



ANNUAL REVIEW

2020

CEO'S INTRODUCTION



The National Physical Laboratory's (NPL) number one priority during 2020 was to ensure that all our people remained safe and secure during the COVID-19 pandemic. Our focus was on prioritising our people and supporting them to navigate their working lives in a pandemic. This ensured that as the UK's National Measurement Institute (NMI), we continued to provide critical services to support the UK's infrastructure and vital healthcare provision throughout 2020.

COVID-19 Response - Our work included: healthcare services to support the National Health System (NHS) and the medical supply chain industry; radiation measurements to allow the medical sterilisation industry to operate; calibrating instruments used in cancer treatment; provision of timing services on behalf of the government, for example to facilitate reliable high-speed

financial trading; and provision of environmental monitoring, declared as critical by the Environment Agency.

We were also able to rapidly transfer resources to support the UK's COVID-19 response, including the government's UK Ventilator Challenge which encouraged manufacturers to re-purpose their assembly lines and support new designs to meet anticipated demand. NPL answered the challenge by designing the PocketVent, a unique, fan-based ventilator, smaller than a laptop, costing less than £1,000.

NPL used its wealth of experience and scientific capabilities to help increase the availability of Personal Protective Equipment (PPE), by signposting new manufacturers of PPE and medical devices to relevant standards and assisting with the interpretation of standards to provide clarity on the requirements for conformity.

Measurement for Recovery -

The NPL-led Measurement for Recovery programme, was developed in 2020 to help UK companies gain access to the expertise and resource of the UK's leading measurement science experts, to help them recover and grow in the challenging economic environment resulting from the COVID-19 pandemic.

Training and Apprenticeships -

In response to the pandemic NPL also made its catalogue of measurement related e-learning

courses available free of charge, allowing industry and academia to freely invest in their workforce whilst they were 'working from home' - nearly 10,000 new learners registered for e-learning and there was a 99% satisfaction rate in the training experience. We also assisted home-schooling by making our Virtual Physics Laboratory (VPLab) educational software available for secondary school pupils and teachers; over 19,500 simulation downloads were made by students to use at home.

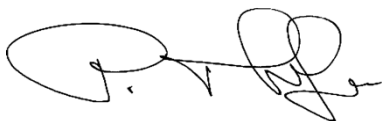
Foresighting - During 2020 NPL published the results of its extensive Technology and Measurement Foresighting programme, which identified major trends in technology and measurement that would impact industry and our society, as well as how we live over the next 15 years. NPL is now sharing these findings with UK Government and national measurement institutes from around the world, as well as using it to shape our future research strategy.

National Challenges – NPL, as the UK's NMI, is helping to address the National Challenges, with a particular focus on Advanced Manufacturing, Lifesciences and Health, Energy and Environment and 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.

Our People - To deliver all this incredible work, we need amazing people, who are supported and enabled to 'give it their all'. At NPL we have over 1,000 scientists, engineers and skilled professionals who work together to deliver exceptional science and engineering. 2020 saw awards in the Queen's Birthday and New Year Honours list to: Andy Morris, who received an MBE for his services to the Manufacturing and supply of PPE during the COVID-19 response; and Fiona Auty, who received a Medal of the Order of the British Empire (BEM), for her services to Science and Engineering Communication.

Diversity and Inclusion – This has remained a priority throughout 2020, with several initiatives undertaken. Alongside our work prioritising the wellbeing of a remote workforce, our key projects this year include a new two-way mentoring programme for senior leaders and individuals from underrepresented groups within NPL.

Our vision is to deliver extraordinary impact from excellent science and engineering as a world-leading and exemplary national laboratory; and during the last year, particularly given the global pandemic, our many achievements show how we are delivering on that vision.



Dr Peter Thompson FEng
Chief Executive Officer

Contents

COVID-19 Response	Page 03
Measurement for Recovery	Page 07
Training and Apprenticeships	Page 08
Postgraduate Institute for Measurement Science	Page 10
Diversity & Inclusion	Page 11
People	Page 12
Meeting the National Challenges	Page 14
Research Highlights	Page 17
Technology and Measurement Foresighting	Page 21
Place	Page 22
Publications	Page 23
Strategic Partners	Page 25

Cover image: Jean Morris from the NPL PocketVent Team, who created a low cost and easy to manufacture ventilator design, the PocketVent, in response to the need for affordable ventilator technologies in emerging markets.
Image credit: Jude Palmer/Royal Academy of Engineering

COVID-19 RESPONSE



As a national laboratory with thousands of customers in the UK and beyond, it was a natural progression to offer our experience of standards, testing and product requirements to meet the unprecedented challenges of COVID-19. We made our facilities available to support UK industry and society, including working with NHS trusts on ventilator provision, oxygen supply and data processing. The global pandemic highlighted the vital role that metrology plays in supporting global measurement systems and helping society function. Our expertise enabled us to advise and inform government, companies and research organisations on a wide range of topics, and our extensive professional networks linked organisations with specialist suppliers to overcome manufacturing challenges.



Temperature measurement: Guidance on fever screening

NPL's world-leading expertise in measuring body temperature has helped develop the standards for fever screening and clinical body temperature measurements. It also contributed to a U.S. Food and Drug Administration study on the use of thermal imaging for fever screening in 2018. During the COVID-19 pandemic NPL was approached by government bodies, councils, hospitals, transport organisations and measurement companies, for advice and guidance on accurate temperature measurements, the available technology and its fitness for purpose.

Although widespread fever screening was not recommended as part of the Government guidelines for COVID-19, NPL gave advice on the deployment of reliable temperature measuring systems to hospitals, care homes and other organisations, when requested. As the UK's National Metrology Institute and a leading expert in the area, NPL disseminated the current guidelines and information.

NPL are now leading a new Task Group on Thermometry for clinical applications, a working group made up from experts from NMIs internationally. In future pandemics, temperature measurement may be used as a key indicator, and the technology and procedures need to be in place to support it.

PPE: Ensuring safe PPE and supporting new manufacturers

Medical devices and PPE are regulated in the UK and internationally, including requirements for manufacturing and testing. NPL signposted new manufacturers of PPE and medical devices to relevant standards and assisted with interpretation, providing clarity on the requirements for conformity.

NPL supported production of face shields, or visors, including companies who were 3D printing parts. We gave advice on designs, materials used and cleaning, as well as modelling critical design aspects, such as field of vision and area of coverage. We also connected manufacturers and designers with materials suppliers, facilitating collaboration between many organisations across numerous projects.

NPL provided support to organisations bringing new face masks and publicly worn face coverings to the market. Initially, this included advice on standards and material selection. We also created a bespoke face mask testing rig for surgical face masks which had to meet the requirements of BS EN14683. We tested filtering facepiece (FFP) type face masks, with the provision of tests in which the mask was fitted to a range of test heads (BS EN149 tests). Test rigs were designed and built by NPL to provide test data to help demonstrate potential compliance with relevant standards, and to give additional data to designers seeking to refine and optimise their designs. We were also involved in determining whether PPE could be effectively cleaned and re-used, through careful specification of the cleaning process and protocols. This involved looking at changes in material properties, and hence performance, during and after cleaning.

NPL North, the team within NPL performing this testing, worked with manufacturers throughout the UK, including many small and medium-sized enterprises (SME), resulting in the safe introduction of large quantities of PPE to the UK market, and the safe introduction of highly novel products that satisfied niche requirements.



NPL creates digital test bed for face masks

NPL is leading a project to create a digital test bed for face masks, helping to drive digital innovation in UK manufacturing supply chains. The project is being funded through the 'Manufacturing made smarter' funding competition run by Innovate as part of the Industrial Strategy Challenge Fund. It is a great example of how NPL is helping UK manufacturing supply chains to develop digital technologies to become more efficient, productive and resilient.

The team at NPL will be creating a digital demonstrator that, once refined, will be capable of evaluating PPE performance against selected standard requirements. The rigs will be testing against critical aspects of the BS EN149 standard and will include demonstrations of three key measurements of face masks, including dimensional, filtration efficiency and total inward leakage testing.

