National Measurement System

National Measurement System Programme for Engineering Measurement Metrology

Programme Document 2013

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National Measurement Office

NPL National Physical Laboratory

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National Measurement System Programme

for

Engineering Measurement Metrology

Programme Document 2013

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Prepared by:

Neil Campbell
Programme Manager
NPL

Authorised by:

Andy Blackmore
EM Head of Division
NPL

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Executive Summary

This 2013 programme document describes all the active projects currently contracted at NPL as part of the Engineering and Flow programme. The document is comprised of three sections, the first two being active projects under contracts EFM11 and 12, as agreed at the decision conferences preceding that of 2013. A list of projects which have been completed since the last issue of the Programme Document is included.

The final section includes those new projects agreed at the June 2013 decision conference.

With regard to the NMS Strategy Document 2011-2015, most of the projects described herein support the NMS infrastructure and demonstrate an impressive level of industrial and academic engagement and impact. Increasingly, support is being provided to the National Challenges (again referenced in the NMS strategy) in particular Growth, Sustainability and Measurement Leadership. Much of this work is being enabled, and augmented, by successful bids into FP7, TSB and EMRP projects.

A key element of this programme is its support of the SI, through maintenance and realisation of 3 of the base units – m, kg and K - and it continues to provide confidence in the measurement standards at the core of the NMS.

2013 saw the completion of the transition of a group of projects from the Physical Programme. These address radiometry and Earth Observation, the latter being a strategic capability area, and is intended to grow.

Development of NPL's Capability – the most significant factor driving the selection of projects in the EFM 13 contract was the success of the Engineering Programme in the 2012 EMRP Call, in which every bid was successful. All areas of our dimensional capability will benefit and, for the first time, one project – "Luminar" on large volume metrology – will be led by NPL.

New projects in the temperature area have focused on applied thermometry and will include work in both non-contact and contact thermometry. This reflects an increasing customer demand for measurements in inaccessible and harsh environments where accuracy needs to be sustained for long lifetimes.

Two projects in the Earth Observation area have been contracted, to cover both instrumentation and quality assurance of climate data. These larger projects will provide the team with the ability to bid for large EMRP and Horizon 2020 projects which are expected to emerge in the next three years.

Continuation of NPL's Core NMI activity – maintenance, development of core measurements and standards required to sustain NPL's position as a leading NMI of global stature and the provider of essential services to UK Industry form a significant proportion of this programme.

Staff at NPL are always available to provide further information on any of the projects within the Engineering programme. Please contact them as required.

Completed projects during 2013

With reference to the 2012 issue of this document, dated 29th November 2012, the following projects have been completed.

GS001DM3	Dimensional Facilities: Essential Support
GS001DM5	Multi-functional dimensional calibration facility
GS001DM6	Metrology Space
GS001DM04	CMM uncertainties for complex parts
GS001DM11	FSI Interferometry
GS001FR3	Force standards - maintenance and development
GS001FR05	Dynamic Pressure Traceability for industrial Measurement
GS001MA2	Maintenance of national standard of mass
GS001MA3	Mass standards
GS001MA4	Density standards
GS001NA06	Next Generation High Precision NPL Interferometer
GS001PR1	Provision of Support for Industrial Pressure Standards
GS001CF7	Co-Funding for TSB Project “High Resolution Nanopositioning”
GS001TH1	Practical acoustic thermometry – Part A
GS001TH3	Humidity – Provision of standards
GS001TH4	Multi-gas and multi-pressure humidity calibration
GS001TH6	Moisture measurement
GS001TH9	High temperature fixed points for the new high temperature scale – Part A
GS001TH10	Contact thermometry - provision of standards
GS001TH12	Radiation thermometry - provision of standards
GS001CF1	Co-Funding for EMRP Energy Gases
TS003201	Optical Technologies Capability
TS003202	Detector Based Scales for Traceability
TS003402	Quality Assurance for EO and Climate Change
TS003405	Co-funding for EMRP Solid State Lighting
TS0040301	Boltzmann Constant redetermination/Primary Ac’c Therm.
EFM11003	Metrology space frame for Freeform Area Tracking Scanner (FATS)
EFM11008	Co-Funding for FP 7 EUMINA FAB (continuation)
EFM11014	Thermal imaging metrology
EFM11015	Contact thermometry – impurity modelling
TS003410	Satellite Microwave Radiometer calibration
EFM12001	Engineering Innovation
EFM12007	Co-funding for TSB TruDat

Contract ENG&FLOWKB_EFM-11

This section contains a list of the new projects approved at the June 2011 Decision Conference and subsequently included in the NMS contract ENG&FLOWKB_NMS-EFM11.

