THE VALUE OF THE NATIONAL MEASUREMENT SYSTEM TO THE ECONOMY

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Measurement has helped define societies, governments and progress since the dawn of civilisation. Length, area, volume, weight and time all had to be quantified and systematised when dividing up goods or land, trading, building and keeping records. One of the earliest measurement devices was the cubit, fundamental to building the pyramids. Our own Magna Carta in 1215, set out some early rules for measurement: "there is to be one measure of wine and ale and corn within the realm, namely the London quarter, and one breadth of cloth and it is to be the same with weights". Eventually such local laws and standards gave way to an internationally agreed system of units in 1875 and it is this system that the National Measurement System upholds for the UK.

All our science and technology depends upon the largely unknown work of Measurement Scientists. These scientists, known as metrologists, define scientific measurement and standards that other scientists then rely on to compare their findings with research done elsewhere or at a different time. Provision of this measurement capability is part of the technical infrastructure that underpins the UK's science, engineering and technology landscape for government, industry, and academia.

Standards help everyone to talk in the same language when something is being measured, a dictionary explains the meaning of a word and how to spell it; in a sense, we do the same for measurement.

Measurement underpins the welfare of a modern society and touches almost every part of daily life. It ensures consistency of international time standards so we can communicate reliably and navigate accurately throughout the world; ensures safety and efficacy of healthcare diagnostics and treatments; quantifies emissions of greenhouse gases to help understand and mitigate climate change; and measures the composition, energy value and quantity of gas piped to our homes, and fuel to our vehicles.

MEASUREMENT IN INNOVATION

It is generally acknowledged that the economic recovery will emerge from innovative and forward-thinking businesses in the UK. New measurement techniques and technologies stimulate and support innovation in products, processes and services.

Today measurement plays a fundamental part in the innovation process. To develop new products and processes, companies need to measure quantity, quality and performance. To trade successfully, companies must have a regulatory framework based upon measurement confidence, which ensures global markets are fair and open by eliminating unnecessary barriers to trade. Supporting this is an established infrastructure of traceable measurement linked seamlessly to the national standards maintained on behalf of the UK.

In some industries the need for accurate measurement is critical. Companies manufacturing precision engines work to tight specifications in which parts must be measured for size, material composition and performance to very accurate levels. Rolls-Royce, for example, employs over 200,000 measuring devices on their production lines.

For many of us a visit to a hospital may not be desirable, but knowing that the treatment has been appropriately measured throughout its development, trials and finally its delivery to the patient is vital to confidence in its application and effectiveness. The National Measurement System directly works with hospitals, underpinning over 200,000 radiation treatments each year for cancer diagnosis and treatment. Indeed, the work undertaken by the National Physical Laboratory (NPL) has been shown in international comparisons to provide the most accurate measurements, resulting in the most accurate doses of radiation, and the saving of hundreds of lives.

Measurement needs are ever changing. Measurement scientists are at the forefront of developing technologies that will drive future growth such as low carbon, nano and quantum technologies. Indeed, work at NPL on graphene was cited in support of this year's Nobel Prize for Physics. Measurement also plays a vital role in ensuring that standards and legislation are based upon robust yet practical measurement practices.

At the heart of the measurement infrastructure there are multi-disciplinary teams of skilled scientists, engineers, mathematicians and support staff. The UK measurement system attracts talent from across the world and nurtures this talent to be the very best – many of these scientists are world leaders in their field. The National Measurement System invests in knowledge transfer to ensure that their know-how is shared within the UK for economic and social benefit.

The National Measurement System is the collective infrastructure of national facilities, expertise, knowledge, science, research and legal framework in the metrology field. Together these elements combine to provide traceable measurement, new measurement standards and techniques and the regulatory system to control trade, based on defined quantities. Equally, they provide a national asset base of skills and knowledge that is essential to developing and nurturing innovation in products and services.

Thousands of businesses each year gain measurement know-how and support through the National Measurement System. In a survey of 1,200 companies who had been supported by NPL, annual profitability gains of circa £700m were achieved in one year through product and process innovation, and improved measurement.

It is critical to ensure that investment in measurement delivers real economic and social impact. This is particularly the case when the investment involves public money. The National Measurement System invests approximately £60m per year across a portfolio of programmes whose role it is to respond to well-defined public, legislative or industrial needs, undertaking R&D to uphold and improve national standards, providing traceability for accredited measurement services or reference materials, as well as developing new measurement capabilities in support of strategic national priorities and the next generation of primary measurement standards. Measurement scientists also represent the UK on the international measurement stage, ensuring that measurement standards and legislative requirements are legal, accurate and fair to the buyer and seller. (NPL scientists support approximately 750 national and international committees and working groups).