NPL will be working closely with the University of Birmingham, who will use the data produced by NPL to validate and refine their models for bespoke face masks production. All data will be captured and analysed electronically, providing evidence that the digitalisation of manufacturing processes is achievable, helping to drive digital innovation within the sector.

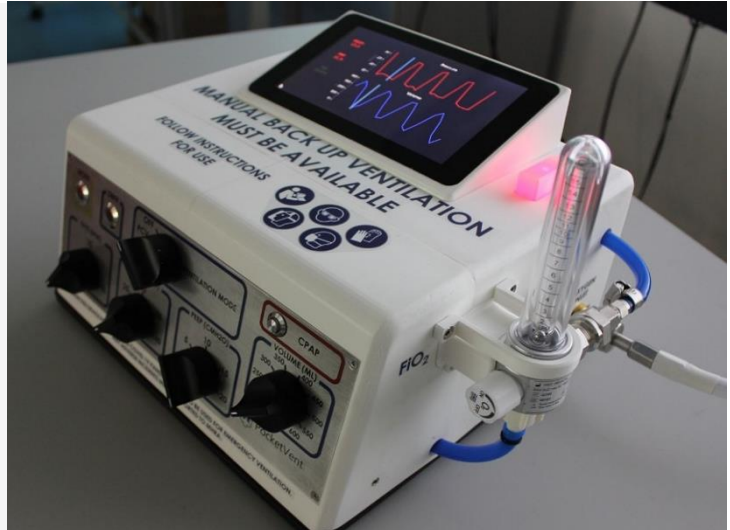
The majority of this work will be taking place in NPL's North of England Laboratory and links closely to the work carried out to support new manufacturers in the design, manufacturing and delivery of safe PPE.

Ventilators

At the start of the COVID-19 crisis the government launched the UK Ventilator Challenge, encouraging manufacturers to re-purpose their assembly lines and support new designs to meet anticipated demand. NPL's broad team of experts, with knowledge of many of the key parameters of ventilator operation, including temperature, humidity, pressure, dimensional measurement, materials and engineering, rose to the challenge. NPL offered advice, guidance and consultancy in the verification and testing stages, as well as the design and prototyping of parts.

After a few weeks, it became apparent that the additional number of ventilators required for the UK would not be as high as anticipated. The specifications for the requirements evolved as continuous positive airway pressure (CPAP) apparatus was found to be more effective than conventional ventilators. We established a test capability based around a lung emulator loaned from Kings College London to test new ventilator designs against the developing Medicines and Healthcare products Regulatory Agency (MHRA) specification.

NPL offered its support, at no cost, to companies developing and manufacturing ventilators. We identified time savings in the test plans and manufacturing process for companies who were repurposing their facilities.



The PocketVent: NPL's low cost ventilator technology

NPL created a low cost and easy to manufacture ventilator design, the PocketVent, in response to the need for affordable ventilator technologies in emerging markets. The PocketVent is a simple to use device that requires limited training time for healthcare professionals and is made from widely available parts. The design meets the critical functionality and performance requirements detailed in the MHRA specification for ventilation, and costs approximately £1,000 to build. It is compact, has low power consumption and can also be operated as a CPAP respiratory device. It has been extensively tested with NPL's dedicated ventilator test facility, and we are now looking to share its designs with local manufacturing and healthcare organisations in areas experiencing demand for ventilators, ensuring these devices can be used where they are needed most.

Data analysis: Accurate and rapid management of data

The need for data analysis and support for remote working generated many requests for our experience and knowledge in data science. NPL helped the Royal College of General Practitioners Research and Surveillance Centre to produce their regular updates on communicable and respiratory diseases for Public Health England throughout 2020. We also worked with the Royal Surrey NHS Foundation Trust on supporting their remote working, not something that had been a priority before the pandemic.

Testing PPE often involves several iterations as designs are refined. Data science allowed certain tests to be simulated, such as field of view tests, so that the computer model could predict if a design would pass the test. This helped streamline the testing and gave confidence that the PPE would pass the tests.

NPL was able to offer help to the Royal Free London NHS Foundation Trust by analysing different kinds of data, including: extracting the maximum amount of reliable data from biomarkers tests, analysing the critical pathways in cancer care to meet the anticipated increase in demand post-COVID-19 and preparing buildings for COVID-safe movement of patients and staff.

Using our expertise to support the national effort

Antiviral surface and materials – we have experts in materials and surface technology, as well as analytical techniques, so reviewed existing research and scientific publications to check the current state of knowledge on antiviral surfaces and coatings. We also looked at 3D printing of antiviral materials and evaluated the performance of antiviral sprays and liquids.

COVID-19 sensors – building on previous work to test for hepatitis and tuberculosis, we developed a proof-of-concept, miniaturised and integrable graphene-based biosensor for detecting COVID-19. Not only are these sensors very sensitive but they can also provide quantitative data, improving our understanding of the virus and the individual's response to it. The test results are rapid and can be transmitted to phones, watches, tracking devices, the cloud or software.

Air quality in dental surgeries - Dental treatment involves a range of equipment and 'aerosol generating procedures' which can produce significant amounts of saliva/water-based aerosols which present a potential transmission risk for the COVID-19 virus. Mydentist asked NPL to measure the amount of aerosols produced by a variety of procedures in a working dental surgery. These were presented to the Scottish Dental Clinical Effectiveness Programme to help them make recommendations on fallow times and aerosol mitigation procedures.

Oxygen supply - At the beginning of the pandemic there was concern over an adequate supply of oxygen for hospitals. So using different grades of oxygen, subject to appropriate validation, or other methods of oxygen production had to be considered. NPL consulted with key suppliers to offer support and expertise. Ventilators require an oxygen sensor to check that the concentration of oxygen in the gas mixture is correct. During the pandemic the supply chain for conventional sensors was exhausted and alternatives were required. NPL developed the concept of a novel electrochemical sensor based on a miniature fuel cell, which did not require batteries and would be cheaper and environmentally friendly.

Sterilisation - Since the beginning of the COVID-19 crisis there has been an increased demand for sterilised medical devices. Around 50% of single use medical devices are sterilised using ionising radiation. The industry is highly regulated, and companies must meet specific requirements on the measurement of radiation dose. We are a 'critical supplier' to many radiation sterilisation companies across the world and ensured that our calibration services were available to support industry as it strived to meet the challenges of maintaining medical device and PPE supply chains.



Providing critical services

As a national laboratory, NPL continued to run several critical services to support the UK's infrastructure and vital healthcare provision, whilst following government advice regarding social distancing. These included:

Healthcare services to support the NHS and the medical supply chain industry:

- Radiation measurements for medical sterilisation
- Calibration of instruments used in cancer treatment
- Quality assurance measurements and supply of materials to radiopharmaceutical manufacturers

Provision of timing services on behalf of the government, for example facilitating reliable high-speed financial trading

Support to the nuclear sector, declared as critical by operators, to keep power stations operational:

- Calibration activities to allow the acceptance of neutron detectors as part of safety cases

Provision of environmental monitoring, declared as critical by the Environment Agency:

- Operation of air particle monitoring network
- Supporting chemical companies maintaining their licences to operate to ensure clean and safe operation

MEASUREMENT FOR RECOVERY

The NPL-led Measurement for Recovery (M4R) programme was developed to help UK companies gain access to the expertise and resource of the UK's leading measurement science experts, in turn helping them to recover and grow in the challenging economic environment resulting from the COVID-19 pandemic.

Over 300 businesses from across the UK are being supported by the BEIS-funded, £3 million programme to address a range of issues such as investigation of feasibility of concepts, validation of products and processes, support for new products and services, aiding in cost reduction, improved productivity and increased product reliability.

