

NATIONAL PHYSICAL LABORATORY

2000

A YEAR OF ACHIEVEMENT

NPL 
National Physical Laboratory

The National Physical Laboratory is operated on behalf of the DTI by NPL Management Limited, a wholly owned subsidiary of Serco Group plc

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2000 - a year of achievement

This report presents a series of case studies illustrating some of NPL's achievements during the last year.

We have had inevitably to be selective in choosing which projects to cover. In doing so, we have sought to give examples that demonstrate our commitment to:

- driving forward the frontiers of science
- working in close partnership with other centres of scientific excellence
- delivering value for UK industry
- improving, continuously, our measurement services to customer communities
- applying our science to improve the quality of life

Case studies can be downloaded from the NPL website, or ordered in hard copy via the NPL Helpline or enquiry point e-mail.

The National Physical Laboratory (NPL)

NPL is the United Kingdom's national standards laboratory, the scientific heart of an infrastructure designed to ensure accuracy and consistency in every measurement made in the UK. With a total staff of 700, we employ more than 570 professional specialists in the physical sciences, materials, mathematical software and knowledge transfer.

The Laboratory is operated under contract to the Department of Trade and Industry (DTI) by NPL Management Limited, a wholly owned subsidiary of Serco Group plc.

During the year 2000 NPL has been engaged in the delivery of 18 major national measurement and materials-based programmes. These are supported under core funding from DTI with a current total annual value in excess of £28 M.

Closely related to this core activity is the continued development of a growing portfolio of commercial programmes for government, industry and export



A new home for NPL: a world-leading laboratory complex is rapidly taking shape on our Teddington site; the first teams of scientists are already working in the new building.

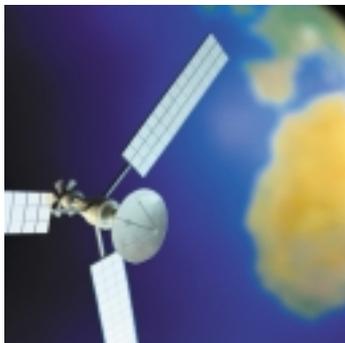
markets. This will have a total value of some £18 M in the current year, having seen more than 100% growth in the last four years.

This growth and our cost reduction programmes have enabled us to increase the science activity at NPL. As a result we currently employ 100 more scientists than in 1995 and we now have a well balanced age profile.

Achievement at the **frontiers** of science

NPL is committed to maintaining and extending its reputation for scientific excellence. We employ one of the largest teams of applied physicists in Europe and continue to develop our people, facilities and management processes to push forward scientific frontiers.

Significant effort is being devoted to nurturing emerging and new fields of metrology such as photonics, biotechnology and nanoscience. The following examples seek to illustrate the breadth and depth of NPL science.



Smaller SQUIDS can detect single spins

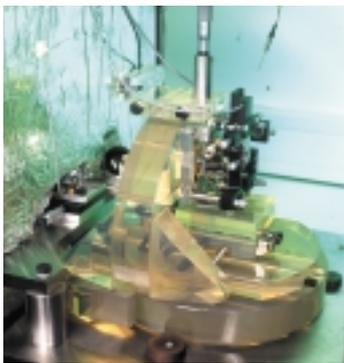
NPL has been investigating the limits of sensitivity for SQUIDs (superconducting quantum interference devices) in detecting magnetic spins. Recent work has shown that for very small inductance SQUID loops there is the potential to detect single electronic spin transitions. This has obvious implications for single particle detection and quantum measurement in general. Researchers at NPL used a SQUID with a loop with a linear size of 2.5 micrometres coupled with low noise electronics to make measurements corresponding to a sensitivity of a few tens of spins.

The experimental results of this study have confirmed that the sensitivity of a SQUID scales with loop dimension and further reduction in loop size should enable a single spin flip to be detected. A paper describing this work was presented at the Conference on Precision Electromagnetic Measurement in Sydney, Australia in May 2000. The low-inductance SQUID system is to be incorporated into the UHV cryogenic scanning tunnelling microscope, a major facility within NPL, and could be used to detect and make measurements on single particles.



Small area SQUID mounted in sample holder (upper object in picture) ready to be inserted into UHV STM system

Traceable surface texture measurement at the nanometre level



A traceable surface texture measuring instrument: Nanosurf IV

A new surface texture measurement service is now available from NPL that provides traceable measurements with uncertainties of less than a nanometre. This measurement service is based on NanoSurf IV - the latest in a range of high accuracy surface texture measuring instruments developed at NPL. Key features of NanoSurf IV are a diamond-tipped stylus to trace the topography of a surface, laser interferometers to provide traceable displacement measurements in both the vertical

and scanning axes of the diamond tip, a novel prismatic slide-way with a maximum scan length of 100 mm and a metrology frame and scanning stage constructed from materials of low thermal expansion.

NanoSurf IV is being used in conjunction with NPL's metrological atomic force microscope to enable surface amplitudes and wavelengths in the range from nanometres to millimetres to be traceably measured at NPL.

Single ion optical clock

NPL has achieved an important step towards building a possible future optical clock. The strategic research project is aiming to develop an ultimate optical frequency standard based on a single ion of ytterbium. The researchers have succeeded in locating the required ultra high-Q optical resonance - an electric octupole transition. This transition forms the frequency reference of the optical frequency standard or optical clock and corresponds to a wavelength of blue light. This result is the culmination of three years' research into locating this magnetic-field-insensitive resonance in an odd-isotope of ytterbium, and follows the first-ever optical octupole observation in an even isotope of ytterbium at NPL some four years ago.

Three papers have been published in *Physical Review A*¹ describing the observation of the odd-isotope octupole transition and the groundwork leading up to it. It is hoped that an initial prototype optical standard may be achievable in three to five



Work on the single ytterbium ion optical frequency standard, which is being developed as a future atomic clock

years, working at the part in 10^{15} level. Ultimately it is expected that the system will achieve reproducibilities in the parts in 10^{17} to 10^{18} level, which is around 100 times greater precision than the best clocks currently available, based on microwave atomic clock technology.