Summary of Project costs and timescales

Ref #	Title	Price (k)	Start	End
EFM11001	Network-based approach for calibration of laser-based coordinate measuring systems	198	Oct 11	Mar 14
EFM11002	Form and surface reflectance standards & verification facilities	683	Oct-11	Sep-14
EFM11023	Traceable absolute distance measurement demonstrator	218	Oct-12	Sep-14
EFM11004	Towards verification and calibration of industrial XCT systems	430	Oct-11	Sep-14
EFM11005	Ultra Precision Manufacturing Metrology (UPMM)	196	Oct-11	Sep-14
EFM11006	Co-Funding for FP7 NANOclear	482	Dec-11	Nov-14
EFM11007	Structured surface metrology	466	Oct-11	Sep-14
EFM11009	Unified micro-co-ordinate measurements	385	Oct-11	Sep-14
EFM11010	Co-Funding for FP7 MIDEMMA	152	Nov-11	Nov-14
EFM11011	Metrology of small structures	63	Oct-11	Sep-14
EFM11012	Scatterometry - Co-Funding for EMRP JRP15i	209	Oct-11	May-14
EFM11013	AFM Metrology to support UK nanoscience	340	Oct-11	Sep-14
EFM11033	Traceable Dynamic Measurement of Mechanical Quantities - Co-Funding for EMRP JRP20i	205	Oct-11	Sep-14
EFM11016	HiTeMS – Co-Funding for EMRP 28i	400	Sep-11	Aug-14
EFM11018	Improved air temperature traceability – Co-Funding for EMRP 02e	232	Oct-11	Sep-14
EFM11034	Practical acoustic thermometry – TH1 Part B	97	Oct-12	Sep-14
EFM11036	Co-funding for EMRP S07 MeP Kg	383	Jun-12	May-15
EFM11037	Co-funding for EMRP s12 NOTED	309	Jun -12	May-15
EFM11038	Co-Funding for TSB Project “High Resolution Nanopositioning”	83	Apr 12	Mar-14
EFM11022	Au/Pt thermocouples	117	Oct-12	May-15
TS003408	EMRP 17e Co-Funding for EO Traceable radiometry (optical)	800	Oct 11	Sep 14
TS003409	EMRP 17e Co-Funding for EO Traceable radiometry (microwave)	64	Oct 11	Sep 14
EFM11024	Force standards - maintenance and development	321	Oct-13	Sep 14
EFM11025	Maintenance of the national standard of mass and development of a method for the practical implementation of the redefined kilogram	128	Oct-13	Sep 14
EFM11026	Mass and Density standards	216	Oct-13	Sep 14
EFM11028	Pressure facilities	86	Oct-13	Sep 14
EFM11029	Dimensional facilities: essential support	535	Oct-13	Sep 14
EFM11030	Humidity - provision of standards	275	Apr-13	Sep-14
EFM11031	Contact thermometry – provision of standards	340	Apr-13	Sep-14
EFM11032	Radiation thermometry – provision of standards	370	Apr-13	Sep-14

Project No.	EFM11001	**Price to NMO**	£198k
Project Title	Network-based approach for calibration of laser-based coordinate measuring systems	**Co-funding target**	Not applicable
Lead Scientist		**Stage Start Date**	1 October 2011
Scientist Team	Karim Nasr, Andrew Lewis, Ben Hughes, Alistair Forbes.	**Stage End Date**	
		Est Final Stage End Date	31 March 2014
Sector	50% Standards & regulation: 50% Advanced instrumentation	**Activity**	100% NMS Infrastructure

Summary

The performance of laser-based spherical polar coordinate measuring systems (SPCMS) depends critically on several internal mechanical alignment and sensor calibration parameters. Current tests that can be performed by end users can determine only some of these parameters, but, crucially, others cannot be determined by the user and no measure of uncertainty in the parameters is ever given. Various standards are in different stages of development for performance verification of this class of instrument. However, the end user community is reticent to adopt these tedious time-consuming tests especially as minimal quantitative information is produced.

A novel network-based laser tracker testing/calibration methodology, demonstrated by NPL has received large interest from the laser tracker manufacturers and industrial community. The method is approximately eight times faster than existing methods in the published standard (ASME B89.4.19:2006) and simple enough to be performed by end users, with no specialist equipment. Furthermore, the network-based test gives detailed quantitative information about the tracker, as well as rigorous uncertainties for the results. The test can be used not only for performance verification, but also for periodic monitoring of tracker sub-systems and drift/wear of mechanics. The uncertainty evaluation can be used to predict task-specific performance of the tracker, enabling users to judge fitness for purpose.