The balance and content of these programmes is identified through extensive consultation with input from a wide range of stakeholders and overseen by independent working groups, with members from industry, government and academia, that ensure they remain fit for purpose.

NATIONAL PHYSICAL LABORATORY

The National Physical Laboratory (NPL) is the UK's National Measurement Institute and sits at the heart of the National Measurement System as the main provider of the measurement research programmes and infrastructure. NPL is one of the UK's leading science and research facilities and a world-leading centre of excellence in developing and applying the most accurate standards, science and technology available. We occupy a unique position sitting at the intersection between scientific discovery and real world application, at the point where science is translated into solutions – a place we have been proud to occupy for over 110 years.

When NPL was established in 1900, Lord Rayleigh expressed its charter, on behalf of the Royal Society, to its first Director, Sir Richard Glazebrook, to "bring scientific knowledge to bear practically upon our everyday industrial and commercial life, to break down the barrier between theory and practice and to effect a union between science and commerce". That remains as true today as it was then.

NPL's role beyond the work for the National Measurement System is to take the knowledge gained and provide companies with access to world-leading support and technical expertise, inspiring the absolute confidence required to realise competitive advantage from new materials, techniques and technologies; as well as supporting organisations and services in a wide range of social applications – helping to save lives, protect the environment and enable citizens to feel safe and secure. Support in areas such as the development of advanced medical treatments and environmental monitoring helps secure a better quality of life for all. Our approach is simple – all that we know we transfer – we do not retain our knowledge for knowledge's sake. Each year we support UK industry by providing a wide range of measurement services and consultancy to over 2,000 industry customers.

NPL has been managed since 1995 on behalf of the Department for Business Innovation and Skills through a government-owned contractor-operated arrangement by Serco. This model has worked very well, bringing to bear the best practices of the private sector whilst sustaining and enhancing the science outputs. Thus, overheads have been reduced by 30%, staff utilisation has increased by 10%, and third-party work has tripled since 2004 (now accounting for over one-third of the lab's revenue); with the number of peer-reviewed publications and citations doubling since 2004.

In 2010 NPL celebrated its 110th anniversary, which provided the opportunity to look back and reflect on some of our achievements. NPL has a rich heritage delivering some outstanding contributions to the prosperity of the UK, including the invention of radar, support to the 'bouncing bombs' used in the Second World War, Alan Turing's pioneering work on the first automatic computing engine, Donald Davies' development of packet-switching that provided the basis of the internet, and Louis Essen's work on the first atomic clock.

However, it is vital that, for NPL to continue to provide the maximum impact to the prosperity of the UK and quality of life of its citizens, we do not rest on our laurels.

FUTURE CHALLENGES

The challenges for measurement in the future are many and far reaching, but it will continue to play an important role in our digital economy. Already we are close to new methodologies for measurement of time that will help in the drive to make satellite navigation even more accurate than it is today. We are working closely with many biotechnology companies to discover whether better measurement techniques can reduce the time to market for new drugs. Mathematical modelling is becoming key in areas ranging from predicting climate change to understanding how aircraft engines will react in adverse conditions, and the measurement and measurement assumptions behind these models need to be accurate if they are to provide us with credible information that we can act on with confidence.

One of the most significant challenges lies in the future of energy generation and the use of low carbon technology. NPL is looking to establish a Centre for Carbon Measurement dedicated to this field – providing the measurement infrastructure required to access low carbon technologies, support financial carbon trading and underpin confidence in climate data.

There is rarely an average week at NPL. Recently we have been involved in developing an intelligent harvesting machine that knows when cauliflowers are ripe for the picking, using the high frequency sound of crunching biscuits as a guide to customer satisfaction, measuring the temperature in the centre of an explosion designed to destroy everything in its path, and assessing the performance of wet suits.

But to sum up the importance of measurement to our economy, I draw upon a quote from the British scientist, Lord Kelvin, who developed the temperature scale named in his honour:

"When you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot express it in numbers your knowledge is of a meagre and unsatisfactory kind."

Fine words indeed!

CAN THE ECONOMY SURVIVE WITHOUT A NATIONAL MEASUREMENT SYSTEM?

DEPENDENCE OF INDUSTRY ON THE NMS FOR MANUFACTURE AND INNOVATION

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The focus presented here is that of an industrialist with an international perspective. It ranges initially from aircraft constructed of wood and linen structures, evolving to metallic frames and aluminium. Indeed, Concorde is the only aircraft ever built and then withdrawn that was not superseded by something better. While initially technically driven, aircraft manufacture from the 1970s was commercially driven and designed to reduce operational costs. Environmental impact from cradle to grave then became more of an impact, though surprisingly, not exceeding two per cent of the overall total. The technology required is driven by 3 key factors: Regulation and Legislation, Environment, and the Airworthiness Authorities.