¹Roberts, M, et al, *Phys. Rev. A.* 1999, **60**, (4), 2867-2872

Taylor, P, et al, *Phys. Rev. A.* 1999, **60**, (4), 2829-2833

Roberts, M, et al, *Phys. Rev. A.* 2000, **62**, 020501(R)

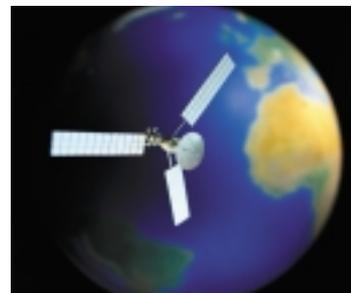
NPL Super Black

In order to make accurate measurements in the UV, IR and visible regions, optical instruments and sensors need surfaces with very low reflectance. These black surfaces are used as efficient radiation detectors or may reduce stray light in an instrument. Highly efficient black surfaces allow smaller, lighter instruments to be made, which is an important advantage in aerospace applications.

NPL has successfully developed a very high quality optical black – known as NPL Super Black. The

process uses an adapted nickel phosphorus electroless plating technique followed by finely controlled etching and gives probably the blackest surface known in the visible region.

NPL has successfully and repeatedly produced the Super Black coating on a small-scale 'cottage industry' basis for a number of years. It is now for upgrading and validating the process for plating much larger substrates with this high quality optical black. The upgrade has led to an opportunity to



collaborate with CNES, Astrium and Sodern, the major space contractors for the European Space Agency, on the space evaluation of the black. If successful this will open up many new opportunities for supplying coated optics to the aerospace industry.

Partnership for success

NPL recognises that scientific excellence and its application to innovation for industry and society are often best pursued in partnership with others. Every year we work with hundreds of partner organisations to generate scientific outputs of the highest quality.

The following case studies illustrate the range of collaborations in which we have been engaged this year; and we should like to take this opportunity to express our gratitude to the many partners we are currently working with.

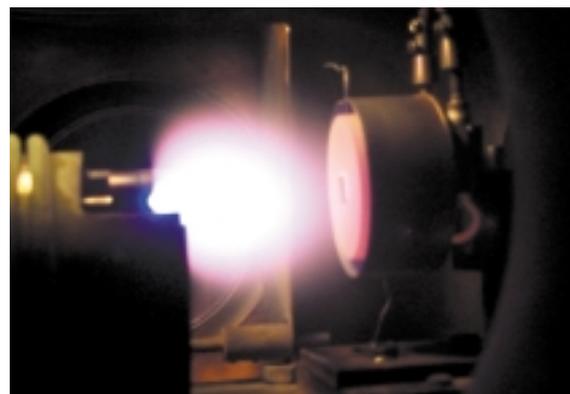


Josephson heterodyne oscillator gives route to new thermometer

NPL's Fundamental Metrology Group has demonstrated an improved high temperature superconducting Josephson device that is part of the Foundation Programme project to develop a primary noise thermometer. The device contains two Josephson junctions which can be independently biased to oscillate anywhere in the microwave range, up to at least 20 GHz. The beat frequency between them can then be adjusted by voltage control up to at least 40 MHz. The beat

frequency is amplified and read out with a frequency counter. The variance of the frequency counts provides a measure of the absolute temperature of the device. The oscillator linewidth has been measured for a variety of parameters including temperature and has been shown to be of order 30 kHz.

This novel SQUID was fabricated at Strathclyde University as part of a longstanding partnership with NPL. The device has been described in a recent paper in the

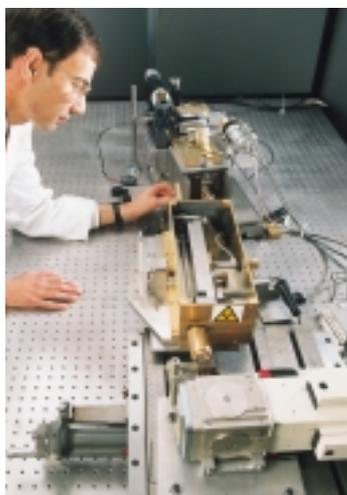


Pulsed laser deposition of high temperature superconductor devices at Strathclyde University

journal *Applied Physics Letters*¹ and may also be relevant to photon detection applications.

¹Macfarlane, JC, et al, *Appl. Phys. Lett.* 2000, **76**, (13), 1752-1754

Combined optical and X-ray interferometer gives improved precision



The combined optical and X-ray interferometer facility

A new instrument, located at NPL and resulting from a collaboration between NPL, PTB and IMG, provides a unique facility for accurate length metrology at the sub-nanometre level. The combined optical and X-ray interferometer (COXI) significantly extends the accuracy of measurements on the nanometre scale. Conventional optical interferometers rely on fringe division to achieve sub-nanometre measurements whilst the use of X-ray interferometry can achieve these measurements without needing fringe division, thereby reducing

uncertainties. COXI is being used at NPL to calibrate and investigate non-linear behaviour in displacement transducers including other optical interferometers.

The facility should be of interest to applied physicists and precision engineers, especially to those working in the field of nanotechnology. A paper describing the development and use of the instrument has been published by the Royal Society in their *Mathematical, Physical and Engineering Science Proceedings*¹.

¹Basile, G, et al, *Proc. Roy. Soc.* 2000, **456**, (1995), 701-729

Nanoscale study of spintronic materials

A collaborative project between NPL, Cambridge University and Imperial College is looking at new materials for future electronic devices. NPL's UHV cryogenic scanning tunnelling microscope has been used to demonstrate the spin-polarised nature of low-temperature electrical transport in lanthanum manganite films. The films were prepared by Cambridge University and characterised at Imperial College.

An understanding of the spin-polarised electrical properties at the surface of these compounds is crucial for the realisation of future electronic devices, whose behaviour will be governed by spin, rather than by electronic charge. Such devices will be much faster and smaller than current microelectronic devices offering the possibility of nanoscale devices.



NPL's UHV cryogenic scanning tunnelling microscope

Digital coincidence counting

Digital coincidence counting (DCC) is a new means of determining the activity of ionising radiation samples. This method, which uses the latest in high-speed electronics and computer technology, promises to be more reliable, flexible and cost-effective than existing methods and will extend the range of standards which can be produced. The DCC system has unique advantages over traditional analogue coincidence counting systems. These advantages include simplified

set-up procedures, cost and space savings and the ability to carry out detailed re-analysis of previously recorded data - vital for short half-life radionuclides.