- 498 applications received
- 337 proposals created
- 102 projects completed

Impact of M4R

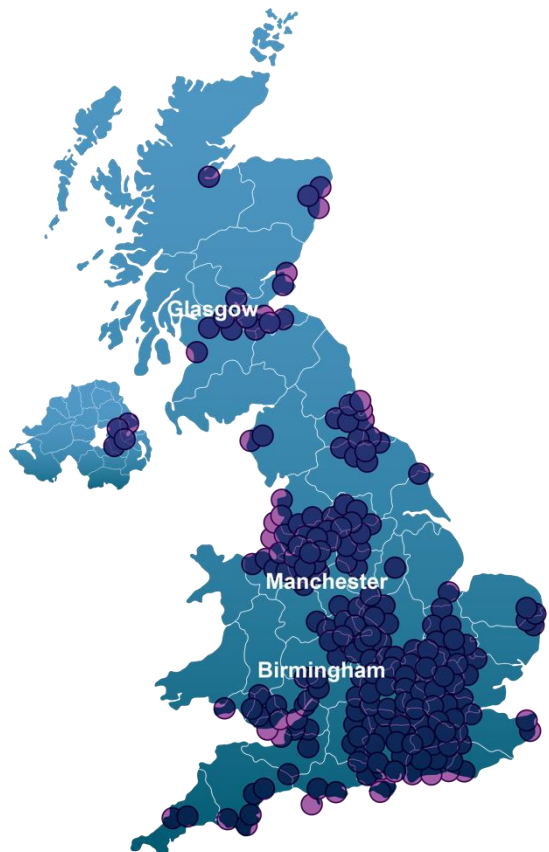
57% of companies expect to secure more investment for their project from internal or external sources
67% of companies expect to see increased sales
27% of companies expect to see reduced costs

Supporting businesses across the UK

Companies supported by Analysis for Innovators (A4I) - a precursor to M4R - have reported sales, licensing and cost reductions of up to £125 million, progress in technology development and impacts that will last for 7 years on average. 82% of companies involved in A4I said their commercial opportunity has greatly or moderately increased as a result.

Rapid COVID-19 testing

Stemnovate is a Cambridge based company, which has developed COVID-19 rapid testing technology that is accurate and faster than commercial alternatives. In June 2020 the company also introduced a new, more accurate, method for testing at airports, schools and offices. The Stemnovate test kit had to run for one hour to confidently identify a positive COVID-19 test, and since then the company had been working on reducing the detection time. Through the programme, NPL's Biometrology and Electronic & Magnetic Materials groups worked together with Stemnovate to increase the sensitivity of the COVID-19 detection.



TRAINING AND APPRENTICESHIPS



NPL is committed to sharing its expertise with industry to build and enhance measurement skills and capabilities. Metrology enables you to question and plan your processes, improve the quality of your products and reduce your costs. This can have a direct impact on productivity and profitability. Our training covers the importance of metrology, advancements in measurement science and the application of good measurement practices.

Upskilling UK industry

At the beginning of April 2020, in response to the COVID-19 pandemic, NPL made its catalogue of e-learning courses available free of charge, and from October 2020 there was a 50% reduction in price. The e-learning covered general measurement, dimensional measurement and a range of specialist measurement courses. Nearly 10,000 new learners registered for e-learning and there was a 99% satisfaction rate in the training experience.

Our objective was to help individual's wellbeing and motivation, as well as enhancing their skills and career pathways. The training has allowed industry and academia to invest in their workforce and prepare them to play a role in helping UK industry to recover quickly post COVID-19.

NPL has always played a leading role in providing training in measurement science, an essential skill for the current and future workforce. We have a wide selection of courses covering a range of metrology topics, from uncertainty and geometrical tolerancing to radiation, electrical and biogas. In 2020 we supported the development of the new Metrology T-level qualification by reviewing the assessment design and technical qualifications to ensure it met with the standard's requirements.

Apprenticeships

NPL's apprenticeship scheme offers young people with a passion for IT, science, engineering, marketing or business the chance to make a real impact, and earn while they learn.

NPL's apprenticeship scheme started in 2013, with 10 apprentices and in 2020 we celebrated recruiting our 100th apprentice. A momentous milestone in a programme that has enabled some enthusiastic and talented people to develop knowledge and skills, whilst contributing to NPL's ongoing success. The apprenticeship scheme has provided a fresh source of skills and talent, as well as a great set of ambassadors for NPL. 80% of our apprentices have gone on to permanent roles within NPL or secured part-funding towards a degree.

NPL developed the curriculum materials for the first Metrology Apprenticeship Standard programme, to enable a new pipeline of talent for industry and to contribute to the long-term success of the metrology profession. The first NPL-trained cohort recently graduated, completing both on and off the job training and demonstrating their metrology skills and knowledge. Three apprentices were directly employed by NPL, and another at the Science and Technology Facilities Council. Another learner cohort from Jaguar Landrover successfully completed their studies using NPL's materials at Make UK's Technology Hub in Aston, Birmingham.

Apprenticeship Awards

Congratulations to **Warda Heetun** for winning the Institute of Physics (IOP) Technician Award 2020 for her outstanding contributions to measurement science and establishing the world's first standard for quantitative nuclear medicine imaging; and **Jamie Mewburn-Crook** who won the IOP's 2020 Apprentice Award for his work in Medical Radiation Physics. Jamie's work helped produce bone-tissue equivalent thermoplastic and supported the development of a 3D-printed full-sized pelvis phantom.



Outreach: Supporting learning at home

As a national laboratory, NPL recognises not only the importance of promoting Science, Technology, Engineering and Mathematics (STEM) activities and inspiring the next generation, but also the requirement to highlight the vital role metrology, or the science of measurement, plays in our everyday lives. To achieve this, Measurement at Home, NPL's new online STEM initiative, was launched in May 2020.

Measurement at Home aims to get everyone, particularly school children, engaged and interested in science and create a measurement community that virtually brings science into households nationally and globally. There are regular challenges posted on the website, and the new, wider 'measurement community' are encouraged to send in results and share pictures of their tests.

NPL's annual Water Rocket Challenge became the Space Rocket Challenges. These were delivered online, in partnership with the UK Space Agency. Widely shared on social media and mentioned by Tim Peake in his podcast, the challenges had a great response, including over 60 designs for rockets, one with 49 pages of details.

The Virtual Physics Laboratory simulation software has proved very popular through lock down. Webinar demonstrations to groups of teachers were broadcast and there were more than 450 downloads of the full resource. Over 19,500 simulation downloads were made by students to use at home, a facility that was not available prior to lockdown. The rate of new users is four times higher than before COVID-19, with the total number well over 6,000.

Presentations and other outreach activities continued remotely to schools, the Association of Science Educators and other groups. NPL scientists judged several 'Young Enterprise' competitions, appeared in Physics World and volunteered for 'I'm a scientist get me out of here'. They also carried out 15 live presentations for schools, co-ordinated by STEM Learning, and these are now being used for other outreach activities and are ideal material to stimulate class discussions and assemblies.

POSTGRADUATE INSTITUTE FOR MEASUREMENT SCIENCE

Since its creation in 2015 the Postgraduate Institute for Measurement Science (PGI) has been developing a pipeline of 'industry ready' professionals.

The PGI is delivering a PhD programme that addresses the need for measurement science to support the development of the UK's economy and improve quality of life. Positioned at the interface between academia and industry, the PGI is a gateway for companies and research organisations looking to utilise measurement to aid research and innovation. It is a pioneering initiative to equip the UK with an exceptionally skilled workforce ready to tackle real life industrial challenges, aimed at creating a step change in industrially relevant postgraduate research and training.

In 2020 a total of 15 industry partners, including GSK, Unilever, Stemnovate and Synaptec, have been recruited, and will part fund studentships co-supervised by NPL's scientists and engineers. We have also established a PGI Strategic Advisory Board with members from industry, national labs, academia and the HVM Catapult. In 2020 our allocation of ten industrial CASE studentships awards from the Engineering and Physical Sciences Research Council was used to leverage further support of up to 9 additional studentships, with cash and in-kind support from 14 industry and other third parties.