Airbus currently employs 52,500 around the world, including France, Germany, Spain, the UK, North America, China, India, Japan and Russia of whom 7772 are in the UK. It has a global network of over 323 customers and 341 operators, who delivered 510 aircraft and sold 644 in 2010. In addition 10,060 aircraft have been ordered by 323 customers. It supports 6,194 aircraft in service with 338 operators.

The main driver for change in the early 70's was Freddie Laker, followed by the need for eco-efficiency, new competitors, safety, regulation and REACH. This resulted in demand for the lowest product cost, a minimised recurring cost and the need to maximise the effectiveness of the non-recurring cost in order to reduce cycle time and the product development cycle. This led to demands for the highest product performance and manufacturing capability regardless of material for optimum weight, resulting in extensive use of composite materials and lightweight metals.

This required the need to cost out the production process and product development time in advance, in order to develop the airframe, combined with tests for material properties, with results needed before it was built in order to provide a full analysis prior to construction.

Indeed, the purpose of testing the 32 metre wing in the test frame (as demonstrated on video at the meeting) is to prove that it will take up to 6m bending, with the prior analysis supported by the subsequent tests. With better analysis fewer expensive and time consuming tests will therefore be required. The aircraft wing failed where and how it was predicted from the prior analysis. Hence the procedure can be limited to a single test if the analysis is accurate.

Where will we be beyond 2020? Carbon nanotube reinforcements that are under development currently tend to agglomerate and demand more research. Even large structures such as wings start with tight tolerance, and especially so with flushness at the surface which is essential to reduce friction.

The National Measurement System provides for following key contributions essential for Airbus. These include robust, traceable standards which are essential for manufacturing; cross-sector best practice and knowledge transfer; manufacturing optimisation and product improvement; and innovative metrology for product improvement and new concept development.

Finally, this raises the following key questions requiring a response; Can Airbus survive without a UK NMS? Can Airbus in the UK survive without a UK NMS? Can the UK supply chain for Airbus remain competitive without a UK NMS? Can UK Industry be competitive in the Global arena without an effective NMS?

UK LEADERSHIP IN NEW TECHNOLOGIES THROUGH THE NATIONAL MEASUREMENT SYSTEM

Dr Julian H Braybrook, Director of Strategy, Measurement Research, LGC
on behalf of David Richardson, Chief Executive, LGC

LGC (www.lgc.co.uk) is an international science-based company and market leader in analytical, forensic and diagnostic services and reference standards. LGC operates in a variety of markets which underpin the safety, health and security of the public and the regulation of industry, for both public and private sector clients.

LGC operates internationally through four divisions – LGC Forensics, LGC Genomics, LGC Standards and LGC Science & Technology. The latter includes specialist laboratories delivering contracts for the Department for Business, Innovation and Skills (BIS) and supports LGC's designated role as the UK's National Measurement Institute for chemical and bioanalytical measurement.

With headquarters in Teddington, South West London, the LGC Group employs ca 1,400 staff in 29 laboratories and centres globally. Privatised in 1996 and now majority-owned by funds managed by Bridgepoint, LGC was founded almost 170 years ago as the Laboratory of the Government Chemist – a statutory function maintained by LGC today.

BACKGROUND

The Coalition Government has set out its agenda with strong, sustainable and innovation-oriented balanced growth a key contributor. Innovation is pervasive and not sector-specific, being spread across more than 20 'traditional' or 'high-technology' industries. It is however skewed, with around 10% of highly innovative firms accounting for almost 40% of innovation investment. Innovation is shaped by the knowledge creation and distribution system, the environment for business investment, public sector innovation, and the education and skills system. Within the knowledge creation and distribution system lies measurement science and technology – an infrastructure of measurement standards, dissemination of units, and science-based policy advice.

THE ROLE OF MEASUREMENT

Advanced measurement capabilities are essential to innovation in every economic area and at every stage of the innovation process. Advanced tools and measurements are required to innovate – to design and incorporate new or better features into next generation products or processes necessary for the UK to compete effectively and stay ahead in the global marketplace. In this way, measurement plays an important role in avoiding market failure for innovative new products. Reliable measurement:

- facilitates fair trade through harmonised standards and internationally
- underpins regulation through policy advice and measurement references for Directives, conformity assessment, and verification, such that
- parts manufactured in one country fit into machines in another country
- products tested and approved in one country can be sold in another country, without further technical inspection
- consumer protection is maintained.