A prototype DCC system has been installed at the Bureau International des Poids et Mesures (BIPM) near Paris by the Australian Nuclear Science and Technology Organisation (ANSTO) and NPL. This follows on from a three-year collaborative agreement between ANSTO and NPL to continue the development



New digital coincidence counting system developed by NPL and ANSTO

and commercialisation of the system. The application of this technology to other areas is also being investigated.

Mechanical metrology clubs

Earlier this year NPL, in collaboration with the South Yorkshire Trading Standards Unit and Sira Test & Certification Ltd, won a competitively tendered contract to run three mechanical metrology clubs (Pressmet, Weighing & Density and Force & Hardness). These clubs are now run together giving uniformity of operation and allowing a flow of information between them.

Each club provides access to technical experts from NPL and industry, and a means of sharing and solving problems; a members-only e-mail distribution system is used for exchanging information rapidly. Members include end-users of equipment, manufacturers and academics; they are able to exchange ideas and information, discuss wide-ranging issues and keep up to date with the latest knowledge, including international metrology affecting trade and competitiveness. An electronic 'directory of members' can be inspected on the NPL

website, together with the corresponding company profiles. A service locator aids those who are trying to locate specific mechanical metrology services.

The three clubs hold regular meetings, both annual and 'special interest', either at NPL or a member's premises. The clubs also publish combined six-monthly newsletters and market digests.

Full Membership is open to any organisation with an interest in one or more of the subjects covered and a 60% discount is offered to those wishing to subscribe to all three clubs. Affiliate Membership is available to organisations with a UK address and provides low-cost 'pay-as-you-go' access to metrology workshops and other meetings across all three clubs, and is particularly aimed at encouraging end-users to join. Through sponsorship by South Yorkshire Trading Standards Unit we are able to offer UK-based organisations the first year of membership free of charge.

Galileo to give time to Europe

Much of our transport, telecommunication and power infrastructure depends on time and navigation signals from the US Global Positioning System (GPS). Recognising the risk of dependency on a single system

outside its control, the EC is commissioning a European equivalent to GPS called Galileo.

The Galileo programme is currently in its Definition Phase, with a number of projects running in parallel to look at user requirements (GEMINUS), system architecture (GALA) and design (Galileosat). Staff from the NPL Time Section have been active in promoting time issues to these groups. This topic is vital to both Galileo and to national time standards laboratories because Galileo, along with GPS, promises to be one of the most accurate

means of distributing standard time around the globe.

John Lavery of NPL chairs the Galileo Time Interface Working Group to review the system designs and make recommendations on the timing aspects of Galileo. He is working with twelve other European time experts to deliver recommendations ahead of December 2000 when the EC will formally decide whether to proceed with the design and build phases of the Galileo Programme.

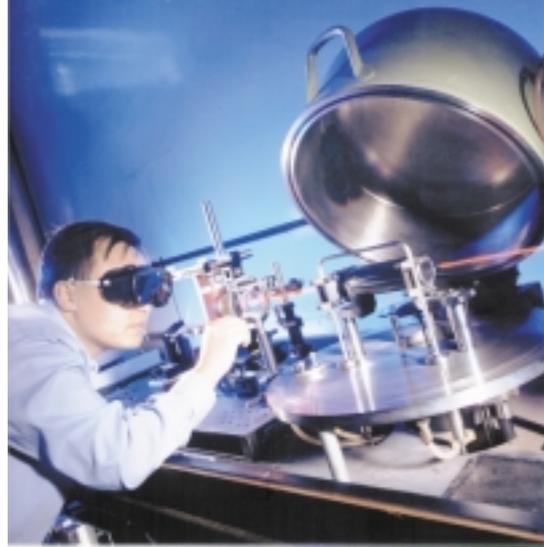


GalileoSat (artist's impression)

Space ceramic to be used as certified reference material

NPL is co-ordinating an EC project to establish a certified reference material for high temperature thermal measurements using Pyroceram 9606. This material is a high specification glassy ceramic material that was originally developed for NASA. The material is particularly well defined, thermally stable and therefore a good candidate for a certified reference material (CRM) for thermal conductivity and thermal diffusivity of solids for temperatures up to 1000 °C.

A batch of Pyroceram 9606 has been obtained and characterised. The material is now being distributed to three groups of partners, each consisting of at least six laboratories, who will intercompare measurements on thermal diffusivity and thermal conductivity by both transient and steady-state methods to produce certified values. Eventually the CRM will be sold by the Institute of Reference Materials and Measurements on behalf of the EC to provide reference material to help assess the measurement performance of widely used thermal measurement apparatus such as laser flash and the



Apparatus for measurement of thermal diffusivity

hot-wire, and to provide calibration and traceability for axial heat flow apparatus. It is hoped that this exercise will be completed by the end of 2001 and will lead to much improved uncertainty values for these measurements throughout Europe.

Partnering with trade associations

A new project is currently being developed to examine material properties relevant to the casting industry. The results of this work will be of benefit to metal producers, suppliers and end-users. The project consortia will include up to eight companies including both large multi-nationals and SMEs.

This project has been developed as a result of NPL's links with trade associations and in June 2000 a meeting was held at NPL at which opportunities for collaborative projects were discussed.

Trade associations, by acting as a gateway to their members, ensure that the knowledge generated at NPL is disseminated to a wide audience including a large number of SMEs. In addition, they aid industrial collaboration and the development of new research projects.

Delivering for industry

NPL was created to serve the UK economy. The provision of science-based services to British business remains at the heart of our mission, supporting quality, innovation, safety and international competitiveness.

Our services to business have grown steadily over the last five years and the following are examples from an impressive array of commercial applications in diverse industrial sectors.



Mobile communications get clearer with NPL



Prototype cryogenic mobile communications receiver (courtesy Marconi Electronic Systems)

The new generation of high temperature superconductors (HTS) based on perovskite structured cuprate compounds is finding rapid application as

cryogenic filters in base stations for mobile communications. These filters are used to separate the various channels received by the station with minimum cross-talk between channels. With the increasing volume of conventional traffic and the imminent introduction of wider bandwidth services, ensuring the quality of the filters used is crucial for maintaining and optimising the efficiency and quality of mobile communication systems. The non-linear microwave response of the HTS thin films used in these filters is a

crucial issue in their performance and NPL is collaborating with Imperial College to develop a two-tone intermodulation measurement technique to better understand these materials' response to microwave radiation. The use of this intermodulation technique provides a more sensitive detection method of non-linearities compared with surface impedance measurements and should therefore help ensure that communications quality remains good as the volume and density of traffic increases.

