techniques to develop an innovative method of detecting underwater earthquakes, using undersea communication cables. We are also involved in working on the world's most advanced network of air quality monitors to better understand Londoners' exposure to air pollution; have helped create a synthetic virus to tackle antimicrobial resistance; and continue to lead a multi-disciplinary consortium to build a 'Google Earth' of cancer, funded by one of the biggest grants ever awarded by Cancer Research UK. Partnerships are key to our success. Our relationship with our strategic partners, the University of Strathclyde and the University of Surrey, has enabled the Postgraduate Institute (PGI) to grow to well over 200 students.

We led an industrial engagement initiative on behalf of

Sir Mark Walport that helped shape the second phase of the National Quantum Technologies Programme, and our independent report on superconducting materials informed the shape and size of the new National Quantum Computing Centre. I am pleased to report that construction of our Advanced Quantum Metrology Laboratory is nearing completion. This new laboratory will provide world-leading facilities and will further enable NPL's work in conducting frontier research in quantum technologies.

We launched the new Metrology for Medical Physics Centre (MEMPHYS) to help accelerate the development and implementation of innovative early diagnostic and therapeutic technologies. This new approach will see NPL focus on tackling some of the world's biggest health challenges, from supporting the diagnosis and treatment of diseases such as cancer and dementia, to drug efficacy evaluation.

We continue to support businesses both small and large through the Analysis for Innovators (A4I) programme, helping companies like Adaptix develop an innovative new technology that could revolutionise medical imaging, and Precision Products UK to better understand its chrome plating process and make major efficiency improvements. Our Measurement Services grew 12% in the last year, and our NPLTime® service has expanded to support more companies in the finance sector. We reached a significant milestone in our quest to commercialise our diabetic foot ulcer device, with the formation of a subsidiary - Footprint Medical Limited.

Over 900 companies responded to a survey on the impact of the National Measurement System (NMS). As the UK's National Metrology Institute we deliver the NMS in line with the UK Measurement Strategy along with other Designated Institutes. We found that customers are highly satisfied with the NMS: there was high satisfaction with the reputation of the NMS, the quality of outputs, value for money of services, and the flexibility of and relationships with staff. In response to feedback we are focusing on continuing to improve the timeliness of our responses and delivery.

All of this means that NPL is continuing to maximise its impact on UK prosperity and quality of life. We have seized new opportunities and are responding rapidly to our customers' needs and continue to play a leading role in the international metrology community. We aim to further enhance our impact by taking the lead on further national challenges where measurement has a key role to play; continuing to develop products and services that our customers can benefit from; and extending our presence across the UK to enable more companies to benefit from our expertise.



Dr Peter Thompson FEng
Chief Executive Officer

NATIONAL CHALLENGES



Our science and engineering is focused on developing solutions for some of the biggest national and international challenges

At NPL we apply our science and engineering knowledge and work with business, governments, researchers and others to address these challenges and opportunities, with a focus on the challenges in: advanced manufacturing, digital, energy and environment, and life sciences and health. With a specific focus on global trends which will transform our future, like: artificial intelligence and data; ageing society; clean growth; and future of mobility.

Advanced manufacturing

We are creating and delivering innovation and measurement technology to enable organisations across all industrial sectors to innovate and compete

Global and national trends in manufacturing such as digital industrialisation, environmental concerns and energy challenges are generating new markets, products and disruptive materials and processes.

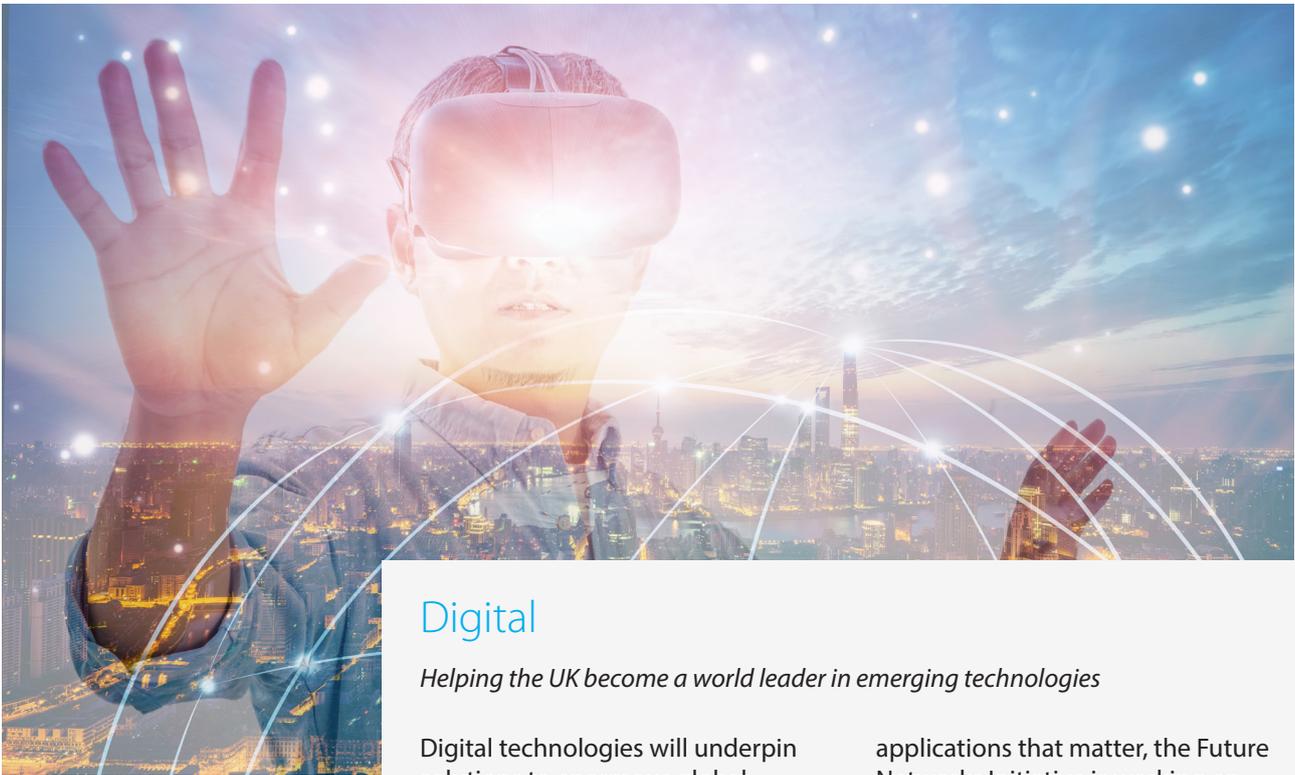
The transition to a digitalised manufacturing landscape will see a step change in the volume of data used in manufacturing, how it is used and why. As people and processes become increasingly reliant on data to inform decisions and actions, trust and confidence in data will become critical. Generating trusted data and providing the confidence to act on the information it provides is dependent on having a good understanding of the measurement system that created it.