So far the technique, which is model-based, has only been demonstrated using an API T3 laser tracker. [B Hughes *et al.* 2011 *Meas. Sci. Technol.* **22**, 045103; *CMSC Journal* Autumn 2010]. This project will extend the technique to a wider range of measuring systems, optimise and validate the performance of the technique. The work will be disseminated through partner organisations, *e.g.* LIMA BTC, to the end user community and through influence of relevant ISO working groups.

The Need

Without compensation for the geometrical and sensor errors, SPCMS can exhibit errors as large as 50 times the Maximum Permissible Error (MPE). Good practice prescribes routine checking of instrument performance before starting any new measurement task. Current testing techniques are limited as detailed above.

With the increasing adoption of laser trackers by a large number of industries as a high precision coordinate measuring system, there is a need for a quick, effective and reliable methodology for the calibration of these instruments. Current performance verification methods rely on lengthy procedures defined by standards, *e.g.* ASME B89.4.19:2006; VDI/VDE 2617 Part 10; ISO 10360 Part 10 (draft). The new NPL network-based methodology promises a reduction of the calibration time by a factor of at least eight (from 8 hours for the volumetric and two-face tests of ASME B89 test to one hour for the network test) and much richer data providing diagnostic insight and allowing for task-specific performance prediction.

The Solution

The solution is to further develop and extend the new technique, with appropriate validation and dissemination. This project will deliver a new capability for performance verification/calibration of laser trackers. Additionally, we will report on the investigation of the use of the technique with other SPCMS *e.g.* laser scanners.

Project Description (including summary of technical work)

This will require:

1) Validation of angle encoder error determination.
2) Adapting the instrument model to trackers from different manufacturers such as Leica, and Faro.
3) Sensitivity analysis of the error parameters' estimates resulting from the network model to the exact network topology (locations of tracker and number and locations of targets).
4) Optimisation of the network layout and verification of its performance via experimental testing.
5) Adaptation of the network model to include calibrated length artefacts (required for end-users who do not have access to laser calibration facilities or other means of verifying ranging system performance).

6) Comparison of the performance of trackers from different manufacturers using the network model and conventional standards such as ASME B89.4.19:2006.
7) Trialling of the technique with similar spherical-polar coordinate laser-based measuring systems, such as laser scanners available from Surphaser, Faro, Leica and Nikon.

Impact and Benefits

One impact route is by giving NMIs and testing laboratories a method for *calibrating* SPCMS. The same technique can be adopted by end users for rapid and comprehensive performance *verification* and task-specific uncertainty prediction. A unique feature of the new method is the inherent rigorous uncertainty evaluation that is an essential pre-requisite for establishing traceability in coordinate metrology. The impact of the work can be measured by citations and adoption by ISO and the end-user community. Financial impact could be calculated based on reduction in time spent by end-users correcting problems caused by poorly-calibrated trackers – this is the first time that end-users would be able to comprehensively test their SPCMS. This will result in early detection of problems, more 'right first time manufacture', reduced waste and improved process control. The project will enhance NPL's international reputation in the field of Large Volume Metrology.

Support for Programme Challenge, Roadmaps, Government Strategies

This work addresses the Government-identified strategic area of Advanced High Value Manufacturing. It fits directly into the 'Metrology 2020' concepts of '*The bespoke factory*' '*The always on always calibrated system*' and '*The distributed NMI*'.

Synergies with other projects / programmes

This project will capitalise on the brief work carried out under a milestone change in the iMERA+ NIMTech project. It complements the laser tracker verification service that will be introduced at the end of the current Programme.

Risks

Technical risks are low, however there is a risk that the relevant ISO committee will not adopt the technique into future standards. An element of cooperation is required from instrument manufacturers (*e.g.* loan of equipment, access to internal error maps).

Knowledge Transfer and Exploitation

We will seek publication in trade and scientific journals. We will investigate possible licence agreements with instrument manufacturers. We will use our membership on the ISO committee to influence their adoption of the technique in the ISO standard currently under development. The technique will be rolled out to end-users through our partners in the LIMA BTC.

Co-funding and Collaborators

Collaboration/co-funding in the form of loan of equipment will be sought from: Faro, Leica, Surphaser, University of Bath LIMA BTC.