Colour 2000

The measurement and specification of colour and light are important in a wide range of applications and industries, including lighting, signalling, imaging and display, printing and design. However the accuracy with which these measurements can be made is influenced by the quality of the reference standards used. Furthermore, there is no international agreement on how the eye behaves under different illumination conditions or how to assess and reproduce colour using different media.

In order to address these problems, NPL recently organised a series of linked conferences and meetings, entitled Colour 2000, in association with the Colour and Imaging Institute at Derby University and the International Commission on Illumination (CIE). NPL took particular responsibility for the conference on Colour and Visual Scales and for meetings of Divisions 1 and 2 of the CIE, which are



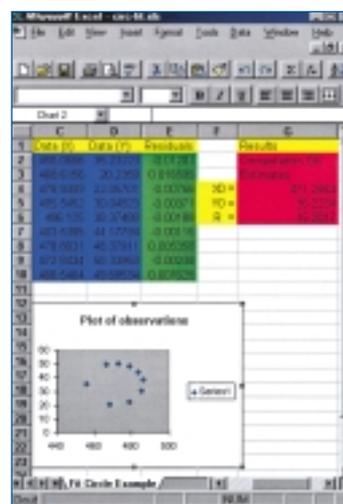
concerned with colour, vision and optical radiation measurement. Together these attracted almost 100 delegates from all around the world and included experts in the physiology of the eye and visual psychology, as well as colour metrologists. The conferences brought a consensus on issues such as measurement at twilight or 'mesopic' lighting levels considerably closer.

EUROMET project offers library of validated software

NPL is leading a collaborative EUROMET project that is establishing a web-based library of 're-usable' software routines. The main interface for the system will be the METROS website developed by NAG Limited and NPL under the Software Support for Metrology 'Software Re-use' project. The METROS system has been established as a resource for solutions in metrology software, including re-usable software components, the means of testing them and related guidance material.

Validated software and algorithms will be promoted through METROS, with the validation status of each clearly stated. Full mathematical descriptions will be documented for all functions held in the system.

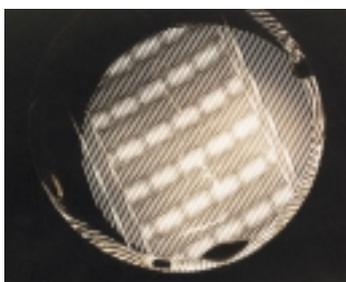
NPL will lead the future development of METROS. The EUROMET project will co-ordinate the provision of contributions of material for METROS, from across Europe and beyond. Twelve countries have so far expressed a wish to



The METROS key function 'Fit Circle'

participate in the project and should be contributing validated routines and other material.

Moiré magnifier to monitor microelectronics



An array of microlenses, each 650 μm in diameter, is used to generate a magnified image of the regular structure of the internal mask of a domestic television screen

As part of its DTI-funded work on micro-structured surfaces, NPL has successfully carried out demonstrations of a novel

technique for optically inspecting periodic arrays of structures such as those commonly found in microelectronic and optoelectronic devices. The technique, which is called the moiré magnifier, uses a microlens array to sample points in the test array to produce a magnified image of the average unit. The device is very simple and robust, making it suitable for use in an industrial environment rather than, say, a conventional microscope, which can also be time consuming to use. The pitches of the devices

so far inspected range from less than 20 micrometres to greater than 500 micrometres.

The technique has application as a low cost, fast inspection method for electronic and mechanical structures such as integrated circuits on wafers, digital camera diodes and image pixels on CRT and LCD displays. A magnification of a thousand has been observed in the laboratory but for industrial applications the practical upper limit of magnification is a few hundred.

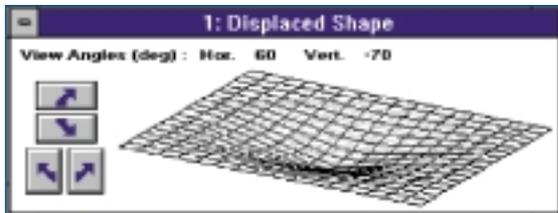
FEA keeps castings correct

A study of a saloon car roof outer die draw assembly has demonstrated how the use of finite element analysis, combined with casting simulation predictions using thermophysical data generated by NPL, can successfully predict solidification rates, shrinkage and mechanical properties. This has allowed the Casting Development Centre, the UK's largest provider of research and technical consultancy to the casting industry, to design and manufacture a robust and lighter cast product with optimised quality and reduced machining costs.

Traditionally the design of castings has been isolated from consideration of manufacturing issues. Consequently optimising the design could be time consuming, expensive and prone to human error. The project has shown how existing technologies can be used to improve the efficiency of the traditional die design and the manufacturing process when combined with accurate thermophysical data. If casting simulation is to achieve its full potential, modellers cannot ignore the benefits of using data derived from traceable measurement techniques.



The honeycomb middle that weighs so little



Deflection of a composites panel under a point load

Advanced Materials & Machines (AMM) develops new applications for composite materials in the automotive, aerospace, marine and related industries. As part of a long-term collaboration, AMM has used a system developed at NPL called CoDa, Composites Design Analysis, to predict the performance of a honeycomb sandwich panel for use as an automotive load floor. A luxury motor manufacturer has shown that the use of the panel could achieve weight savings of 50% and the technology could lead to a completely recyclable component.

New types of thermoplastic material have the strength, stiffness and low processing costs that engineers need in order to take advantage of their inherent low weight compared to metal. NPL has over a decade of experience working with AMM to develop new methods of measuring and predicting the performance of components and structures made from fibre-reinforced plastics - and thermoplastic matrix composites in particular. CoDa has been designed to help engineers select and use the right materials in appropriate designs.