Throughout its five years, the PGI has helped develop the next generation of world-class measurement scientists, with the number of students steadily increasing to over 200 researchers this year. Over 140 of our students have graduated, 43% of which have moved into industrial roles and are now making significant contributions to the scientific community, collectively publishing over 350 papers. A focused approach to industrial engagement has resulted in 41 studentships with 30 partners made up of industry and publicly funded bodies. PGI alumni are also established in academic and other research roles (29%) at prestigious organisations worldwide, and a further 19% becoming full-time researchers at NPL.

Our priority during 2020 was to support students affected by the pandemic by ensuring NPL's policy on funding and lab access met the diverse needs of the cohort. Our approach was in line with UK Research and Innovation (UKRI) policy and was extended to PhDs funded from all sources. Even with the effects of the pandemic a total of 28 postgraduate researchers submitted their PhD thesis in 2020 and we saw an increase in the overall proportion going directly into industrial careers, taking the cumulative total to 46%.

A PGI Mentoring Programme established by PGI Ambassadors Dannielle Cox-Pridmore and Ben Webster is currently facilitating focused one-to-one support for ten PGI postgraduate researchers.

COVID-19 did not stop the Annual PGI Conference from taking place. In September 2020 we virtually welcomed 180 delegates to one or more of our sessions, totalling nine hours over a four day period.



DIVERSITY AND INCLUSION

In an organisation where the impact of our work is vital to our success, ensuring diversity in our people continues to be the key to inspiring creativity, accelerating the impact of our research and unlocking new ways of working. NPL's goal is to attract, engage and retain a diverse workforce where people feel they belong and can contribute their whole self at work.

Our Diversity and Inclusion Task Force brings together people from across NPL to promote inclusive working practices and ensure that diverse views are represented in all our work and activities. Special interest groups, which include: Mental Health; Faith and Religion; and Dyslexia and Neurodiversity, provide support and guidance to our employees as well as giving us access to representative voices and lived experiences to inform our actions as an organisation.

We continue to challenge ourselves to improve and hold a number of accreditations. NPL is an Institute of Physics Juno Practitioner (a scheme recognising action taken to address the underrepresentation of women in physics and encouraging better practice for men and women), a Stonewall Diversity Champion and a Disability Confident Committed employer.

During the COVID-19 pandemic and lockdowns, the safety and wellbeing of our people was our number one priority, through activities such as our internal campaign 'remote but not apart'. This helped our people feel supported and connected by providing a compilation of resources to encourage local conversations and navigate challenges both in and out of work.



Other Diversity and Inclusion activities in 2020 include:

- **Introduction of our first Navigator programme**, a work and personal development programme for men, which follows three successful cohorts of the Springboard Women's development programme.
- **The launch of Discover**, a two-way mentoring programme, for senior leaders and individuals from underrepresented groups within NPL. In addition to providing advice and career support for mentees, the scheme is designed to encourage perspective sharing and to support inclusive conversations to build allyship across the organisation. The scheme covers a range of diversity and inclusion themes extending beyond protected characteristics alone, to help our diversity and inclusion activities to evolve.

PEOPLE

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

Andy Morris, NPL's North of England Operation's Manager, has been awarded an MBE for his services to the Manufacturing and supply of Personal Protection Equipment during the COVID-19 response in the Queen's Birthday Honours List 2020.

Fiona Auty, Head of Government Relations at NPL, has received a Medal of the Order of the British Empire (BEM) in the New Year's Honours list, for her services to Science and Engineering Communication. Fiona spearheaded the highly successful international communications campaign to Government, industry and the general public.

Roy Sambles, NPL Distinguished Visitor and Professor of Experimental Physics at Exeter University, received a knighthood for services to scientific research and outreach.



Andy Morris



Fiona Auty



Roy Sambles

NPL Fellows

NPL Fellowship is a recognition of individual merit awarded to scientists who are making significant contributions to NPL's scientific achievement and standing.

Nick Ridler has been appointed an NPL Fellow in the field of High-frequency Electrical Metrology, in recognition of his international leadership in establishing traceability for measurements made in the radio-frequency, microwave, millimetre-wave and terahertz parts of the electromagnetic spectrum.

Alexander Shard has been appointed an NPL Fellow in the field of Surface Chemical Metrology, for his outstanding and pioneering contributions to surface chemical analysis and nanoparticle metrology.

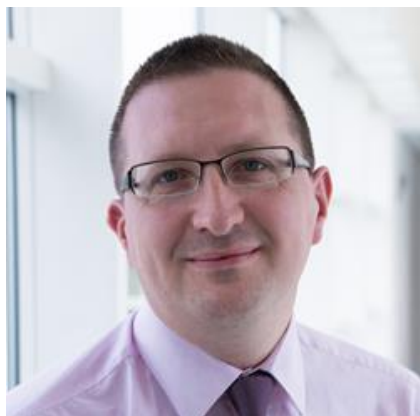
Patrick Regan has been appointed an NPL Fellow in the field of Nuclear and Radiation Science and Metrology, in recognition of his scientific leadership in the field of nuclear and radiation physics and its applications to both fundamental and applied measurement problems.

Prestigious Awards



Image courtesy of Jude Palmer/Royal Academy of Engineering

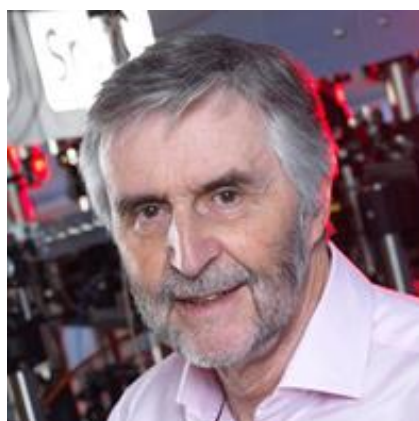
The NPL PocketVent team were awarded the President's Special Award for Pandemic Service by the Royal Academy of Engineering in recognition of their contributions in helping society to address the challenges presented by the COVID-19 pandemic. Jean Morris, Arthur Vie, Joshua Bayfield, Joshua Schofield, Chris Bull and Jolyon Caplin designed a fan-based ventilator, PocketVent, that met the critical functionality and performance requirements details in the MHRA specification for ventilation.



Richard Brown, Head of Metrology at NPL, has received the Royal Society of Chemistry, 2020 Theophilus Redwood Award, for excellence in theoretical and practical aspects of chemical measurement leading to the recent redefinition of the mole, and the communication of these changes.



Alexander Shard, NPL Fellow, has received the Royal Society of Chemistry, Industrial Analytical Science Award, for his pioneering work on accurate surface chemical analysis.



Patrick Gill, Senior NPL Fellow, received the prestigious Rumford Medal from the Royal Society for his outstanding contribution to the scientific community. Throughout his distinguished career, Professor Gill has made significant contributions in the field of physics. The Rumford Medal has been awarded for his development of optical atomic clocks of exquisite precision, of ultra-stable lasers and of frequency standards for fundamental physics, quantum information processing, space science, satellite navigation and Earth observation.



Jamie Mewburn-Crook, Assistant Research Scientist, has won the IOP's 2020 Apprentice Award for his work in Medical Radiation Physics during the first year of his apprenticeship.



Warda Heetun, Research Scientist, has won the IOP's Technician Award for her outstanding contributions to measurement science and establishing the world's first standard for quantitative nuclear medicine imaging.

MEETING THE NATIONAL CHALLENGES

NPL undertakes excellent science and engineering to deliver extraordinary impact for the UK and provides the measurement capability that underpins the UK's prosperity and quality of life. NPL is the UK's National Metrology Institute, developing and maintaining the national primary measurement standards, providing the national measurement infrastructure and delivering the UK Measurement Strategy on behalf of the UK government's Department for Business, Energy and Industrial Strategy (BEIS).