NPL is developing the metrology tools to give UK manufacturers the confidence to adopt digital technologies and devices. It is

working to de-risk the use of data and its application throughout the manufacturing process and supply chains. As the UK's independent and impartial National Metrology Institute, NPL is uniquely placed to lead the measurement, metrological and data confidence challenges that are arising in the space of industrial digitalisation.

NPL is working with industry to develop embedded sensors that give the highest quality information, for in-process monitoring. A recent example is the development of printing sensors onto cutting tools that enabled real time monitoring of tool wear. Overcoming the challenges of extracting and understanding the data flowing from such a harsh and noisy environment is not an easy task but enabled significant improvements in overall equipment effectiveness and reduction in waste. It is this kind

of in-process technology that will help reduce the costly and time-consuming end-of-line inspection. NPL is also working with national and international stakeholders in the autonomous transport sector to develop and deploy new measurement technologies to support the assurance of autonomous systems. This includes ground breaking projects with Lloyds Register to develop the testing framework to support Marine Audio Video classification; and the development on behalf of Centre for Connected and Autonomous Vehicles, of standardised sensor testing frameworks and infrastructure, including complex data models for weather types, to support the safe and reliable deployment of connected and autonomous vehicles on UK roads. In both cases NPL is helping UK businesses develop a position of international leadership.



Digital

Helping the UK become a world leader in emerging technologies

Digital technologies will underpin solutions to enormous global challenges, such as energy consumption, emissions and food security. Measurement and standards are key to an effective digital infrastructure, providing confidence that will accelerate societal engagement with all things digital. The cornerstone of NPL's digital sector strategy is to embed measurement into processes using digital and data science, delivering confidence in the intelligent and effective use of data and emerging technologies.

In 2019 NPL initiated a national endeavour known as The Future Networks Initiative. This is an industry-led activity to establish a mechanism for pre-commercial collaborative research and development to place the UK at the forefront of digital technologies, together with the communications networks required to enable digital transformation across multiple applications and uses. The focus of the initiative is to create a government-supported, national scale, converged network test bed that connects multiple communications networks and operators. By focussing on convergent communications, automated and delivered at the 'speed of AI', to the areas and

applications that matter, the Future Networks Initiative is working on evolving the UK's existing digital infrastructure while developing our future communications networks, technologies, services and supply chain.

Scientific teams across NPL have also combined expertise and capability to generate new measurement solutions for the important UK precision farming and food market. Yields have stagnated in many regions of the world, but an increase of over 70% is needed to meet the projected food demand by 2050. In 2019 NPL developed a new solution for imaging wheat, a key UK crop, in large scale field trials. The solution incorporated 3D sensor measurement systems, computer vision, a tractor pulled vehicle and post processing algorithms to offer a data-driven final product for agronomists and plant breeders.

Food waste in farming remains a concern and we have continued our collaborative work for automated harvesting and sorting sensing systems, with strawberries and raspberry robotic pickers all in progress through this year's current season to ensure all fruit is picked, disease detected at an early stage, helping to mitigate the continuing challenge of labour.



Energy and environment

Enabling a clean, efficient energy system and working towards the sustainable use of natural resources, to ensure a healthy environment

The need to decarbonise our economy, while monitoring and adapting to climate change, is driving huge transformation in all sectors.

The UK government is committed to reducing our impact on the environment and transforming our energy system to make it cleaner and more affordable, through the Clean Growth Strategy and the 25 Year Environment plan, as well as collaborating and supporting other countries to reduce their impacts. Our greenhouse gas emission reduction targets are among the most ambitious globally and the next few years will see record investment in clean growth innovation.

NPL is focusing on creating an integrated approach to transitioning to a net-zero UK economy by 2050, leading and delivering on climate science and assuring a sustainable relationship with our environment through resource efficiency, waste and pollution reduction.

Our science supports the entire energy value chain: from energy sources and through the energy vector, to energy efficiency in high emissions sectors such as transport, industry, land use and the built

environment. Specific sectors where NPL works to address challenges include for renewables, nuclear, batteries, carbon capture usage and storage, and hydrogen. Through NPL's work on hydrogen electrolysis, we have discovered how to half the cost of the most expensive component, the electrodes.

We have worked closely with Government to ensure good science underpins climate decisions and have successfully proposed the NPL-designed TRUTHS (Traceable Radiometry Underpinning Terrestrial- and Helio-Studies) satellite mission into the European Space Agency (ESA) Earthwatch programme. TRUTHS will establish an SI traceable, space-based climate and calibration observing system to improve confidence in climate measurement and climate forecasts.

To help reduce pollution and improve air quality in the UK, NPL is running a network of ambient measurement sites that provide public health information, monitor compliance with UK and EU regulations and input to air quality modelling and research aims on behalf of the Department of the Environment, Food and Rural Affairs.

Life sciences and health

Working to deliver personalised medicine, new treatments and earlier diagnosis

In line with the industrial strategy, there is a drive for greater translation of technology development and improved patient access from academia to industry into the healthcare system.

NPL helps to maintain the UK's position as a world leader in translating life sciences research, accelerating access to new diagnosis and treatment techniques, and supporting rapid adoption of advanced healthcare technologies across the country.

We continue to lead the improved diagnosis and treatment of important diseases including cancer, heart disease, diabetes and dementia. Through work in our National Measurement System programme, we have supported improvements in the application of advanced treatments in proton

beam therapy used to treat cancer. NPL won The Engineer's Collaborate to Innovate Healthcare and Medical Award for its work with Lightpoint Medical for their laparoscopic molecular probe for prostate cancer surgery. And our research funded by Cancer Research UK to build a 'Google Earth of cancer' has delivered further insight to tumour biology, which will help to enable improvements to battle a disease that is forecast to impact 1 in 2 people in Britain over their lifetime.