Compounding the problem

Materials compounding is a vital process in the plastics industry and is dependent on the magnitude and consistency of the rheological properties of the compound during processing. Traditionally these properties have been measured off-line using Melt Flow Index (MFI) techniques, however this can produce a significant delay between sampling and result. In addition the results are not always consistent.

NPL has collaborated with Raychem Limited and Porpoise Viscometers Limited to develop an on-line measurement technique based on viscosity. The viscosities measured are used to determine automatically MFI values.

Trials of the new technique with heavily filled polymers showed that the on-line method worked well. Process engineers were able to monitor the



consistency of compounds, detect subtle differences between polymers made by different plants, and identify the time taken to switch compounding to a different formulation. Trials have shown that better quality control can be achieved with minimal operator intervention.

Wheels within wheels

Alloy Wheels International (AWI) makes over 3.5 million wheels per year and as a brand leader in 'designer wheels' it has exploited a wide range of new technologies to fine tune its operations. Lightweight alloy wheels have 'green' appeal, as well as aesthetic attraction, as they cut fuel consumption.

AWI's production operations is based on a low-pressure die casting process. The computer programs that control the casting machines and the shape of the

dies were generated with the help of NPL's accurate thermophysical measurements. This unique data set includes the enthalpies, specific heats and melting ranges of many commercial alloys. AWI has combined this data with the ProCAST computer package to model the industrial process.

ProCAST analyses initial designs for wheels to assess their manufacturability, allowing rapid feedback and modified design. This allows the time to market for a new design to be shortened.



The finishing room at Alloy Wheels International, where data supplied by NPL is used in the production process

The principal advantage however is the freedom that the system gives to design stylists because the system allows the engineers to cope with more complex designs.

Coats for electronics

The prime requirement of all modern electronic assemblies is reliability. An assembled printed circuit board (pcb) may have been subject to a dozen or more chemical processes and most of these will leave some contamination that could affect reliability and therefore requires cleaning. Collaboration between NPL and CONCOAT Limited has produced an improved method for predicting the reliability of electronic assemblies and minimising associated problems.

The collaboration has developed a test system that assesses the actual effects of any

contamination by measuring the surface insulation resistance (SIR) of the pcb. Electrochemically benign surface contamination has no effect, however non-benign contamination increases surface leakage resulting in dendrite growth and/or deterioration of SIR.

The newly developed instrument CONCOAT Auto-SIR can detect SIR down to less than 10^{-12} A, providing a much more sensitive test than available previously. The development of the instrument also provided valuable input into international manufacturing standards involving the SIR test.



The increase in interconnection density on PCBs makes increased demands on assembly techniques

The system provides test templates for the existing range of international standards and user-definable templates to enable incorporation of future standards.

TCD role in Queen's Awards



TCD carried out the initial appraisal of applications for the Queen's Awards for Enterprise: Innovation, 2001. This was the second time that TCD has been contracted by the Queen's Awards Office to deliver this service.

New categories of Award were introduced, under the collective title of 'The Queen's Awards for Enterprise' following a Review in 1999 chaired by the Prince of Wales. The Innovation Awards replaced the Queen's Awards for Technological Achievement. The purpose of the Awards

is to recognise and encourage commercially successful innovative achievements in the UK.

TCD's role was to undertake the initial appraisal of applications for the Awards. The final selection of firms recommended for an Award will be made by the Prime Minister's Advisory Committee in March 2001. The role complements TCD's activities supporting innovation in business through programmes such as TCS.

BP outsource corrosion testing to NPL



The Aqueous Corrosion Group in the Materials Centre at NPL has recently been awarded the contract to undertake corrosion testing for BP's research centre at Sunbury.

NPL will be undertaking corrosion testing relating to upstream activities for Sunbury including sulphide stress corrosion work and related

activities covering hydrocarbon production from drill head to refinery intake. NPL is conveniently situated for BP's staff at the Sunbury facility and offers world-class expertise in corrosion studies combined with extensive testing facilities. Some BP staff have transferred to NPL together with a number of test rigs.

Get up to date with corrosion

The Materials Centre at NPL has produced updated versions of five of its very popular corrosion guides. The corrosion guides provide information on the nature of corrosion problems, where they are likely to occur and how the problems can be avoided or controlled. The guides draw on NPL's expertise in this area and are produced in collaboration with other industry experts.

The five new guides cover *Stress Corrosion Cracking*, *Corrosion in Pumps and Valves*, *Surface Preparation for Coatings*, *Guidelines for the Protection of Structural Steelwork* and *Bimetallic Corrosion*. At present there are 15 NPL guides. Two further guides will be available in the near future dealing with corrosion control checklists for design offices, and guidelines for the control of corrosion in plumbing systems. The updates are in response to continued demand from end-users for the latest information available. Copies of the guides can be ordered from the National Corrosion Service at NPL.



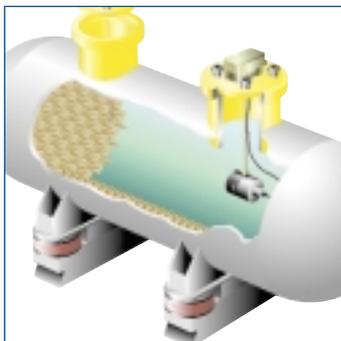
Measurement - a service ethic

NPL is dedicated to maintaining world-class metrology facilities and offering calibration services with the highest accuracy available in the UK.

In 2000 we carried out more than 5 000 UKAS-accredited calibrations for measurement and instrumentation companies, manufacturing industry and others.

These services are the starting point for calibration chains (traceable back to the national standards at NPL) which ultimately result in billions of quality-controlled measurements for industry, research, medicine, regulation and trade.

The following examples illustrate this vital aspect of NPL's mission.