We apply our science and engineering knowledge and work with business, governments, researchers and others, with a specific focus on global trends which will transform our future.

Digital

Developing the digital measurement infrastructure, which is applicable across all sectors and underpins the UK's society and industry.

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.

The National Timing Centre Programme

In July 2019, the £36 million National Timing Centre (NTC) programme officially began and during 2020, the COVID-19 crisis provided the backdrop for a vast amount of research, design and industry engagement activity, despite a challenging external environment.

Timing is an underpinning capability across multiple sectors and is essentially an 'invisible utility'. The assumption that we can always rely on the ubiquitous Global Navigation Satellite System for time is untenable. Through the NTC programme NPL aims to increase resilience in time dissemination to underpin reliable timing service for the future.

Over 55 colleagues from NPL and the partner organisations have successfully progressed all three programme objectives: a resilient national time scale, innovation opportunities for UK companies, and responding to the skills shortage in time and frequency. More specifically, the NTC team has been forging ahead with the design phase of what will become the enhanced resilient and accessible source of timing for the UK. Engagement with sector stakeholders is ramping up to capture current and future needs and challenges. As emerging applications such as autonomous vehicles, smart cities and distributed ledger technologies go mainstream, we plan to be ready to enable them.

Innovate UK worked with NPL to scope the £6.7 million of innovation funding available via competitions starting in 2021, based on feedback from industry and with the aim of supporting a UK supply chain and building an innovation community in timing in the UK. Additionally, the team has completed an industry wide skills assessment and produced a training blueprint with recommendations for learning opportunities.

The economic and industrial recovery following the COVID-19 crisis is going to be complex, but NPL is keen to balance the immediate requirements with the need to invest in the future. The NTC programme is a significant step towards protecting our critical national infrastructure and developing new opportunities.

Energy and Environment

Developing and maintaining the metrology capability to fulfil the requirements of society and industry while assuring sustainability.

The UK government is committed to reducing our impact on the environment and transforming our energy system to make it cleaner and more affordable. 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, leading and delivering on climate science and assuring a sustainable relationship with our environment through resource efficiency, waste and pollution reduction.

Enabling ‘measured’ climate action

Following formal adoption by European Space Agency (ESA) member states and commitment of €32.5 million from five nations, UK, Greece, Switzerland, Czech Republic and Romania, the NPL-conceived TRUTHS satellite mission has embarked on the first phase of its development towards launch. The satellite is designed to transform our understanding of the health of our planet, providing observations of incidents and reflected solar energy with unprecedented accuracy (approximately 10 times better) robustly tied to the SI. Its spectrally resolved data will establish a benchmark of the state of the planet from which to test climate forecasts and assess the adequacy/success of global net zero ambitions, as well as serve as an in-orbit reference to upgrade the performance of the global Earth observing system as a whole.

NPL is contracted, as part of an industrial consortium, to support the detailed design and prototyping, into space-worthy hardware, of the technologically disruptive on-board calibration system. It will also lead efforts to assess and assign uncertainty to the mission’s data and the calibration of other sensors.

In addition, NPL Fellow, Professor Nigel Fox, the UK’s Lead scientist of the mission, is leading a separate consortium to support ESA, the industrial consortium and the mission’s international science advisory group with analysis and advice on science objectives and technical implementation. NPL is also supporting the UK Space Agency (UKSA) on the mission’s technical development from a national perspective and to help ensure its development underpins even broader ambitions for the UK economy. In particular, the vision for the UK to be a global leader in the provision of ‘trusted data for climate and earth observation applications and services’, and national capacity to deliver a comprehensive ‘end to end’ supply chain, satellite/sensor build through to delivery of timely evidenced based information.

To date, NPL has established novel pre-flight calibration methods for satellite instruments, organised international comparisons under field conditions, surveyed desert, ocean, snow and vegetated field sites for post-launch validation and initiated research to enable uncertainty in observations to propagate through transformational algorithms into information.



Lifesciences and Healthcare

Developing, maintaining and applying a national science and measurement infrastructure, and providing expert metrology capability.

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.

Advanced Manufacturing

Meeting the global challenge to continuously improve productivity and competitiveness to ensure continued economic growth.

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 NMI, NPL is uniquely placed to lead the measurement, metrological and data confidence challenges that are arising in the space of industrial digitalisation.

Google Earth' of cancer – CRUK Rosetta programme

Funded through Cancer Research UK's Grand Challenge scheme, NPL is leading a group of international and multidisciplinary chemists, physicists and biologists to develop a reproducible, standardised way to fully map tumours with extraordinary precision.

The metrology and new measurements have enabled the consortia to generate confidence in the data from the cancer tumours. From the identity of molecules we measure, and therefore how we interpret the data in terms of metabolism, to providing confidence in the machine learning approaches that are used to define regions of interest within a tumour, or confidence in accurate registration of one dataset to another, building the knowledge to instil that confidence is critical.

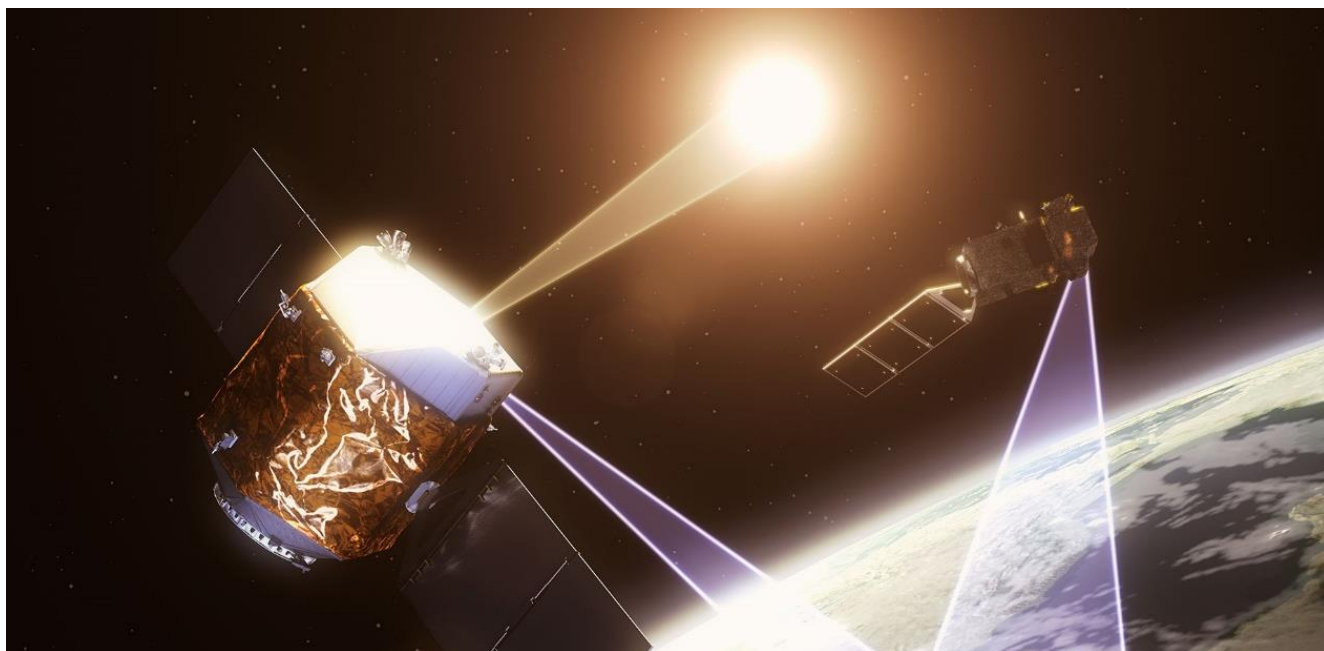
That confidence in data has enabled AstraZeneca (AZ) to change its approach to how molecular imaging is used. Previously the methods used were discreet and simple evaluations of drug compounds. Now integrated molecular imaging and biomarker methods are being adopted in 85% of all active AZ oncology programmes for pre-clinical assessments of drug distribution.