Ongoing investment in our Stimulated Raman Scattering microscopy instrumentation will further strengthen our imaging capability, and working with regulators around the world, we are developing methodologies to enable improved testing and analysis of drug therapies delivered through the skin.



RESEARCH HIGHLIGHTS

We provide advice and information to industry, regulators and academia on a range of international metrology issues. We represent the UK, both at a technical level and at the highest level of metrology, on many international networks and committees.

We have more than 440 world-class laboratories, which enable the highest precision measurements to be realised. We contribute to the UK's National Measurement System and deliver new advancements that deliver real impact on prosperity and quality of life.

Home to over 650 scientists employed across almost every discipline, from physicists to biochemists, and mathematicians to materials scientists, we push the boundaries of what is possible.

SuperFab

NPL opened the UK's first nanofabrication facility dedicated to superconducting quantum technologies at Royal Holloway, University of London. This new national facility houses highly advanced electronic nanofabrication equipment within a clean room and brings together some of the UK's most experienced scientists in superconducting quantum technologies. This facility will enable research and development in the areas of superconducting electronics including on superconducting qubits, quantum sensors and communication devices.

Revolutionising graphene printed electronics

NPL helped carry out measurements for researchers at the National Graphene Institute (NGI) at The University of Manchester, who have found a low-cost method for producing graphene printed electronics. NPL and NGI have also partnered to provide a materials characterisation service to provide the missing link for the industrialisation of graphene and 2D materials; and have published a joint good practice guide which aims to tackle the ambiguity surrounding how to measure graphene characteristics.

DIAL in China

NPL has strengthened its ties with the Chinese National Institute of Metrology (NIM) by signing a Memorandum of Understanding that focuses on Environmental Metrology and simultaneously, a contract for the supply of the NPL Differential Absorption Lidar (DIAL) system was signed. DIAL is a sophisticated remote sensing system that can measure and map emissions of atmospheric pollutants, in real time, and is housed in a completely self-contained mobile laboratory.

UK Centre for Engineering Biology, Metrology and Standards

NPL and Imperial College have announced the establishment of a new £7 million virtual lab to underpin their joint Centre for Engineering Biology, Metrology & Standards to help the UK synthetic biology industry improve the manufacturing and adoption of new products. This new lab will develop and provide relevant reference materials and methods in the form of a toolbox aiming to improve the reproducibility of research results that will help convert innovation in synthetic biology into valuable products and services.

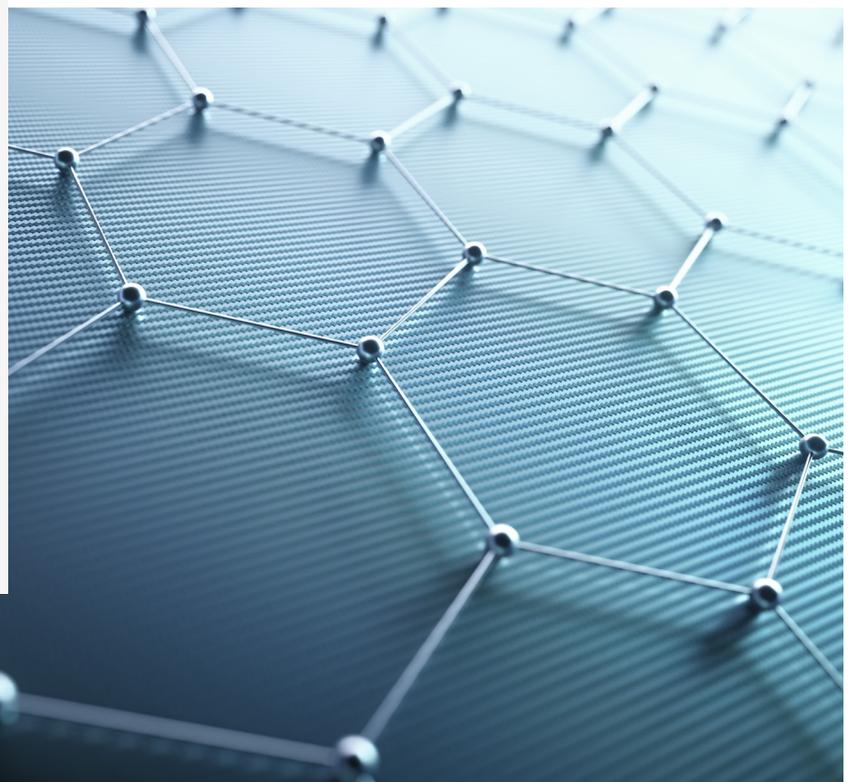


Synthetic virus to tackle antimicrobial resistance

NPL and University College London (UCL) have engineered a new artificial virus that kills bacteria on first contact. The synthetic virus acts as a 20-nm spherical 'drone' that, upon recognising bacterial cells, attacks their cell walls with bullet speed and efficacy. The findings pave the way for exemplar synthetic biology tools for research and therapeutic use, while demonstrating how effective innovative measurement can be in addressing real-life challenges. This will help improve the reproducibility of biological research and technologies, and bring innovative and robust solutions to the market.

Using graphene to detect ultralow concentrations of NO₂

NPL, as part of an international research collaboration, has discovered a novel technique to monitor extremely low concentrations of NO₂ in complex environments, using graphene epitaxial sensors. By developing these very small sensors and placing them in key pollution hotspots, there is a potential to create a next-generation pollution map – which will be able to pinpoint the source of pollution earlier, in unprecedented detail, outlining the chemical breakdown of data in high resolution in a wide variety of climates.



Detecting underwater earthquakes

NPL and the Istituto Nazionale di Ricerca Metrologica (INRiM, Italy) have developed an innovative method of detecting underwater earthquakes by taking advantage of the vast undersea telecommunications cable infrastructure, a global network for underwater earthquakes could be implemented using laser-based techniques.

Quantum

Recent highlights from NPL's Quantum Metrology Institute (QMI) include supporting the commercialisation of Quantum Key Distribution, a theoretically ultra-secure method of communications, by developing and validating methods for counting photons and measuring their quantum states. The QMI is also developing cold-ion microtraps, a scalable on-chip technology for encoding quantum information, and a strong candidate for use in quantum computers. Work is continuing on producing the MINAC Miniature Atomic Clock, a portable reference that brings atomic timing to many new applications and also developing ways to use atomic clocks as sensors of gravity potential. Research is being undertaken to develop atomic magnetometers, which could be used as quantum sensors able to detect brain waves, heart arrhythmia, explosive residue, and corrosion under insulation of pipework.