Measurement at the technology frontiers enables and drives innovation in advanced production and instrumentation – after all, 'one can manufacture only what one can measure'.

However, there are three commonly accepted areas where innovation is being held back:

- inadequate accuracy
- a lack of accurate sensors
- a lack of standards, benchmarks, metrics and protocols.

CHEMICAL AND BIOANALYTICAL MEASUREMENTS

Issues associated with physical measurement have been addressed for the best part of 50 years by the UK measurement system, but only within the last 25 years have the measurement issues associated with the chemical sciences been addressed in a similar fashion. The issues of biological measurement still remain in their relative infancy. UK leadership in these areas is acknowledged worldwide, but is under threat from measurement initiatives in the US and several of the new entrant developing countries, such as Korea and China.

LGC delivers the designated UK national measurement institute (NMI) role for chemical and bioanalytical measurement. Its model in the private sector differentiates itself from the other UK NMIs. As the first management buy-out (MBO) of a public sector research establishment (PSRE) from Central Government, internal investment and acquisition has increased LGC's public and private sector activities worldwide. Its fundamental approach is centred on:

- leading accurate and traceable measurement in relevant disciplines for the UK
- acting as a solution point for Government, where measurement makes a difference
- acting as a provider of value to UK industry, especially where it creates innovation.

Drawing on its strapline of 'science for a safer world', the following examples highlight where LGC has been providing its leading measurement expertise on behalf of the UK national measurement system (NMS) to bring value to existing and emerging chemical and bioanalytical technologies and industries – especially early support at the small and medium enterprise (SME) level to maximise opportunity for innovation.

GENOMIC MEDICINE

DNA sequencing has long been the 'gold standard' method for analysing regions of the genome, but it is prohibitively expensive and laborious. 'Next-generation' sequencing (NGS) technologies offer orders of magnitude increases in throughput and decreases in costs. However, despite their potential and rapid uptake across multiple disciplines, inconsistencies associated with target preparation mean that NGS technologies have mostly been applied to qualitative studies. Recently, however, the technology is being applied to quantitative profiling, where maintenance of accurate representation of starting material becomes even more critical.

The UK is helping set the lead to establish a measurement capability, within national measurement institutes worldwide, to identify requirements for NGS technologies and initiate development of a framework for standardisation.

CLINICAL MEDICINE

Cholesterol is a fatty substance which is found in the blood and which plays an essential role in how every cell in the body works. However, too much cholesterol in the blood can increase your risk of heart problems. The accurate measurement of small molecules in clinical samples is essential for the safe and efficacious diagnosis/treatment of patients. In the case of cholesterol measurement, a 10% error in its determination means 13% of the population do not receive the treatment they should and 20% receive treatment unnecessarily. The UK is leading traceable purity and mass spectrometry methods to assign reference values to a number of reference materials intended for the clinical sector.

PHARMACEUTICALS

The WHO estimates that counterfeit drugs, which now account for 10% of the global market, cost the pharmaceutical industry US$46 billion annually. For the consumer, it is the missed health benefits associated with any uncertainty over the likely effectiveness of the medicine or, indeed, the potential health risk associated with any unexpected clinical effects arising from the unknowing use of counterfeit medicines. Traditional detection and discrimination of counterfeit drugs rely on visual examination and physical and chemical analysis of goods and packaging, but counterfeiting is becoming more sophisticated.

The UK has taken the lead in developing new approaches based on the measurement of small, naturally occurring isotopic variations in compounds present in the product and packaging and have demonstrated the potential for these high accuracy mass spectrometry techniques to provide the low level of measurement uncertainties required for legal prosecution purposes.

FOOD SUPPLEMENTATION

Providing a sound basis for measuring a vital element in the diet – with long-term benefits for public health – could be enormous. Selenium is known to have important functions in key enzymes and recent studies suggest that selenium supplementation can help protect against cancer, HIV and other diseases. However, selenium is believed to be deficient within the UK diet due to our consumption of European wheat. It is important however for the selenium to be present in the right chemical form/species. The UK has helped establish accurate measurement approaches for detecting the different forms of inorganic and organic selenium for selenium supplementation through the diet.

Additionally, this work developed the analytical basis for the characterisation of organo-selenium compounds that, for the first time, enable pre-clinical and human clinical trials for novel prospective cancer therapies within the UK, Europe and the US.