Deliverables

1	**Start: 01/10/2011**	**End: 31/3/2014**	

Deliverable title: Network method extension, validation and optimisation

- Existing software updated to cater for different instrument models (Leica and Faro trackers), incorporate calibrated artefacts and network optimisation.
- Independent validation of calibrated parameters published in peer-reviewed journal paper and presented at an international conference.
- Comparison of the performance of trackers from different manufacturers using the network model and conventional standards such as ASME B89.4.19:2006. To be presented at an international conference or published as a journal paper.
- Trial of the technique with similar spherical-polar coordinate laser-based measuring systems, such as laser scanners available from Surphaser, Faro, Leica and Nikon presented at an international conference or as a journal paper.
- Output of the work will be presented to the ISO committee working on a new standard for laser tracker testing.

Project No.	EFM11002	**Price to NMO**	£ 683 k
Project Title	Form and surface reflectance standards & verification facilities	**Co-funding target**	£300k
Lead Scientist	Michael McCarthy	**Stage Start Date**	Oct 2011
Scientist Team	FreeForm, Photonics, Mathematician, ES.	**Stage End Date**	Sept 2014
		Est Final Stage End Date	30th Sept 2014
Sector	50% Standards & regulation: 50% Advanced instrumentation	**Activity**	100% NMS Infrastructure

Summary:

Optical scanners are rapidly being adopted by industry replacing fixed tactile based CMMs. However, unlike the ISO-10360 standard available for tactile CMMs, there are no optical scanner standards available to verify their freeform dimensional performance. There are also added problems for optical scanners associated with surface properties, for example when measuring different surfaces like colour, reflectivity, surface finish, angle of view etc. This can lead to poor metrology practices and thus unknown manufacturing outputs. Often assumptions naively are made, that non-contact technologies work well, no matter what form or surfaces parameters prevail or what the environmental conditions are. In such cases this can lead to increased scrappage rates and poor manufacturing. However there are many positive sides, including in particular speed and equipment portability.

It is proposed here to further develop NPL's FreeForm standardisation capabilities by addressing the performance of equipment and related technologies ability to measure surface having different optical properties, roughness and rapidly changing form such as those with convex or concave shapes. In addition, surfaces bearing sinusoidal profiles at different amplitudes and periodicity will be studied.

The NPL Freeform dimensional standard developed during 2009-11 is the subject of much interest within UK manufacturing sectors, as it is with a number of NMIs and of the ISO.213-WG10 community.

The Need:

Europe's largest industrial dimensional metrology 'fair' in support of advance manufacture is without question 'Control' based in Germany. A significant noticeable change in the type of equipment shown there during the past decade, is now the vast quality and diversity of portable non-contact coordinate measuring systems, which now dwarf the once dominating and impressive tactile CMMs. UK manufacturing Industry is now rightly a flood with non-contact systems.

Impartial experience has shown, only too often, the merits of such optical systems have been incorrectly demonstrated, using test components of ideal surface form and bearing optically cooperative finishes. The results are impressive, but more often than not the same measuring system will fail, or partly fail, to measure other real engineered components, such as those consisting of concave shiny metal surfaces. Manufacturers in real life do not normally produce optically cooperative components or surfaces. Many problems emulate from the lack of verification standards and availability of impartial test facilities. (Note: ISO, VDI & ASME do not address these).

The Solution:

To develop UK documented standard and NPL based facilities for verification of laser, white light and monochromatic based coordinate measuring systems.

To develop a set of traceable test artefacts that address Freeform (although much work has already been completed on this in the last E&F program), and now more importantly, optical wavelength and surface finish response. Development and document verification procedures. Develop an in-house non-contact scanner based verification facility. Promote developments via UK and International presentations, publications and direct contact with equipment suppliers and standards bodies. Offer industry 'system verification' consultancy and testing services. Promote adoption by BSI / ISO.213-WG10.

Project Description (including summary of technical work):

Investigate performances of the current state of the art fringe projection and laser scanning systems to measure 'form' on both cooperative and less cooperative surfaces (for example: black, white, various range from colour spectrum, shiny surface, diffuse surface, energy absorbent surface etc).

Develop a range of surfaces, including ones with reference Lambertian finishes and analyse their optical response to different wavelength sources using a custom design spectrometer.

Investigate response of surface on viewing angle and their bidirectional reflectance distribution function (BRDF).

Develop freeform surface with diminishing sinusoidal waves (blades and wings) and features with significant radii that emulate the fringe width form of commercial projectors and laser scanners.

Develop lightweight optical (volume) reference artefact (possibly tetrahedral) nominally 600 mm in size.

Develop multi faceted portable reference artefact(s) incorporating form, scale and surface parameters.

Develop techniques to calibrate reference artefacts.

Develop methods for updating the original CAD file, such that the final CAD contains the new traceable measurement data.