New ways to twist and shift light

NPL researchers investigated how light can be controlled in an optical ring resonator, a tiny device that can store extremely high light intensities, revealing unusual qualities in light that could lead the way to entirely new electronic devices and applications. The results could open doors to new quantum technologies and telecoms systems.

World's first commercial-grade quantum communications testing link

UKQNTel a collaborative venture between research and industry, is the world's first commercial-grade quantum test network, and a milestone in the progress towards developing secure quantum communications for the UK. NPL collaborated with many industry partners to test and characterise new quantum communications hardware under development.

Measuring gravitation

NPL, working with German and Italian clock experts, has used one of the world's only transportable optical atomic clocks to measure gravitation for the first time. The transportable clock was operated in a laboratory located 1,700 m below a mountain top, in the middle of the Fréjus road tunnel between France and Italy and compared to a second clock located 90km away in Torino, Italy, at a height difference of about 1,000 m. With improvements to the accuracy of the transportable clock, this technique has the potential to resolve height differences as small as 1cm across the Earth's surface. This technology could be used to monitor how sea levels are responding to global climate change.

EMPIR projects

NPL is leading 9, and a partner in 8 further new pan-European projects, as part of the European Metrology Programme for Innovation and Research (EMPIR). NPL is addressing challenges such as realising the newly redefined temperature scale, enhancing the optical techniques for time and frequency dissemination and supporting electronics technologies and electrical goods. NPL is leading the network on the important topic of climate and ocean observation.

Metrology for Medical Physics

NPL has launched a Metrology for Medical Physics Centre (MEMPHYS) to accelerate therapies for cancer, dementia and heart disease. MEMPHYS will function as an international centre for excellence, fostering interdisciplinary and inter-sector research to inspire cutting-edge innovations; working closely with the NHS, academia and industry to enable the rapid and widespread implementation of a host of new diagnostic and therapeutic technologies.

Industrial Internet of Things

NPL in the North of England is involved in a programme of research on Industrial Internet of Things solutions within applied manufacturing processes. Actively building demonstrators, retrofitting sensors and microcontrollers to existing equipment to enable the captured data to be sent to the cloud and processed. We have also been collaborating with an SME to build an industrial demonstrator, upgrading one of their manufacturing processes as a testbed, with plans to evaluate and characterise the sensors and processes remotely.

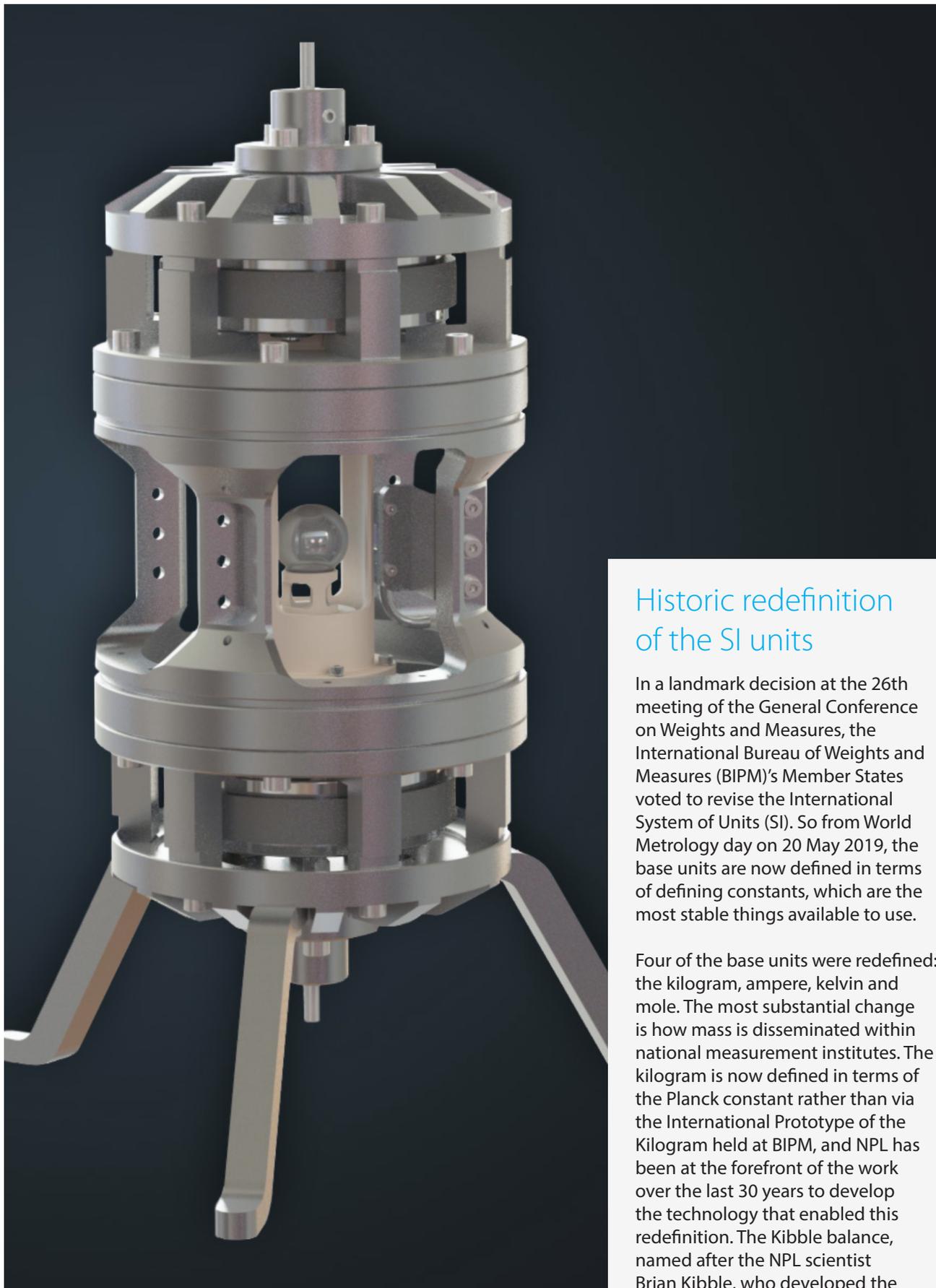
'Google Earth' for tumours

NPL is leading a multi-disciplinary consortium to build a 'Google Earth' of cancer. The project, which won one of the biggest funding grants ever awarded by Cancer Research UK, will work to create a reproducible and standardised map to understand different tumours in unprecedented detail. The multi-disciplinary consortium, led by NPL, is built up of physicists, chemists and biologists, and includes researchers from Imperial College London, the Cancer Research UK Beatson Institute, AstraZeneca, the Francis Crick Institute, the Institute of Cancer Research, Barts Cancer Institute and the Cancer Research UK Cambridge Institute.