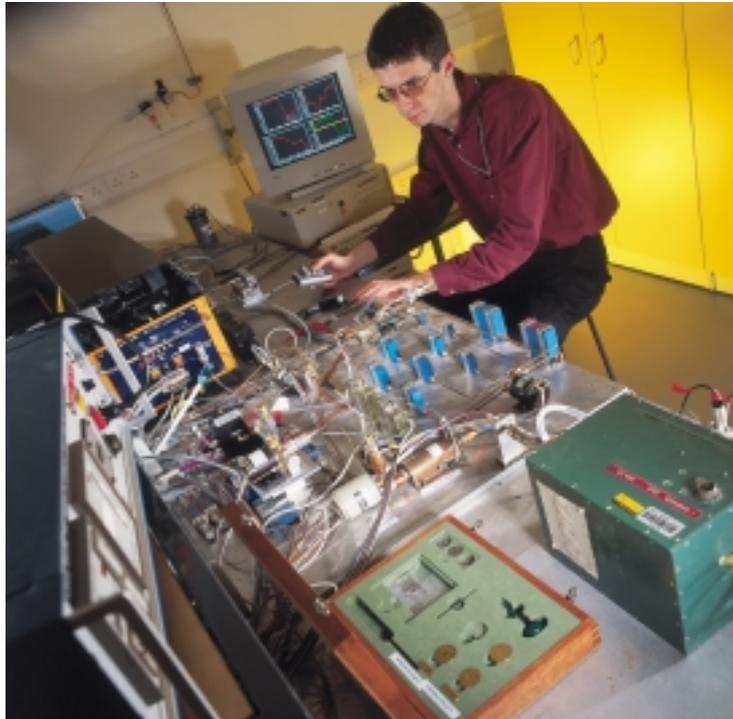


Adaptor decreases uncertainties in noise measurement

The reliable measurement of noise in radio frequency and microwave components and systems is crucial for their successful technical and economic exploitation in diverse applications ranging from mobile and satellite communications to radar and remote sensing of the environment.

Previously, noise calibration of instruments fitted with coaxial connectors between 2.75 GHz and 40 GHz have been performed using waveguide primary standards, which are used to calibrate a coaxial transfer standard using waveguide to coaxial adaptors. This transfer standard is subsequently used to calibrate the working standard on a coaxial radiometer. The use of transfer standards introduces uncertainties, so NPL has been investigating other techniques.

Recent work at NPL has concentrated on the elimination of the intermediate step by using waveguide primary standards directly with the coaxial radiometer through an adaptor. Measurements have so far been



The coaxial 18 GHz radiometer (CR18)

successfully completed in one waveguide band and the results from this look promising. It is intended that the technique will be applied across all six waveguide bands in this region in due course. The adaptor has to be well matched to the other components in the calibration system.

Since coaxial calibrations represent the great majority of the RF noise calibration work provided to industry by NPL, improved uncertainties will give a significant benefit.

Internet calibrations give industry direct link to national standards

NPL is developing revolutionary new internet calibration facilities in collaboration with UK industry. This new approach to calibration increases efficiency and collapses the traceability hierarchy to a single link with national measurement standards at NPL. The services will improve measurement uncertainties, reduce down time for instrument calibration and give companies access to NPL expertise.

One such collaboration, with industrial partner Fluke Precision Measurement Ltd, is producing an internet calibration capability which was demonstrated at the National Conference of Standards Laboratories (NCSL), held in Ontario, Canada, in July. The system was demonstrated using the Fluke 4950 multifunction transfer standard that can provide traceability at low uncertainty for a number of



The NPL/BAE SYSTEMS team 'test-driving' the internet ANA calibration facility at the BAE SYSTEMS' Warton location. (Photograph courtesy of BAE SYSTEMS.)

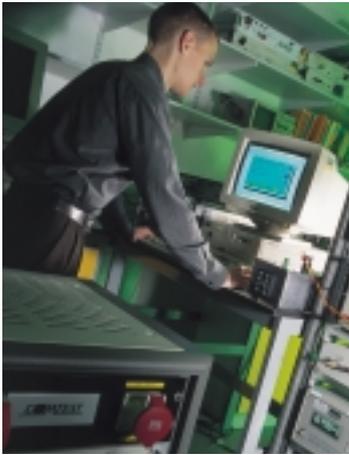
parameters and values simultaneously. Control, automation and monitoring of the measurement process is possible directly from NPL via the internet.

Another collaboration is taking place with BAE SYSTEMS, Warton, who have been 'test-driving' an internet calibration facility developed by NPL for RF and microwave automatic network analysers (ANAs). This system is based on the established NPL Primary Impedance Microwave Measurement Software, used for many years by NPL to provide traceability through conventional calibration routes. Extending this service by an internet calibration application allows instant access to the facilities by any company at any time, day or night. ANA control, operator instruction and measurement results are all sent from the NPL server direct to the client's laboratory, via the internet.

A presentation on the above facilities was also given at NCSL for which the authors were awarded Best Paper award (in the Management and Quality category). Copies of this paper¹ are available from NPL.

1 R A Dudley, N M Ridler and J M Williams, 'Internet-based calibrations of electrical quantities at the UK's National Physical Laboratory', NCSL Workshop and Symposium 2000 (National Conference of Standards Laboratories), Westin Harbour Castle, Toronto, Ontario, Canada, 16-20 July 2000.

Power analyser calibrations for mains harmonics



Harmonic analyser calibration system

The harmonics and fluctuations that are generated in the mains supply by various electrical and electronic devices are of increasing concern in many commercial and research environments. These harmonics can cause major surges in the supply with potential to destroy equipment. In locations with high densities of personal computers – call centres, trading floors and most office buildings – understanding and combating harmonics is a growing issue.

Under a new EC Directive to

come into force in 2001 equipment manufacturers will have to show that the 'harmonic pollution' from their equipment is within specified limits. Reliable measurement of harmonics is important to underpin this Directive. Power analysers are used for this purpose and NPL has recently launched a new service in accord with the relevant IEC standards aimed at the calibration of analysers for harmonics and flicker, including what is believed to be the first traceable calibration for fluctuation harmonics.

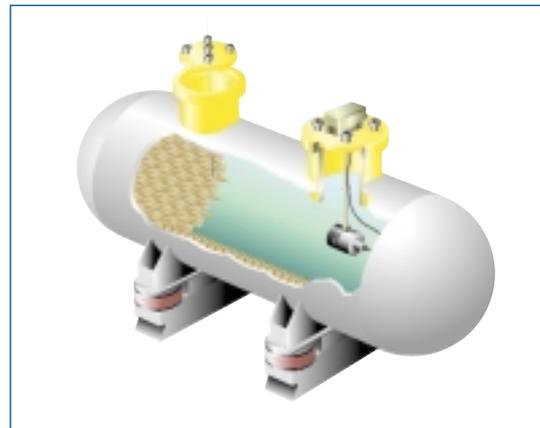
High pressure acoustics

NPL now has Europe's largest commercially available underwater acoustics pressure vessel facility. This purpose-built acoustic pressure vessel facility will provide vital measurements needed by the manufacturers of sonar equipment used in the oil and gas, oceanographic and defence industries.