This is now extending beyond oncology into areas, such as respiration and immunology. But the findings are even more profound than that. Recent results from the Rosetta team show how the measurements may even be used for screening using urine or blood. The Rosetta pipeline has now shown potential to be deployed at all stages of the patient journey: screening, diagnostics, surgical treatment, non-surgical therapy and patient follow-up.

PPE manufacturing

During the COVID-19 pandemic, NPL provided support to organisations bringing new face masks and publicly worn face coverings to the market. Initially, this included advice on standards and material selection. NPL then created its own bespoke face mask testing rigs for breathability, filtration efficiency and liquid penetration resistance. We then extended our capability to tests associated with FFP-type face masks, providing tests in which the mask is fitted to a range of test heads (BS EN149 tests). The test rigs were completely designed and built by NPL to provide test data to demonstrate potential compliance with relevant standards, and also to give additional data to designers seeking to refine and optimise their designs.





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 (NMS) 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.

NPL and partners develop new protein imaging method

Scientists from NPL, the University of Birmingham and the University of Nottingham have established a new method to image proteins that could lead to new discoveries in disease through biological tissue and cell analysis plus the development of new biomaterials that can be used for the next generation of drug delivery systems and medical devices.

Using the state-of-the-art 3D OrbiSIMS invented by Ian Gilmore at NPL's National Centre of Excellence in Mass Spectrometry Imaging, the first matrix and label-free in situ assignment of intact proteins at surfaces with minimal sample preparation was demonstrated. This research has been published in Nature Communications.

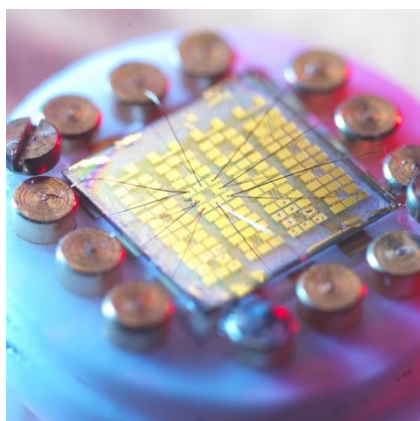
NPL and Henry Royce Institute sign Memorandum of Understanding

This commitment to collaborate further and formalise strategic engagement is an initial step towards the joint ambition to develop the concept of a National Advanced Materials Verification Centre to serve the UK advanced materials community and to provide confidence to accelerate the commercialisation of these game-changing materials. Initially it will focus on building confidence in the repeatability and reproducibility of the characterisation of materials, through NPL's measurement expertise and Royce's state of the art facilities. It will also support the development of postgraduate doctoral and broader training.

NPL and CQC collaborate in quantum computing

Scientists at NPL are working with Cambridge Quantum Computing (CQC) to accelerate research and development to support the commercialisation and optimisation of their quantum technologies, such as IronBridge™, and help with the characterisation of photonic components. This includes the metrology of emerging ultra-low loss optical connectors, for example, to meet the exacting requirements of IEC standards for improving the efficiency of quantum optical networks.

CQC's IronBridge™ is a photonic quantum device, built to provide high grade entropy to be used for post-quantum encryption algorithms, cached entropy generation for IoT devices, key generation for certificates, quantum watermarking and many other uses in cybersecurity, science, engineering, finance and gaming by utilising verifiable quantum randomness.



NPL and Lloyd's Register partner on marine autonomy assurance

NPL and Lloyd's Register will collectively establish and enhance the current body of knowledge for marine autonomy, and ensure that appropriate levels of service and competence can be achieved within the maritime industry. This combination of skills, expertise and experience will be built upon to bring clarity to the requirements for the assurance of autonomy and assist allied stakeholders in realising the potential of these systems in the market. It will allow standards to be set and consistently applied and will bring security to risk management and certification for autonomous and unmanned systems and vessels.

NPL and UCL collaborate on major scientific challenges

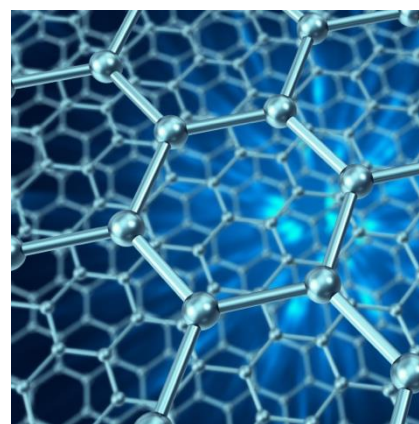
NPL and University College London signed a Memorandum of Understanding, stating their commitment to collaborate further and focus on areas of fundamental and applied research including: energy materials and devices, environmental science, biological science / healthcare technologies, synthetic biology, large dataset handling and quantum technology.

Innovative method of producing graphene at scale

Used to measure the magnitude of a magnetic fields, Hall Effect sensors are a critical electronic component in a variety of applications, from proximity sensing and speed detection through accelerometers to current sensing.

However, historically, their deployment in high-radiation environments such as satellites and nuclear power plants has faced significant challenges, since conventional sensors made from silicon and other semiconductor materials react adversely to neutron radiation. They need to be encapsulated in radiation-hardened packaging which entails a complex, lengthy and costly manufacturing process and may require the sensor to be replaced if the packaging is damaged. By contrast, tests conducted at NPL have shown that Paragraf graphene Hall Effect Sensors are not affected by extremely high neutron doses of radiation.

This is the first time that a commercially-available, graphene-based electronic device has proved impervious to neutron radiation.



Collaboration to support nuclear decommissioning

Three new Research & Development contracts have been awarded, to look for innovative solutions to the technical challenges of delivering the National Decommissioning Authority's mission. This funding means the UK has a huge opportunity to unlock thousands of green jobs by developing the next generation of nuclear energy technology.

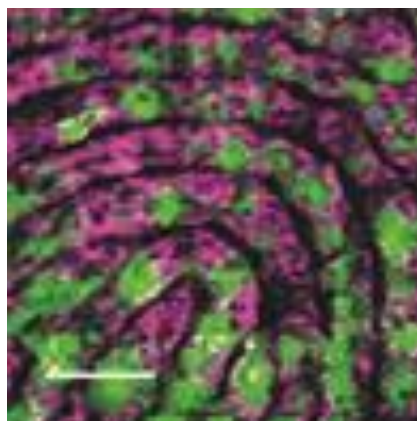
Experts from NPL will be working alongside the National Nuclear Laboratory, Frazer-Nash Consulting Ltd and Arup to ensure the development of key technical skills required to deliver decommissioning plans and provide fundamental understanding of the science and engineering of key processes. Collaboration between nuclear companies and national laboratories is key in realising the potential opportunity for nuclear energy to underpin the UK's commitment to achieving net-zero.

Scientists create artificial virus to fight superbugs

Scientists at NPL, working with partners from the University of Cambridge, University of Exeter, King's College London and University College London, developed a mechanism to combat persistent and resistant bacterial infections. The rise of superbugs is a serious concern in the medical community as bacteria evolve to evade existing treatments faster than new antibiotics can be developed. Rather than seeking out antibiotics that exist in nature, as has been the case with previous advances, the team of experts have designed one from the ground up, inspired by viruses.

Cryo-OrbiSIMS: label-free biomolecular imaging

NPL, in collaboration with the Francis Crick Institute, The University of Nottingham and the National Institute for Biological Standards and Control have launched the Cryo-OrbiSIMS with two landmark papers. The paper in the journal *Angewandte Chemie* showed that the new cryogenic technique increased the range of different biomolecules that can be imaged, including semi-volatiles. As a proof-of-principle they imaged lipids and other molecules in human fingerprints, plant leaves and also in a popular genetic model organism, the fruit fly, *Drosophila*. It demonstrated that Cryo-OrbiSIMS could be used for a diverse range of tissue samples, and could be useful for a large number of research and industrial applications. The second paper, in *Analytical Chemistry*, showed the metrology and development of a comprehensive workflow to preserve biological samples in their native state, without ice formation, using high-pressure freezing. It was discovered that analysis in the frozen-hydrated state yields a 10,000 fold increase in signal intensity for polar molecules, such as amino acid, which has important implications for imaging of metabolites and pharmaceuticals.