Model form and dimensional properties of reference artefact at different temperatures (e.g.: in the range 16 ^{o}C to 24 ^{o}C).

Set up laboratory based dedicate test rig for verifying the performance of optical scanners.

Produce NPL documented guidelines and measurement verification procedure. Promote to BSI & ISO (and possibly VDI).

Roll out the NPL verification guide and services to UK industry and deliver KT (Papers, UK & International presentations, network meetings and workshop based around the newly developed laboratory based dedicate test rig).

Impact and Benefits:

A previous NMO project (2008-11) included the development of The Freeform Centre at NPL. Within this project was the requirement to develop dimensional freeform surfaces. These have been very successfully manufactured in shiny metal and are having significant impact in UK industry, where they are highlighting measuring system weaknesses and capabilities. They are also being used in European NMIs, there is interest about them from the US and they are being discussed with interest in ISO circles.

The impact of the proposed work here (focusing on surface finish and response to light) and the development of a verification facility including a document guideline procedure, can only but increase the value of the work from the NMO FreeForm sponsored activities. The impact will be that end users will be much more informed about the performance of equipment available in the market place and will be able to select equipment that best fits the requirements.

It is anticipated, based on current levels of interest that more equipment suppliers and end users will want to acquire NPL artefacts and have access to the future NMO verification facility to be developed during the project.

Although commonly quoted in the industry, the non-contact German VDI.2634 guideline which was introduce over 10 years ago, neither addresses freeform or surface finish characteristics. VDI members indicate that there are no plans to updated their guide to cover these important issue, so this project offers a very good opportunity for UK to develop a more relevant standard. Thus the NMO facilities and guide to be developed could easily attract interest, not only from within UK, but from within Germany (where much of the worlds scanning equipment is produced), extending globally to much wider circles, such as that of ISO. All this will help NPL maintains is high metrology worldwide status.

Support for Programme Challenge, Roadmaps, Government Strategies:

This project directly fits in with both the NMO Eng & Flow programme on CMM advanced manufacture and EURAMET road maps, which show needs to establish sound freeform metrology standards and facilities in support of high value advanced manufacture by 2015. This will move in time towards the goal of traceable contact & non-contact techniques at industrial level being established by 2020. The outputs of the project will support UK's alignment of growing in advance manufacture. The outputs from the project will attract interest form just about every manufacturing community involved in high value machining and assembly.

Synergies with other projects / programmes:

This project will extend the successfully developed, internationally recognised NMO FreeForm Centre at NPL, by increasing the science base with the development of this new unique measurement technique and facility.

The project will build on the outputs of the recently ended (4-2011) IMERA plus project NIMTech, where aspheric and turbine blade form reference artefacts were produced. The verification process will be aligned with BSI driven standardisation protocol and ISO213 GPS.

Risks: The risk to negate here, is to avoid friction / confrontation with equipment manufacturers, by exposing the weakness of their systems too early and thus reducing the sales of their equipment, just because it does not conform to the NPL guide. The plan will be to work with the suppliers and introduce the proposed test methods slowly, so they have time to react to the situation before it become public. Although 'head count' does not represent a risk in itself, the skill resource base needs to be carefully selected to align with the tasks.

Knowledge Transfer and Exploitation:

Publications, UK & international conferences, continues direct input with BSI & ISO. NPL Network meetings. Direct interaction with equipment manufacturers, suppliers, end users.

Co-funding and Collaborators:

In kind co-funding in the form of loan of high value equipment will be provided, for example by, Breuckmann, GOM, Phase Vision, Minolta, Jaguar Landrover, Nissan, Airbus, NNL, AWE, etc. Collaborators to include Loughbrough Uni, Heriot Watt, IMERA plus NIMTech partner MIRS, EURAMET members, Breuckmann, API, Airbus, BAE, Jaguar Landrover, Rolls Royce, AMRC, UCL and (TBC).