The facility features a 7.5 metre long, acoustically lined, steel pressure vessel with access ports capable of accepting devices up to 0.84 metre diameter.

NPL's facility is designed for acoustic testing of underwater devices over the frequency range 1 kHz to 2 MHz, and under simulated ocean conditions to a depth of 700 metres with a temperature range of 2 °C to 35 °C. The pressure vessel is owned by the UK's Defence Evaluation and Research Agency and is provided on permanent loan to the Department of Trade and Industry and operated at NPL.

Future testing undertaken over a range of hydrostatic



NPL's new underwater acoustics pressure vessel facility

pressures and temperatures will include absolute acoustic measurements of transducers, projectors and receivers, the determination of material properties, beam forming characteristics, array performance, model simulations and pressure integrity testing. Measurement standards will be developed to provide industry with traceable calibrations.

Leading the world of uncertainty

Laboratories worldwide make statements of uncertainty to accompany the measurement results they produce. The main international guidance for this is the *Guide to the Expression of Uncertainty in Measurement* (GUM) published by the ISO in 1995. In the UK, implementation of GUM is provided by *The Expression of Uncertainty and Confidence in Measurement, Publication M3003* produced by the United Kingdom Accreditation Service. NPL has produced a best-practice guide on uncertainty evaluation and statistical modelling as part of the Software Support for Metrology (SSfM) Programme.

Following recent workshops and conferences organised by NPL as part of the SSfM Programme there has been a consensus that the guides need to be extended and revised to handle the wide range of problems in evaluating measurement uncertainty that arise across the various metrology disciplines. A Working Group of the Joint Committee for Guides in Metrology (JCGM) has been established and has agreed to two proposed extensions of the GUM: i, The Propagation of Distributions for Uncertainty Evaluation – concentrating on the application of computer-intensive techniques (e.g. Monte Carlo simulations); and ii, Uncertainty

Evaluation for Multivariate Output Quantities (e.g. matrix notation, complex values etc.).

A British Standards Panel has been set up to track the JCGM Working Group and is planning a guide that will complement GUM and M3003. Maurice Cox of NPL who is also a significant contributor to the JCGM Working Group chairs the Panel. The new guide will have a major emphasis on the needs of industry in uncertainty evaluation at the design, testing, manufacture and selling stages of production.

Measurement system validation *Best Practice Guide* published

NPL has recently published a *Best Practice Guide on Validation of Measurement Software*. This is one of ten *Best Practice Guides* being produced by the Software Support for Metrology programme. This guide has been produced to help both the manufacturers and users of analytical instruments and laboratory software. The guide will help manufacturers to use the most appropriate software functions and validated routines in their instruments, whilst users will be shown how to

demonstrate validation requirements for rigorous quality control procedures, for example those found in the pharmaceutical industry. The guide explains the issues in the use and validation of measurement systems, what level of validation may be appropriate and the validation techniques that can be used.

The guide was developed using practical experience from metrologists in industry and from experts at NPL. The techniques include the use of reference datasets and reference software,

which have been developed and used successfully in the Software Support for Metrology work on numerical software testing. The guide is available on the NPL/SSfM website, with internal links to aid navigation through the document and external links to reference other documents. NPL will be offering a training course relating to the guide and the work will be extended to cover safety-critical software validation and the validation of self-calibrating instruments.

Science for **quality** of **life**

We are very conscious that as a major national laboratory NPL has responsibilities to society; and that measurement has an important role in sustaining quality of life.

There is a vital role for measurement in protecting the consumer through trading standards, which are underpinned by NPL and supported directly by our colleagues at the National Weight and Measures Laboratory. In addition to this traditional aspect of our mission, projects which deliver societal benefits, through environment, health and safety-related projects, now account for more than 15% of our activity.



Flying high!

Cosmic rays are not a significant source of exposure to radiation for the majority of the population, however at higher altitude doses may be several orders of magnitude greater as the shielding effect of the atmosphere is reduced. Recent EC directives have instructed Member States to make arrangements to monitor the exposure of aircrew that may be subject to larger doses on long-haul flights. There are three potential sources for the radiation: galactic cosmic rays, solar energetic particles and

magnetospheric particles. The importance of these sources at aircraft altitudes is at present relatively unknown.

NPL has participated in a series of experiments at the CERN-CEC reference field facility in Geneva in order to investigate the response of various Tissue Equivalent Proportional Counters (TEPCs) to a simulated cosmic ray field. The experiment reproduced the conditions present at the altitudes used for long-haul civil air flights and evaluated three types of TEPC including



a prototype system designed to fit inside a small suitcase.

The work is now being extended with measurements in long-haul flights to measure and assess the nature of the risk to aircraft and aircrew.

New Cobalt-60 irradiator facility improves healthcare

NPL's new purpose-built Cobalt-60 irradiator facility is now complete and staff have moved into the new laboratories and offices. This new facility, located alongside the NPL linear accelerator, will focus on delivering a range of state-of-the-art radiation dosimetry services to the NHS medical community and the UK's nuclear industry.

Medical radiation exposures are now familiar to many individuals with the use of radiopharmaceuticals and therapeutic treatments for tumours with radiation sources. In the UK about 150 000 new

cancer patients each year receive radiotherapy treatment. NPL's traceable therapy and protection-level radiation dosimetry services play a vital role in the dissemination of the UK's National Measurement System Programme for Ionising Radiation Metrology and have a direct impact on the health of the nation.

The new facility has larger exposure rooms with closer temperature control than its predecessor: factors that enhance the quality and efficiency of NPL's services. This will ensure increasingly accurate calibration of equipment used in hospitals



NPL's new radiotherapy calibration room

that enables vitally important accurate measurements of patient dose for radiotherapy treatment to be delivered. The facility will also provide services for calibration of instruments used for monitoring radiation levels in a wide variety of industrial, medical and research settings.