London's Mayor launches world's largest air quality monitoring network

NPL is working alongside a team of experts on Breathe London, a new project which uses the world's most advanced network of air quality monitors to better understand Londoners' exposure to air pollution around the city. NPL's role is to carry out calibrations for the high-accuracy instruments inside the Google cars to confirm the accuracy of the measurements collected.





Historic redefinition of the SI units

In a landmark decision at the 26th meeting of the General Conference on Weights and Measures, the International Bureau of Weights and Measures (BIPM)'s Member States voted to revise the International System of Units (SI). So from World Metrology day on 20 May 2019, the base units are now defined in terms of defining constants, which are the most stable things available to use.

Four of the base units were redefined: the kilogram, ampere, kelvin and mole. The most substantial change is how mass is disseminated within national measurement institutes. The kilogram is now defined in terms of the Planck constant rather than via the International Prototype of the Kilogram held at BIPM, and NPL has been at the forefront of the work over the last 30 years to develop the technology that enabled this redefinition. The Kibble balance, named after the NPL scientist Brian Kibble, who developed the instrument, precisely measures mass using electrical current. NPL also led the international campaign to launch the new definitions, reaching over 2.2 billion people globally.

PLACE

A growing presence around the UK

NPL is expanding the community it works with, to help more businesses and organisations to prosper and progress through exposure to world-leading research, facilities and people. We want to ensure that all parts of the UK benefit from the impact of our work. We are a national laboratory with a nationwide presence.

By taking our internationally recognised science to companies across the UK we help companies understand the role of good measurement practice and how it can increase productivity. We also give the confidence to innovate through new products, accessing new markets and using new technology. Our national presence helps provide local access to NPL's expertise, so that all of UK industry can benefit, especially SMEs. As we continue to develop our national presence, we aim to increase both the volume of measurement research in the UK and the impact of the UK national measurement infrastructure on the UK's prosperity and quality of life.

In addition to our Teddington site, we have centres in four regions across the UK:

Scotland

NPL in Scotland, using their data science capability, is working with Keysight Technologies Ltd on formulating and delivering a cross-theme project on digital manufacturing; developing concepts and protocols for the calculation of dynamic uncertainties in product systems and families of equipment.

North of England

Our North of England based Manufacturer's Measurement Network, offers SME manufacturers extensive expertise in measurement and product verification related support to help them identify appropriate validation methods within their business to increase efficiency, reduce waste and improve product quality. Members have access to a range of benefits including attendance at events with manufacturing themes and networking with other manufacturers at different tiers in supply chains.

East of England

NPL in the East of England is working with Nu Quantum, a small spin out company from Cambridge University, on components for secure quantum communications systems. NPL is engaged with Nu Quantum and helped them submit proposals to the Analysis 4 Innovators programme, which are now underway with NPL's quantum technology experts. This engagement has resulted in a proposal for a much larger project to be delivered by a consortium including NPL, Nu Quantum, and many other companies and universities. The project would aim to establish a national capability for commercial-grade, room temperature, high performance single-photon visible/NIR wavelength sources and detectors and to establish national protocols for the testing methodology and certification for quantum single-photon components.

South of England

NPL in the South of England is working with the Institute for Communication Systems at the University of Surrey, on building of a demonstrator system to evaluate high-throughput millimetre wave (mm-wave) wireless transmission, which will play a pivotal role in future communications systems and networks.

WORKING WITH COMPANIES

Solving problems and designing the right solution

NPL's mission is to enhance quality of life for the UK and improve the productivity of UK industry. Our commercial products and services are designed to help you do just that. Whatever the size of your organisation or industry, we use our cutting edge, multi-science capability to help you to:

- Exploit the latest science and technology developments to continuously innovate and gain a competitive edge
- Solve your most complex technological or business challenges
- Have the confidence to adopt new technologies and processes or develop new products
- Meet your business requirements for regulation, compliance and quality

We are able to apply a wide range of science disciplines and expertise, and having that choice at our finger-tips means you can use us for a variety of needs. If we are not best positioned to solve your problem, we are able to sign-post you to one of our partners to provide the right solution. We do this with independence and impartially that our unique position as a government laboratory provides.

Whatever your industry or size, from start-up, scale-up or corporate, we have something to help you operate, improve or transform your business.

NPL as the UK's National Metrology Institute, has a central position in the National Measurement System (NMS). The NMS provides a UK laboratory infrastructure dedicated to world-class measurement science, delivering services to businesses and public sector organisations. The NMS conducts a regular customer survey to understand its customers, learn from feedback and improve services so that it continues to deliver impact. Highlights from our 2019 survey include:

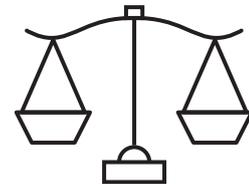
- **The NMS has a large reach and many business customers are highly economically active.** NMS laboratories are used by around 6,000 UK organisations, most of which operate in the private sector, with over half in the manufacturing sector. NMS customers employ just under one million people in the UK and the business sites supported by the NMS laboratories have an aggregate turnover of around £188 billion.
- **The NMS helps companies innovate:** each year, companies who use the NMS receive around £539 million in annualised revenues from sales of products that respondents believe would not exist without support from the NMS laboratories.
- **Customers are highly satisfied with the NMS:** there was high satisfaction with the reputation of the NMS, the quality of outputs, value for money of services, and the flexibility of and relationships with staff. One area to work on is the speed and timeliness of service delivery.

Helping customers through the National Measurement System

- **More than 75% of NMS customers use measurement for...**



Product development



Ensuring suppliers' materials are of adequate quality



Process control



Ensuring their own products meet customers' specifications

Analysis for Innovators (A4I)

A4I is a programme developed by Innovate UK and NPL to help UK businesses of any size access cutting edge measurement expertise and facilities to help solve their measurement problems. The companies NPL has assisted include two UK-based companies, Adaptix and SteelRock, where we helped accelerate the development and commercialisation of their new products.