Deliverables

1	**Start: 01/10/11**	**End: 30/09/12**	
Deliverable title: Design, manufacture & investigate surface reflectance characteristic**: Artefacts & Report**			
2	**Start: 01/10/11**	**End: 30/09/13**	
Deliverable title: Develop large area FreeForm reference artefact (600 mm): **One large-area high-precision reference standard**			
3	**Start: 01/10/12**	**End: 30/09/14**	
Deliverable title: Design integrated FreeForm test artefacts and develop verification test facility at NPL for optical scanners Perform fundament trials on new industrial measuring systems (i.e.: monochromatic fringe source). KT and exploitation via publication, presentation and ISO activities. **Freeform equipment verification facilities, Reference artefacts and ISO interaction.**			

Project No.	EFM11023	**Price to NMO**	£218k
Project Title	Traceable absolute distance measurement demonstrator	**Co-funding target**	Not applicable
Lead Scientist	Ben Hughes	**Stage Start Date**	October 2012
Scientist Team	Ben Hughes, Andrew Lewis, Matt Warden	**Stage End Date**	Sep 2014
		Est Final Stage End Date	Sep 2014
Sector	50% Process control; 50% Advanced instrumentation	**Activity**	80% NMS infrastructure; 20% Challenge driven R&D

Summary

In the area of coordinate metrology, absolute distance measurement (ADM) methods are rapidly replacing displacement interferometry in tools such as laser trackers. However, ADMs typically lack the inherent traceability of displacement interferometry. This project will demonstrate a novel, traceable ADM method, based upon the technique of frequency scanning interferometry (FSI). Traceability is achieved with the use of a quantum reference standard, formed by the absorption lines of molecules in a gas cell.

The Need

The chief scientist of a leading instrument manufacturer has said "conventional [displacement] interferometry will be dead within 5 years": The large volume metrology industry is moving away from conventional, reliable interferometry based on simple fringe counting towards absolute distance measurement methods that offer the user flexibility and convenience at the expense of measurement traceability and accuracy. For example, over the last few years the range measurement methods available on new laser trackers have changed: Initially, only interferometers were available; then instruments having ADMs in addition to interferometers arrived; and now ADM only models are available.

ADM technology, which is typically deployed in laser trackers, is relatively complex and, depending upon the implementation subject to zero-drift, scale error, noise etc. and typically requires periodic calibration. This is normally achieved by comparison with an interferometer. Given that many laser trackers no longer incorporate an interferometer, recalibration of the ADM is not practical in the workplace. This potentially exposes the end user to the possibility of measurement errors.

To address this industry trend there is a requirement for R&D at NMI level to establish an absolute distance measurement capability with inherent traceability. Such a capability could be used as a reference standard for performance verification of commercial large volume metrology systems – not just ADMs – and could be deployed directly in advanced metrology concepts such as FATS .

The Solution

A demonstration of a traceable, high accuracy ADM will be produced, based around a novel implementation of the established method of frequency scanning interferometry (FSI).

This system will achieve traceability through the use of a gas absorption cell as a length/frequency reference. This is a little used technique in FSI, but NPL has experience with this: one such system was built in the 90's at NPL, achieving a relative accuracy of 10^{-10}. This required expensive equipment and long measurement times. Our system will aim at a more industrially focussed accuracy of 10^{-6} using cheaper components and a simpler setup.

The project will exploit the recent increase in availability and capability of tuneable lasers (a core component in FSI), and in particular from an NPL-EPSRC collaboration with Glamorgan University in a project to develop a high spec. tuneable laser designed specifically for FSI.

Use will be made of new FSI analysis methods, developed by a team member who has recently finished a PhD in the Oxford University FSI group and has two patents in this area. These offer the capability of faster, more accurate measurements than previous FSI analysis methods.

A major benefit of this approach is that the system will require a single calibration, valid for the life of the instrument, to identify the absorption lines within the laser tuning range.

Project Description (including summary of technical work)

The project shall start with a review of implementation options, including choice of gas cell frequency reference, choice of laser(s) and operating wavelength, method of identifying absorption line frequencies, and choice of laser operation method, e.g. one vs two laser implementations.

This will be conducted alongside an investigation of uncertainty sources such as accuracy of fitting absorption peaks, calibration of peak frequencies, and the influence of unwanted optical paths.

This will lead to a design specification for hardware and signal processing software. A demonstration measurement system will then be designed and built. Different implementation options may be compared against each other.

Performance will be tested, including evaluation of accuracy, and short and long term measurement repeatability. This will be determined by tests including comparison with a conventional interferometer and repeated measurements of fixed distances.

Impact and Benefits

There is a growing demand for flexible, convenient quick and accurate measurements particularly in high-value industries. Absolute distance (as opposed to displacement) measurement technologies have the potential to meet current and future requirements particularly in the large volume metrology industry. To be at the forefront of this trend NPL should play an active part in developing this technology with a strong focus on traceability to provide for the needs of industry.

Benefits to NPL: New measurement capability, reference instrument for verification of other systems, potential licensing agreements.

Benefits to industry of widespread use of a more traceable ADM system: more efficient construction, right first time with less scrappage.