NANOTECHNOLOGIES

The unique mechanical, thermal and catalytic properties that materials develop when structured at the nanoscale has led to nanomaterials being incorporated into more than 800 commercial products that impact on every aspect of human life. The UK is leading standardisation initiatives in nanotechnology, both in terms of setting an understanding of vocabulary and characterisation methodologies, but increasingly in nanotoxicology as a result of the inconsistent behaviours displayed by nanoparticles in traditional screening models. Employing UK expertise in *in vitro* toxicology assays, a label-free, real time, cell electronic sensing system has been validated. Such continual cell analysis has provided quantitative information about the rates and mechanisms of toxicity which can be missed using traditional assays.

REGENERATIVE MEDICINES

Tissue engineering uses cells, engineering and materials to manufacture functional replacement tissues for clinical application. Regulation is critical for product quality, safety and development. However, the novel aspects that make the technology so promising also make regulatory compliance more of a challenge. New product development and evaluation using high throughput cell imaging capability is being used to overcome the measurement difficulties associated with a more representative 3D (rather than traditional 2D) test environment for cell-based testing. The approach of using fluorescent probe technologies to visualise cells within 3D systems fills the technology gap.

The UK's pivotal role in the preparation of the first documentary publicly available specifications (PAS) for the cell-based therapeutic industry has been supported by leading measurement capability in single cell and 3D stem cell bioprocessing.

CONCLUDING REMARKS

The international picture for measurement science has never been healthier. UK leadership is reflected in its Chair roles for three (inorganic, bio-analysis and gas) of the six consultative committees, and in its founding role in a fourth, of the *Bureau International de Poids et Mesures* (BIPM). This organisation ensures world-wide uniformity of measurements and their traceability to the International System of Units (SI).

It is clear from the rapid increase in attendance of measurement scientists at the annual meeting of BIPM, measurement science is being seen as underpinning economic prosperity globally and is being invested in substantially in the developing countries and in the US. This is particularly strong in the 'newer' bio-analytical areas.

So whilst the UK currently 'punches well above its weight', the wealth of measurement challenges means European and international partnerships are becoming ever more important to ensure differentiated, but complementary, measurement offerings between NMIs.

100 YEARS OF NUCLEAR PHYSICS

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Today the model of an atom with electrons orbiting a central nucleus consisting of protons and neutrons is familiar to many of us and is taught as part of the GCSE science curriculum. One hundred years ago our understanding of the atom was very limited. Based on experiments conducted at The University of Manchester, Ernest Rutherford announced his theory of orbiting electrons and a central nucleus at the March 1911 meeting of the Manchester Literary and Philosophical Society and then published a paper in the May edition of the Philosophical Magazine.

Significant evidence for the Rutherford Model of the atom came from experiments directed by Rutherford and conducted by Hans Geiger and Ernest Marsden. The most famous of these experiments is the alpha scattering experiment where alpha particles (helium nuclei) were fired at thin foils of various metals, including gold. Geiger and Marsden were instructed to use a scintillator to observe the scattering of the alpha particles at various angles around the target. If the prevailing model of the atom (Thomson's plum pudding model with negatively charged electrons dispersed through a central positively charged mass) was correct then some alpha particles, which are positively charged, would be deviated slightly off their incident line.

Slightly deviated alpha particles were duly observed but then Rutherford instructed Marsden to look for any back scattering, ie alpha particles bouncing backwards. Marsden observed a small percentage being scattered backwards, which led to the famous quote from Ernest Rutherford that "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." To explain these results Rutherford proposed that the electrons must be orbiting around a central nucleus which contains most of the mass and is positively charged. This is still the basis of our understanding of the nucleus. For hydrogen 99.9% of the mass of the atom in in the nucleus and the sole electron orbits at a distance equivalent to 100,000 times the diameter of the sole proton.

Due to this remarkable insight Rutherford is known as the Father of Nuclear Physics and our understanding of the nucleus, developed from these initial experiments, over the last 100 years has led to some spectacular achievements. Understanding the nucleus allows us to understand phenomena such as radiation and nuclear fission and develop technologies that are beneficial. X-rays were discovered before Rutherford's experiments but his description of the nucleus shows how electrons moving between energy states, or different orbital sizes and shapes, releases the energy. In the nucleus itself the emission of alpha particles (helium nuclei with two protons and two neutrons), beta particles (electrons) or gamma rays is the basis of many everyday technologies such as smoke detectors and the specialist equipment used for medical diagnostics techniques, for example PET (Positron Emission Tomography) Scanners. Radiation is also used in medicine as a therapy in procedures such as cancer treatment.

Another way we have learned to harness the energy within the nucleus is to provide electricity through nuclear fission and in the future through nuclear fusion. The UK is currently undergoing a nuclear renaissance with new reactors due to come online before the