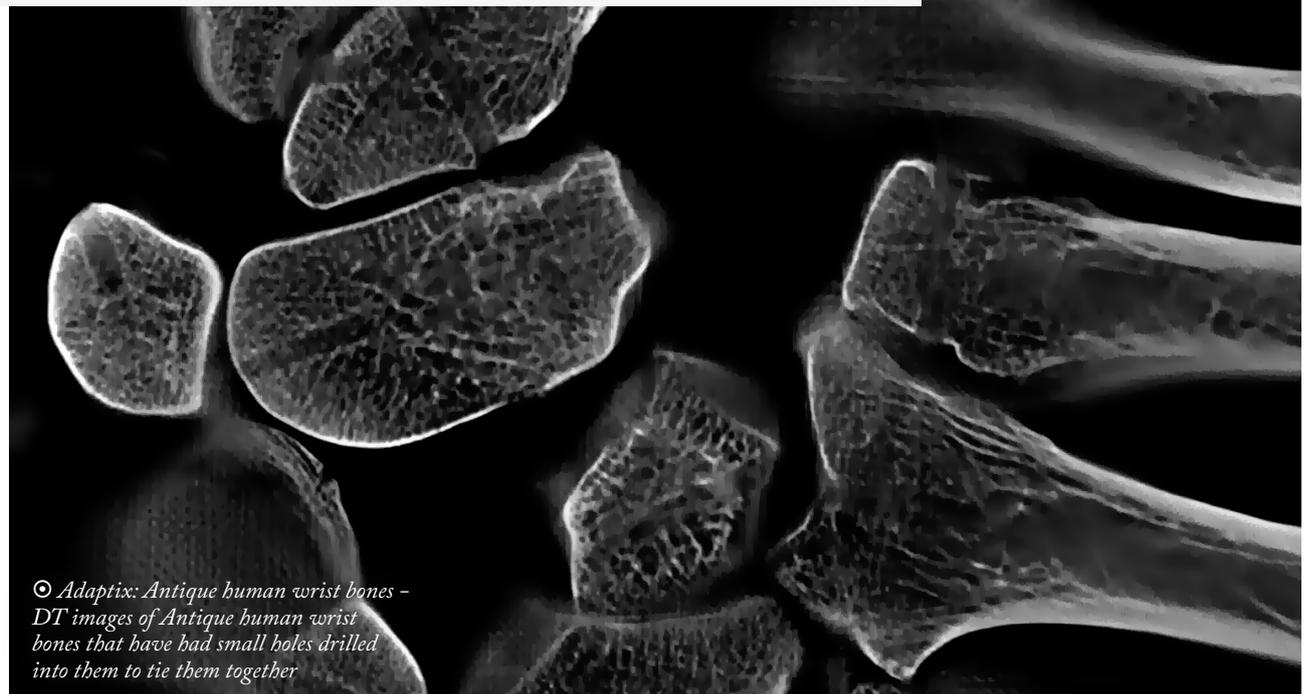
Adaptix: Adaptix's innovative 3D imaging technology helps patients and health-care professionals get the best possible diagnostic imaging information, giving quicker and more accurate diagnosis, reducing radiation exposure and saving cost and time. Adaptix worked with NPL to resolve measurement issues to improve the performance and reliability of their product by analyzing potential materials and coatings for the product, which enabled Adaptix to select the best performing materials. This has helped Adaptix to create a prototype and take this forward to manufacturing.

Mark Evans, CEO of Adaptix said "NPL has allowed us to take something that would be science – you can make it once and it works – into something you can reproduce and

manufacture. NPL is a world-leading facility where some of the best tools, techniques are available, run by an amazing group of scientists."

SteelRock: SteelRock Technologies is a leading provider of innovative technology solutions for Unmanned Aerial Vehicles, commonly known as drones. SteelRock developed a new solution to counter the threat of unauthorised drone usage and needed a verified data set to demonstrate to the UK Government that its system is safe to operate and highly effective. NPL helped SteelRock by characterising its product and measuring the impact of the energy it produces on humans. As a result, the UK Government has accepted the data provided and the system has been adopted by the UK security services. This has also helped SteelRock with the export potential of their product.

Rupert English, CEO SteelRock said "This project has been transformational for us in terms of what it has done for our business and how it has accelerated our progress. I'm looking forward to proceeding with further innovation and projects as we go down the road with the development and improvement of our products."



© Adaptix: Antique human wrist bones - DT images of Antique human wrist bones that have had small holes drilled into them to tie them together

PEOPLE

Breaking new ground in science

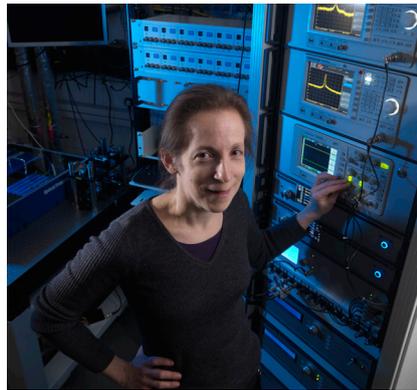
Over 1,000 scientists, engineers and skilled professionals work together to deliver our exceptional science and engineering work. Meet some of our people to learn more about the drive behind the work we do.

The Honours

Helen Margolis, Head of Time and Frequency at NPL, has been awarded an MBE for her services to metrology in the Queen's Birthday Honours List 2019. Her area of research expertise is optical frequency metrology using femtosecond combs, part of NPL's research programme to develop a new generation of high accuracy optical atomic clocks based on laser-cooled trapped ions and atoms.

Andrew Hanson, NPL's Outreach manager, has been awarded an MBE in the Queen's Birthday Honours List 2019, for his services to STEM education. Andrew has inspired hundreds of thousands of children and helped thousands of teachers and parents to make STEM (Science, Technology, Engineering and Maths) education accessible, interesting and exciting.

Martin Seah, Emeritus Senior Fellow in Surface & Nanoanalysis at NPL, was awarded an MBE for services to Measurement Science in the New Year's Honours list 2018. Martin's research in to X-ray Photoelectron Spectroscopy (XPS) has been the basis of the UK becoming a world leader in XPS instrumentation.



© Helen Margolis



© Andrew Hanson



© Martin Seah

Fellows of the Royal Academy of Engineering

The following member of staff were elected as Fellows of the Royal Academy of Engineering.