Support for OxSonics Therapeutics

OxSonics, a UK-based spin-off from the University of Oxford, has developed a drug delivery platform called 'SonoTran' that comprises 'SonoTran Particles' (stabilised gas bubbles) and a portable ultrasound 'SonoTran System'. The Ultrasound and Underwater Acoustics group has supported OxSonics in measuring the acoustic output of the SonoTran System's ultrasound transducer. The state-of-the-art testing facility comprises a 10-axis beam-plotting facility combined with acoustic modelling of the 3D acoustic field. Mechanical and thermal safety indices, pressure, intensity and power parameters of the SonoTran System were characterised according to IEC standards.

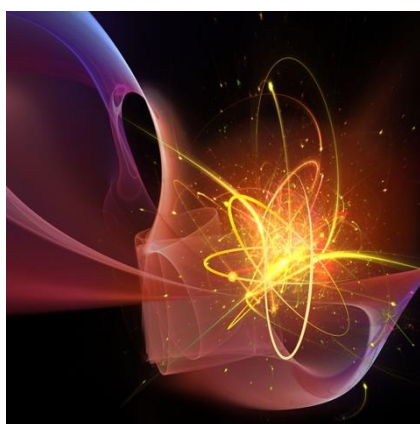
Memo of Understanding signed with National Metrology Institute of South Africa

NPL and the National Metrology Institute of South Africa (NMISA) have signed a Memorandum of Understanding which builds upon the close ties NPL already has with NMISA and supports further collective work, specifically in areas such as the realisation of the revised SI and dissemination of units, training, medical physics and environmental monitoring.

Supporting the national effort on quantum

NPL has successfully delivered an integrated and high impact programme in support of the National Quantum Technologies Programme. This has been the largest one-year programme NPL has ever delivered, both in scale and scope. It was delivered by a large team of NPL scientists and engineers from Quantum Technology, Time and Frequency and other departments, particularly Electromagnetics. The team has also included critical work from project management, procurement, commercial, strategy, training and finance.

We have designed, purchased and installed facilities to deliver new capability, extended our research and experimental investigations into how to characterise quantum technologies, created access schemes for industry to make use of our capability, raised the profile of international standards development and reviewed both the future industry and skills needs for the UK quantum sector. We worked closely with industry in collaborative innovation projects, installing equipment and connections to other locations, and joined academic consortia investigating fundamental questions of nature.



The first year of this programme has set a strong basis for continued activity to establish the enduring capability needed to support a growing economy based on quantum technologies. Through this programme, NPL will deliver the capabilities needed to make the best return for the UK from the government's investment in the National Quantum Technologies Programme.

2020 Rayleigh Award winners

The Rayleigh Award is given to NPL's most outstanding published paper. Yameng Cao, George Koutsourakis, Gavin Sutton, Sebastian Wood, James Blakesley and Fernando Castro won the 2020 Rayleigh Award for their paper: In situ contactless thermal characterisation and imaging of encapsulated photovoltaic devices using phosphor thermometry. The work was carried out as part of informal cross-departmental research between the Electronic & Magnetic Materials Group and the Temperature & Humidity Group, highlighting the value of multidisciplinary collaboration in generating significant advances.

The paper demonstrated a novel technique that allows contactless, traceable measurements of the operating temperature of photovoltaic (PV) devices within their encapsulation and with high spatial resolution, which was not possible before, without compromising accuracy or the integrity of the PV module. Imaging phosphor thermometry overcomes the challenges faced by thermocouples and infrared imaging because it operates at visible wavelengths (allowing measurements below the surface of the encapsulation) and is independent of emissivity and background thermal radiation.

Impact from Science

The Underwater Acoustics team has been awarded the 2020 NPL Impact from Science Award for their work on metrology for in-situ measurement and assessment of man-made marine noise. They have provided pioneering technical guidance in an immature field, assured the quality of environmental assessments for regulators and monitoring schemes for EU Directives, and supported licensing in the dredging industry. To date this work has directly contributed to the consenting of 15 UK offshore windfarms at a total project cost of around £10 billion, with eventual total capacity 13 GW.

NPL awarded major European contract to manage collaborative research funding

NPL will host the Management Support Unit for the proposed new EURAMET funding programme. The bidding competition for the contract was fierce but resulted in overwhelming support from the delegates at EURAMET's General Assembly. The funding programme, the European Partnership on Metrology, builds on collaborations in the metrology community. EURAMET, the European association of national metrology institutes, aims to develop and disseminate an integrated, cost effective and internationally competitive measurement infrastructure for Europe.

NPL has provided an excellent service over many years, as observed by both EURAMET auditors and the EC independent observers. The team received praise from EURAMET for running the current EMPIR programme: 'The competence, experience and motivation of the MSU team is at an extraordinarily high level, contributing to the timely professional performance'.

TECHNOLOGY AND MEASUREMENT FORESIGHTING

NPL carried out a Foresighting programme to identify major trends in technology and measurement that would impact industry and our society, as well as how we live, over the next 15 years.

Technology and Measurement Foresighting identifies which technologies will be vital and explores their implications on metrology.

As the pace of technological change accelerates, society needs to adapt to realise the full benefits and opportunities. Whether it's driving the green recovery or ensuring intelligent use of data, the UK's position as a science superpower, in part, depends on looking to the future and being one step ahead.

Drivers of change are the pressures that make society evolve or industry develop. They may include legislation, environmental considerations, changes in human behaviour, cultural differences or financial factors. Technology and Measurement Foresighting identified three drivers of change:

- Wellbeing
- Enterprise
- Sustainability

These three drivers are seen in every industry and country, and will impact all of us. We used these drivers to analyse industries and highlight which technologies are key for the future.

The overarching findings cover the trends and technological advances that are vital to one or more industries, and investigate the measurements required for society

to adopt new technology with confidence.

The three key conclusions for metrology were:

1. Metrology will support a digitally enabled global measurement infrastructure

Manufacturing, energy and other industries will increasingly rely on digital technology for controlling processes, planning their activities and liaising with customers. The new technology, from better sensors and AI to sophisticated customer communication, needs to have more accurate measurements with lower uncertainty to be robust, safe and trusted.

2. Metrology will improve understanding of complex systems

The climate, the human body and the effect of pollution on health are all complex systems which we are keen to understand and control. To do this we rely on combining scientific measurements with data which is more subjective or uncertain. A 'metrology mindset' allows us to analyse complex systems in a logical way.

3. Metrology will give confidence in decision making

Measurements allow us to make decisions – from the criteria for accepting or rejecting a manufactured product to the level of pollutants that is unacceptable. Making good decisions relies on making accurate measurements, communicating them effectively and understanding the uncertainty.

We developed visions for six example industry sectors to give insights into possible developments in the 2030s.



Built environment



Energy



Food production



Healthcare



Manufacturing



Transport

PLACE

NPL is expanding the community we work with, to help more businesses and organisations to prosper and progress through exposure to our world-leading research, facilities and people. Our regional network provides local access to NPL's expertise, providing significant benefit to UK industry, especially SMEs.

NPL Scotland

NPL in Scotland has continued to serve as a gateway for NPL to engage with academic and industrial research teams. NPL employees hold a variety of visiting roles within the University of Strathclyde as well as several academics that have served in joint appointments with NPL. Highlights include the Measurement Fellowship scheme that has led to several fruitful collaborations and partnerships as well as the integration of NPL's Data Science capability into the Medicines Manufacturing Innovation Centre.

Working in partnership with the University of Strathclyde's Executive team, the NPL team in Scotland were able to quickly re-establish technical delivery in our laboratory with the Technology & Innovation Centre and have maintained that operation since re-opening in June 2020. The University of Strathclyde helped promote NPL's e-learning training which was made available for free during the pandemic and reached significant audiences.