Support for Programme Challenge, Roadmaps, Government Strategies

Directly supports advanced manufacturing in high-value industries, including R & D in related areas such as metrology assisted assembly.

This project supports the vision of the Metrology 2020 roadmap in several areas. It supports the vision of the 'always on, always calibrated system', where FSI traceable through quantum standards (gas cells) allows frequent, fast, repetitive data acquisition and self-calibration, in situ. Also, the 'distributed NMI' where NMI level traceability is delivered directly at the source relies upon traceable measurement technologies such as this. Both of these will be enabling factors for the 'Bespoke factory', which delivers high efficiency, high quality production.

Synergies with other projects / programmes

This project complements a current FSI based project at NPL: The outcome can be used as a ‘bolt on’, improving the accuracy and traceability for the measurement tool developed in that project. Future projects using FSI will benefit from this project’s deliverables.

The capability developed will be relevant to the FATS project as a potential provider of a high-accuracy, 6DOF capable measurement system for tracking area scanners over a large volume.

Risks

If the shapes of the absorption peaks are not fitted with enough precision and reliably, it may not be possible to make measurements with a high enough level of accuracy.

Knowledge Transfer and Exploitation

Knowledge transfer will be by peer-reviewed journals, and from conference presentations e.g. LVMC and/or CMSC. Exploitation through licensing will be sought.

Co-funding and Collaborators

There are currently two NPL-EPSRC PDRAs working on FSI related technologies. One developing a visible, widely and quickly tuneable laser source for FSI, and the other incorporating FSI into the NPL laser tracer. Both these projects will feed directly into this work.

Deliverables

1	**Start: 01/10/2012**	**End: 30/09/2014**	

Traceable absolute distance measurement demonstrator

Review of implementation options leading to design specification. This may include some practical work.

Working absolute distance measurement system using gas cell absorption lines for traceability.

Software and algorithms for fitting gas cell absorption spectra for use as a frequency reference.

Evaluation of demonstrator system’s uncertainty by comparison with another distance measurement method.

Test results reported via peer reviewed journal / conference presentation.

Project No.	EFM11004	**Price to NMO**	£430k
Project Title	Towards verification and calibration of industrial XCT systems	**Co-funding target**	£100k per year
Lead Scientist	Richard Leach, Mike McCarthy	**Stage Start Date**	October 2011
Scientist Team	Richard Leach, Mike McCarthy, Wenjuan Sun, Stephen Brown	**Stage End Date**	September 2014
		Est Final Stage End Date	On-going
Sector	60% Advanced instrumentation; 40% Standards & regulation	**Activity**	80% NMS I'ture: 20% Challenge R&D

Summary

Following on from the use of x-ray computed tomography as a medical diagnostic tool, advancements in the technique are leading to its increasing use in the fields of manufacturing and engineering as a general metrology tool. However, the verification of XCT systems for dimensional measurements (and related materials properties measurements) has not kept abreast of its use. This project will carry out the basic research that will lead to a traceability infrastructure for XCT measurements. The project will also develop performance verification artefacts that can be used in industry.

The Need

With the rapid development in both XCT hardware and software, major features including resolution and reconstruction speed have been significantly improved in the last decade. The improvement in the technology enables XCT systems to meet the requirement of industrial applications and further extend the applications in medicine. Current industrial XCT systems have voxel resolutions of several micrometres (note that one commercial system has a resolution down to 50 nm) and can penetrate, in some cases, up to several hundred millimetres, making XCT a rival to the conventional CMM but with the additional capability of being able to measure tomographically (internal structure). However, the complex operating principles and model-based measurement approach are slowing down the evolution of XCT from an imaging tool to a traceable metrology tool. To give industry confidence in dimensional and related measurements when using XCT, a comprehensive understanding of XCT systems is required and performance verification artefacts are needed to investigate machines on the market. Research institutions and UK industry are not able to deliver all aspects for all beneficiaries. Thus, the project should be NMS funded in order to assist UK industry to compete in this technology at a world-class level.

The Solution

Following on from the capability review produced in the previous XCT project in the NMS programme, this project will develop the deep understating of XCT that will ultimately lead to a traceable calibration infrastructure. To achieve this, the project will be split into two concurrently running work packages. The first work package will investigate the fundamentals of XCT measurements, both hardware and software. Sources of error will be identified and the mathematical models will be addressed. In the second work package, a small number of performance verification artefacts will be developed to cover the sort of dynamic ranges in industrial machines at present. Whilst such methods do not allow the instrument to be fully calibrated, they will allow users to have confidence in their measurements are a necessary first-step towards calibration.