Peter Thompson, NPL's Chief Executive Officer, has been recognised for his exceptional ability to nurture and lead world-class organisations, developing science and engineering that meets strategic national priorities in social, economic, defence and security applications.

Graham Machin, NPL Fellow in Temperature Measurement, is internationally recognised as a world-leading expert in temperature measurement and its application. In his 30-year career he has led many thermometry innovations, particularly at high temperatures, in harsh environments, and made many improvements in SI temperature realisation and dissemination.

Gareth Hinds, NPL Fellow in Electrochemistry is an outstanding multi-disciplined scientist who has pioneered the development of advanced in situ diagnostic techniques and standard test methods for assessment of corrosion and material degradation in energy applications.

Perdi Williams selected as one of the UK's Top 50 Women in Engineering

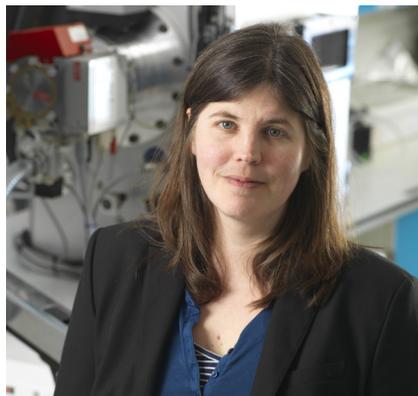
In celebration of International Women in Engineering Day 2019, NPL's Research Scientist, Perdi Williams, has been selected as one of the UK's Top 50 Women in Engineering. Perdi Williams was nominated for the impact she has created in her work on helping to redefine the kilogram. She has been a central player in NPL's outreach events, explaining the redefinition of the kilogram and encouraging young people into science and engineering.



© Perdi Williams

NPL Board member to become President of the Royal Academy of Engineering

Professor Sir Jim McDonald FREng FRSE, Principal and Vice Chancellor of the University of Strathclyde, and NPLML Board member, has been confirmed as President of the Royal Academy of Engineering following a vote by Fellows at the Academy's AGM. Sir Jim, who is the Academy's first Scottish President, will serve a term of five years.



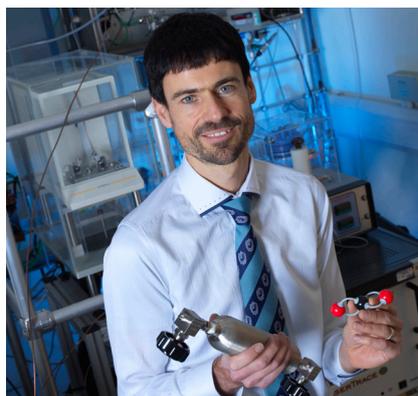
© Josephine Bunch

President of the CIPM Consultative Committee on Ionizing Radiation

Martyn Sené, NPL's Deputy CEO has been elected as President of the Consultative Committee on Ionizing Radiation (CCRI). The work of the CCRI benefits end-users of ionizing radiation, including: operators of the 450 nuclear power stations that produce 10% of the world's electricity; and the people who deliver and receive the four billion diagnostic X-rays procedures each year.



© Olga Kazakova



© Paul Brewer

NPL honoured with Sir George Earle Trophy at RoSPA Health and Safety Awards

NPL won the Sir George Earle Trophy at the Royal Society for the Prevention of Accidents (RoSPA) Health and Safety Awards 2018. NPL was recognised for its strength of health and safety management capability and how health, safety and wellbeing are embedded in the organisation's culture. NPL was also awarded the Research and Development Sector award, which recognises outstanding performance in health and safety, robust and high-quality safety management system, together with a minimum of four years' consistently excellent or continuously improving health and safety performance.

New NPL Fellows

Josephine Bunch, Olga Kazakova and Paul Brewer have been appointed NPL Fellows. NPL Fellowship is a recognition of individual merit awarded to scientists who are making very significant contributions to NPL's scientific achievement and standing.

Josephine Bunch has been appointed an NPL Fellow in the field of Biomolecular Analysis, in recognition of her ground-breaking work in the fields of mass spectrometry and tissue imaging, and her inspirational scientific leadership at NPL and in the international community.

Olga Kazakova has been appointed an NPL Fellow in the field of Quantum Materials and Sensors, for her profound research experience in nanotechnology, materials science, graphene & 2D materials, spintronics, development of novel sensors.

Paul Brewer was appointed for his role in Chemical Metrology. His Fellowship is in recognition of his innovative and revolutionary scientific advances in atmospheric chemistry, air pollution monitoring and the quality assurance of emerging fuels and his inspirational scientific leadership.

SKILLS AND LEARNING

We provide the skills and training needed to drive productivity in the UK

With more than a century of experience, we pride ourselves on our world-class measurement skills. We enable UK industry to benefit from these vital skills by providing businesses with training. Ranging from early interest to expert level, we help to improve quality, productivity and global competitiveness. We aim to inspire all scientists, technologists and engineers.

Measurement and calibration training

NPL is committed to sharing its expertise with industry to build and enhance its measurement skills and capabilities. Metrology, the science of measurement, enables employees to apply good practice, question and improve processes and has a direct impact on productivity and profitability.

We work with companies who require absolute confidence in their measurements and sensing applications, across all industry sectors. Our training covers the importance of metrology, advancements in measurement science and the application of good measurement practices.

Training for apprentices

NPL apprenticeships deliver measurement skills for a wide range of sectors, including manufacturing. We have created a Level 3 training programme to support the Institute for Apprenticeships & Technical Education's Metrology Technician Standard, which is the ideal route into skilled employment for technicians working in research, laboratories or measurement and quality related roles.



Postgraduate Institute for Measurement Science

The Postgraduate Institute for Measurement Science (PGI) is a pioneering initiative equipping the UK with an exceptionally skilled workforce ready to tackle real life industrial challenges. The vision of the PGI is to be the number one institute for postgraduate research and training in measurement science.

The PGI has continued to develop and sustain a pipeline of industry-ready researchers, adding more than 100 PhD graduates since 2015 to the pool of researchers in measurement science that have benefited from the unique training and cohort experience at NPL. In 2019 many of the new studentship projects are linked to industry, which allows NPL to play a role in generating wider impact and connections from PhD research. Out of the over 200 studentships that have run during 2019, 13% have been supported by industry via additional funding and supervision.