Five EPSRC Industrial Cooperative Awards in Science & Technology (iCASE) were awarded to University of Strathclyde and NPL partnerships in the last year, providing funding for PhD studentships where businesses take the lead in arranging projects with an academic partner of their choice.

There are close working relationships with the Power Network Demonstration Centre and the National Manufacturing Institute Scotland. Ongoing work between NPL's National Timing Centre and our Quantum Test and Evaluation Programme is soon to deliver the next phase of these collaborative programmes, which will establish unique traceable facilities in Scotland for the very first time.

NPL North of England

NPL North of England specialises in helping SME manufacturers which dominate industry in the region. This includes direct access to NPL Scientists and Engineers to provide measurement support, problem solving, knowledge transfer, digitalisation support and day-to-day metrology advice. NPL's Manufacturer Measurement Network (MMN) is managed out of Huddersfield and attracts a diverse community of manufacturing businesses to its knowledge sharing events which are held in-person and online. More recently the Huddersfield based team has had a major impact in helping UK businesses to manufacture PPE products for the first time and to get them into the UK market quickly. This has resulted in tens of millions of new items protecting key workers and the general public.



PUBLICATIONS

In 2020 NPL published 534 papers in peer-reviewed scientific journals. The following NPL publications have been highlighted for their scientific contribution.

Life Sciences and Health

Engineering chirally blind protein pseudo-capsids into antibacterial persisters, ACS NANO

Ibolya Kepiro, Irene Marzuoli, Katharine Hammond, Helen Lewis, Mike Shaw, Smita Gunnoo, Emiliana De Santis and Maxim Ryadnov (with King's College London, University College London, University of Cambridge and University of Exeter)

Cryo-OrbiSIMS for 3D Molecular Imaging of a Bacterial Biofilm in Its Native State 'Analytical Chemistry'

Justing Zhang, Paulina Rakowska and Ian Gilmore (with The University of Nottingham and National Institute for Biological Standards and Controls)

The challenge of ionisation chamber dosimetry in ultra-short pulsed high dose-rate Very High Energy Electron beams 'Nature'

Michael McManus, Francesco Romano, Nigel Lee, Hugo Palmans and Anna Subiel (with University College London, MedAustron, CERN, Istituto Nazionale di Fisica Nucleare and CEA-Saclay)

Advanced Manufacturing

Bringing Real-time Traceability to High-Speed Atomic Force Microscopy 'Measurement Science and Technology'

Edward Heaps, Andrew Yacoot, Herve Dongmo, and Freddie Russel-Pavier (with University of Bristol, Virginia Commonwealth University, Czech Metrology Institute and Brno University of Technology)

The lattice parameter of silicon; a secondary realisation of the metre 'Measurement Science and Technology'

Andrew Yacoot (with Physikalisch-Technische Bundesanstalt and National Institute of Standards and Technology)

Energy and Environment

Operando characterisation of the impact of carbon monoxide on PEMFC performance using isotopic labelling and gas analysis 'Journal of Power Sources Advances'

Hans Becker, Thomas Bacquart, Niamh Moore, Gareth Hinds and Graham Smith (with Anatune Ltd and VTT Technical Research Centre of Finland)

The increasing atmospheric burden of the greenhouse gas sulfur hexafluoride (SF₆) 'Atmospheric Chemistry and Physics'

Tim Arnold and Chris Rennick (with University of Bristol, Swiss Federal Laboratories for Materials Science and Technology, University of California, Met Office Hadley Centre, Commonwealth Scientific and Industrial Research Organisation, Georgia Institute of Technology, Massachusetts Institute of Technology, Kyungpook National University, Goethe University Frankfurt, University of Urbino and University of Edinburgh)

Example of Monte Carlo Method Uncertainty Evaluation for Above-Water Ocean Colour Radiometry 'Remote Sensing'

Agnieszka Bialek and Sarah Douglas (with University of Tartu and European Space Agency)

Half-life measurements in ^{164,166}Dy using γ-γ fast-timing spectroscopy with the v-Ball spectrometer 'Physical Review C'

Rhiann Canavan, Patrick Regan, Sean Collins, Giuseppe Lorusso and Robert Shearman (with University of Surrey, Technische Universität Darmstadt, IPN Orsay, Université Paris-Saclay, Extreme Light Infrastructure -

Nuclear Physics, Universidad Complutense de Madrid, Università degli Studi di Milano, Polish Academy of Sciences, Université de Strasbourg, University of Warsaw, Université Paris-Saclay, Universität zu Köln, GSI Helmholtzzentrum für Schwerionenforschung, Horia Hulubei National Institute of Physics and Nuclear Engineering and European Commission)

A high-resolution β - γ coincidence spectrometry system for radioxenon measurements 'Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment'
Steven Bell, Sean Collins and Patrick Regan

Novel thermometry approaches to facilitate safe and effective monitoring of nuclear material containers 'Nuclear Engineering and Design'
Graham Machin, Rob Simpson, Gavin Sutton, G., Wesley Bond, Edward Heaps, Michael Hayes, Sofia Korniliou, Jamie McMillan, James Norman, A Sposito, and Vivek Panicker (with Sellafield Ltd)

Quantum and Digital

Building confidence in digital health through metrology 'British Journal of Radiology'
Nadia Smith, David Sinden, Spencer Thomas, Marina Romanchikova, Jessica Talbott and Michael Adeogun

Modelling energy demand response using long short-term memory neural networks 'Energy Efficiency'
José Joaquín Mesa Jiménez and Valeria Livina (with Brunel University London and Mitie)

SI / Intercomparisons / Reproducibility

A strontium optical lattice clock with 1×10^{-17} uncertainty and measurement of its absolute frequency 'Metrologia'
Richard Hobson, William Bowden, Alvis Vianello, Alissa Silva, Charles Baynham, Helen Margolis, Patrick Gill and Ian Hill (with Clarendon Laboratory and Imperial College London)

Spectral extension and synchronization of microcombs in a single microresonator 'Nature Communications'
Shuangyou Zhang, Jonathan Silver and Pascal Del'Haye (with Max Planck Institute for the Science of Light, University of London and Friedrich Alexander University Erlangen-Nuremberg)

Direct comparisons of European primary and secondary frequency standards via satellite techniques 'Metrologia'
F Baynes, Charles Baynham, W Bowden, Patrick Gill, Rachel Godun, Ian Hill, R Hobson, J Jones, S King, P Nisbet-Jones, A Rolland, Setnam Shemar, Peter Whibberley and Helen Margolis (with Physikalisch-Technische Bundesanstalt, Leibniz Universität Hannover, Istituto Nazionale di Ricerca Metrologica, Politecnico di Torino and Observatoire de Paris)

Evolution of the International System of Units: considering the challenge of user adoption 'Metrologia'
Richard Brown

Realisation of a quantum current standard at liquid helium temperature with sub-ppm reproducibility 'Metrologia'
Stephen Giblin and Masaya Kataoka (with VTT Technical Research Centre of Finland, Aalto University and NTT Basic Research Laboratories)

What is a mole? 'Metrologia'
Richard Brown and Paul Brewer

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 collaboration between the two universities and NPL brings together their track record of working with business and industry and their complementary academic strengths, making a step change in capability, influence and impact. The partnership includes:

- 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.



www.npl.co.uk

Disclaimer. Although every effort is made to ensure that the information contained in this annual review is accurate and up-to-date, NPL does not make any representations or warranties, whether express, implied by law or by statute, as to its accuracy, completeness or reliability. NPL excludes all liabilities arising from the use of this annual review to the fullest extent permissible by law. NPL reserves the right at any time to make changes to the material, or discontinue the annual review, without notice. The NPL name and logo are owned by NPL Management Limited. Any use of any logos must be authorised in writing.

© NPL Management Ltd, 2021.