Road traffic, aircraft noise and children's health

Recent research by NPL, in collaboration with Queen Mary, University of London, has shown that noise pollution can pose a potential risk to young children. A study of some 450 children attending 20 schools in west London near Heathrow Airport was undertaken. Ten of the schools were exposed to chronic high levels of aircraft noise due to proximity to flightpaths and ten schools were exposed to lower aircraft noise.

The results showed that children from high noise schools had raised annoyance and impaired reading compared with children from low noise schools. Noise was not associated with impairments in



A class of 8 year olds

all the tests administered (e.g. memory and attention) suggesting that chronic noise exposure is associated with selective cognitive impairments on difficult tests in children. NPL was responsible for the noise exposure assessment of the schools and designed the most comprehensive protocol in this research field to date. Results have been reported to the Department of Health and to the Department of the Environment, Transport and the Regions (DETR) who funded the study.

NPL is now working with Queen Mary, University of London on a new three-year project under the EU Framework V programme on 'Environment and Health' to assess Road Traffic and Aircraft Noise and Children's Health (RANCH Study). Other European partners include the University of Gothenburg, University of Stockholm, Instituto de Acústica in Madrid and the National Institute of Public Health and the Environment in the Netherlands. NPL's role will be to develop noise measurement protocols for use by all partners, and to provide measurement capability in the UK field studies.

NPL to monitor benzene emissions

NPL has managed the DETR Hydrocarbon Network, which provides hourly measurements of 25 different hydrocarbon species at 13 sites around the UK, for over three years. Due to new EC requirements, DETR needs to monitor benzene (one of the current species) at a total of at least 40 sites in the UK. Benzene is a component of vehicle fuels but is carcinogenic and is being reduced and/or replaced in new formulations. The measurements

will check ambient levels of benzene in the atmosphere and indicate if current measures are helping to reduce concentrations.

NPL has won an open tender to develop an economical method of measurement and establish the new benzene monitoring sites. The contract will also include continued managing of the present Network until the end of 2000, and management of a related research contract.



NPL has established a pilot study to test equipment and methodology with the aim to roll-out equipment to 41 sites within a year.

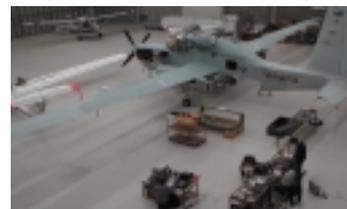
Airborne measurement of atmospheric tracers

A collaborative project, involving NPL, Cambridge University, Aberystwyth University, and Airborne Research Australia¹ (funded by NERC), has studied how gravity waves and filamentary structure affect turbulence and mixing in the boundary region between the troposphere and stratosphere. Understanding the gas transport mechanisms across this region is crucially important to the study of both stratospheric ozone depletion and climate change.

NPL contributed a near-infrared tunable diode laser spectrometer

to make high-resolution measurements of methane, a long-lived tracer gas, as part of a package of instruments on board a high-altitude research aircraft. The aircraft was flown in a series of experiments in the summer, taking off from Boscombe Down and flying over northwest Wales at altitudes of up to 15 kilometres.

The measurements from the NPL instrument were combined with the results of the other instruments involved in this project - including ground-based radar, balloon and aircraft measurements of ozone, water



The Egrett high-altitude research aircraft being prepared for launch during the Airborne Measurement of Atmospheric Tracers campaign

vapour, temperature and winds, and a ground-based ozone lidar - in order to obtain an improved picture of the fine scale mixing processes around the tropopause.

¹ ARA was established by the Australian Commonwealth Government under the Major National Research Facilities Program.

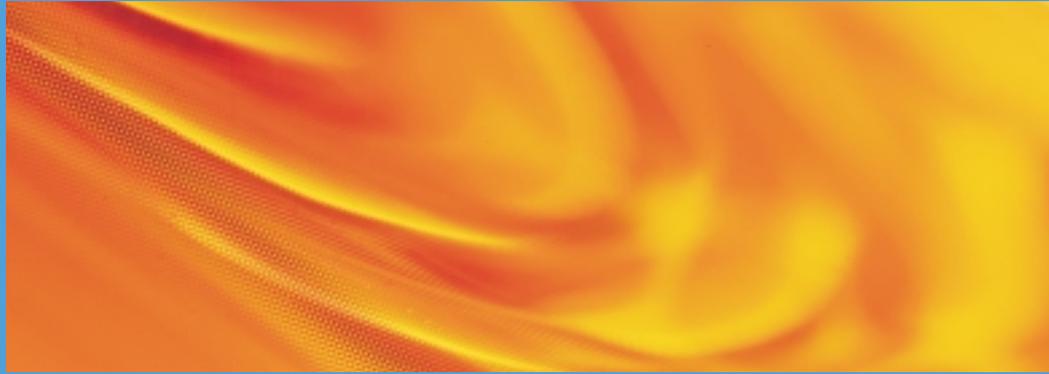
NPL provides early warning for climate change

Experts from NPL have been commissioned by DETR to represent the UK at an expert working group meeting of the Intergovernmental Panel on Climate Change (IPCC). As a result of the Rio and Kyoto Climate Conventions, all nations are required to reduce emissions of active greenhouse gases. Commitments to such reductions are based on accurate estimates of emissions in 1990 and projected emissions in 2010. The methodology used to do this is established by the IPCC. NPL's activity in this area is based on more than five years' work carrying out research for DETR

into methane emissions from solid waste sites. This work drew upon NPL's expertise in the development and field deployment of in-situ and optical remote measurement techniques for the accurate measurement of methane concentrations and fluxes.

NPL also plays an important role in a global monitoring network aimed at improving our understanding of climate change and stratospheric ozone depletion. The Network for the Detection of Stratospheric Change (NDSC) was established in 1991 and comprises a network of monitoring stations each

equipped with a range of complementary state-of-the-art instruments. The network aims to provide accurate data for the determination of long-term trends in atmospheric composition, to provide an early warning of significant atmospheric change and to provide an independent means of calibrating satellite data. NPL is responsible for the quality assurance of data produced by network instruments. This has been achieved through a series of side-by-side instrument intercomparisons at sites around the globe, ranging from Eureka in the Canadian Arctic to Lauder in New Zealand.



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