The PGI's coordination of NPL's involvement in the Engineering and Physical Sciences Research Councils (EPSRC) CDT call in 2018 resulted in NPL supporting 40 bids at full proposal stage of which 16 were funded. The PGI has also raised the profile of NPL as a training organisation leading on industrially relevant high-level skills. The growing provision of PGI training now covers relevant technical and professional skills training based on an ongoing evaluation of Post Graduate Researcher needs and is coordinated and delivered nationally to ensure an inclusive approach for researchers wherever they are based.



DIVERSITY, EQUALITY AND INCLUSION

We flourish on the diversity of our people

NPL is committed to creating a fair and inclusive environment where every individual can feel valued. We believe that we all profit from the different perspectives that the wide range of people in our organisation brings. We encourage a culture where everyone can enjoy working and perform at their best, for the advancement of science and the benefit of all.

NPL's Diversity & Inclusion Task Force brings together people from across the organisation to promote employee diversity and inclusivity. There are several interest groups including: LGBT+; Mental Health; Faith & Religion; Dyslexia & Neurodiversity; Gender Equality; Ethnicity; and Disability.

As part of NPL's commitment to Diversity & Inclusion, we signed up to the Institute of Physics' Project Juno in 2015 as a Juno Supporter. NPL was proud to be awarded Juno Practitioner status in 2018.

NPL also joined Stonewall as a Diversity champion in 2015, participating in their annual Workplace Equality Index for the equality of LGBT+ community at NPL, and has made considerable progress since taking part.

In 2018, NPL became a member of the Business Disability Forum and joined the disability confident scheme as a Level 1 committed employer.

Closing the gender pay gap

For the second year, NPL has published a gender pay gap report. As a proud employer of a diverse and inclusive workforce, offering support to all through an increasing range of diversity and inclusion activities, creating a dialogue around gender equality is essential. We know that we must do more to recruit women, particularly into our senior science and engineering roles, and we acknowledge that it will take time to achieve our aim of closing the gender pay gap by increasing the proportion of women employed at all levels.

We continue to prioritise initiatives such as the Springboard Women's Development Programme and the Daphne Jackson Trust Fellowships. NPL is an active member of the Institute of Physics' Project Juno and our apprenticeship programme has a gender split of 44% females and 56% males. On International Women's Day 2019, NPL launched a brand-new Gender Equality group to help attract, enable and develop women and to create a working culture and environment that supports gender balance.



PUBLICATIONS

In 2018 NPL had published 359 papers in peer-reviewed scientific journals. The following NPL publications have been highlighted for their scientific contribution.

Estimation of above-ground biomass of large tropical trees with terrestrial LiDAR

Methods in Ecology and Evolution

Kim Calders (with Wageningen University & Research; Tampere University of Technology; Center for International Forestry Research; Swedish University of Agricultural Sciences; University College London; and Australian National University).

A hybrid 2D/3D inspection concept with smart routing optimisation for high throughput, high dynamic range and traceable critical dimension metrology

Measurement Science and Technology

Christopher Jones and Daniel O'Connor

Charge quantum interference device

Nature Physics

Sebastian de Graaf, Teresa Hoenigl-Decrinis, Alexander Tzalenchuk and Oleg Astafiev (with Physikalisches Institut; Karlsruhe Institute of Technology; Royal Holloway University of London; Moscow Institute of Physics and Technology; Leibniz Institute of Photonic Technology; Skolkovo Institute of Science and Technology; and Russian Quantum Center).

Suppression of low-frequency charge noise in superconducting resonators by surface spin desorption

Nature Communications

Sebastian de Graaf, Alexander Tzalenchuk and Tobias Lindstrom (with Laboratoire de Physique Theorique et Hautes Energies; L.D. Landau Institute for Theoretical Physics; Chalmers University of Technology; and Royal Holloway University of London)

Geodesy and metrology with a transportable optical clock

Nature Physics

Antoine Rolland, Fred Baynes and Helen Margolis (with Physikalisch-Technische Bundesanstalt; Institut für Erdmessung, Leibniz Universität; Laboratoire Souterrain de Modane; and Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino).

Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables

Science

Giuseppe Marra, Jochen Kronjäger, Louise Wright and Stephen Robinson (with Istituto Nazionale di Ricerca Metrologica; British Geological Survey; Politecnico di Torino; and Department of Physics, University of Malta).

The Boltzmann project

Metrologia

Michael de Podesta, Robin Underwood and Gavin Sutton (with Physikalisch-Technische Bundesanstalt; Laboratoire Commun de Métrologie; Istituto Nazionale di Ricerca Metrologica;

National Institute of Metrology; National Institute of Standards and Technology; Measurement Standards Laboratory of New Zealand; Università degli Studi della Campania "Luigi Vanvitelli"; Université Paris 13; Laboratoire National de Métrologie et d'essais; University of Valladolid; and Centro Español de Metrología).

Exploring Ion Suppression in Mass Spectrometry Imaging of a Heterogeneous Tissue

Analytical Chemistry

Adam Taylor, Alex Dexter and Josephine Bunch

Air temperature sensors: dependence of radiative errors on sensor diameter in precision metrology and meteorology

Metrologia

Michael de Podesta, Stephanie Bell, and Robin Underwood

Three-dimensional behavioural phenotyping of freely moving *C. elegans* using quantitative light field microscopy

PLOS One

Michael Shaw (with University College London and Massachusetts Institute of Technology).

Nanoscale chemical imaging of solid-liquid interfaces using tip-enhanced Raman spectroscopy

Nanoscale

Naresh Kumar, Andrew Pollard and Andy Wain (with Debye Institute for Nanomaterials Science; and Hangzhou Dianzi University).

STRATEGIC PARTNERS

The University of Strathclyde and the University of Surrey, have been engaged by the Department for Business, Energy and Industrial Strategy (BEIS) as partners within NPL's operating model. The partnership enables us to work more closely with the academic community and is the basis of our Postgraduate Institute for Measurement Science, which is creating the next generation of world-class measurement scientists.

The partnership means that the two universities and NPL collaborate to bring together their track record of working with business and industry and their complementary academic strengths. It builds on the strengths of the partners to allow NPL to make a step change in capability, influence and impact. These include:

- Joint working in areas such as space, healthcare and industrial applications of metrology.
- Developing a presence for NPL, in partnership with other organisations, across the UK through regional hubs; bringing expertise and services closer to user communities who can benefit.
- Creating a vibrant research community at the Teddington site, including the Postgraduate Institute which trains up to 300 high-calibre PhD students, and provides a pipeline of skilled researchers.



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