Project Description (including summary of technical work) (SB)

The project will be split into two concurrent work packages:

Work package 1: Fundamental understanding of XCT measurement principles. This will involve pinpointing and defining the sources of error with XCT systems, understanding the nature of the errors and investigating correction procedures. Investigation of edge detection methods will help to understand three-dimensional rendering of artefacts. It is proposed that mathematical modelling of the associated systematic errors will help to give a better understanding of the abilities of such techniques and equipment. Ultimately, this stage will lead towards volumetric calibration strategies for XCT systems (expected in a later project). The work for Work package 1 will be conducted at NPL with appropriate support through PhDs and post-docs though academic collaborators.

Work package 2: Performance verification of XCT systems. The main geometrical influence factors for performance verification of XCT systems as CMMs and as tomographic systems, will be investigated along with their ability to CAD compare. This investigation will lead to a small number of performance verification artefacts using an informative selection of materials. These artefacts will be measured at NPL (using traceable instrumentation where possible) and then used to performance verify a number of industrial and academic XCT systems. Comparisons will also be made with other NMIs or appropriate experts. The work for Work package 2 will be carried out at NPL with appropriate in kind contributions from industry and academia.

Impact and Benefits (WS)

The take up of industrial dimensional XCT, is rapidly growing and used in both research and in-process measurement over a large size range across many industrial sectors. The potential worldwide revenue of the x-ray inspection

market is predicted to be $450.6million, where the European market counts roughly 30 % of this figure. The outputs of this project will enable the UK to be strongly placed with respect to tomographic measurements, in an arena where ISO standards are unlikely to be available for many years.
The development of the verification artefacts will allow XCT systems to be used as metrology tools rather than visualisation tools. For example, radiologists use XCT systems to scale the size of tumours and engineers use XCT systems to inspect cracks and defects for aeroplane engines. The impact can be directly measured by the revenue generated, and savings made, using XCT systems as traceable dimensional tools.
For example, XCT is one of the only methods for non-destructively assessing items such as turbine blades, a method that could potentially save UK industry millions of pounds per year. Failure of turbine blades has already caused the grounding of aircraft. It is envisaged that having artefacts to verify systems, will ultimately reduce the radiation dosage required for medical scans, thus reducing the probability of contracting secondary cancers, which is ~2 %.

Support for Programme Challenge, Roadmaps, Government Strategies
The project is in direct response to requirements in the NMS and EMRP Roadmaps for traceable tomographic measurements. The government strategies in High-Value Manufacturing and Sustainable Energy (see TSB reports) are both focussed on exploiting the UK's ability to design and manufacture innovative products. Maximising this wealth generation mechanism will depend on successfully realising next generation innovative production systems – this will require appropriate metrology. The project will also leverage the work conducted under the EPSRC CIM in Total Machining & Advanced Surfaces (Huddersfield).

Synergies with other projects / programmes
The project has obvious synergies with the existing freeform and CMM projects funded under the NMS. However, XCT covers a much larger field of applications that just geometry measurement. The ability to measure tomographically makes XCT highly advantageous in the field of materials properties measurement, for example tracking crack propagation, failure mechanisms and stress/strain analysis. Micro-XCT systems are also being developed that can resolve features less than 1 μm and can be used to enhance the area on micro-CMM development.

Risks - This is a medium risk project in that it is technically challenging but only investigative. Any risks will be mitigated by the availability of the review from the previous project.

Knowledge Transfer and Exploitation
The outputs of the project will be disseminated via journal and conference publications and through periodic presentations at NPL Measurement Network and KTN events. The outputs of the project will be communicated to the ISO 213 group on CMMs. The verification artefacts will be disseminated to industry…

Co-funding and Collaborators - In kind contributions from the μ-VIS Imaging Centre at University of Southampton to provide direct access to five XCT systems with ranges from millimetres to metres (£43k for first year for a KTP project to allow NPL staff use of their facilities). In kind contributions from Manchester University's Henry Moseley X-ray imaging facility, including a post doctorate research partnership. In-kind contributions from industry partners (use of facilities, data analysis), including Zeiss, Xradia and Nikon, Rolls Royce and AWE. EMRP funding for a project in the 2011 Heath call (£800k over 3 years, 15 % success, PTB, BAM, INRIM, DFM). Collaboration will be through universities of Southampton, Manchester, Loughborough (one of the lead scientists has a visiting chair), Birmingham and Huddersfield (this will include PhDs, masters students and leverage for EPRSC funding).

Deliverables

1	**Start: 01/10/2011**	**End: 30/09/2014**	**Cost:**

Deliverable title: Towards calibration of XCT systems
Develop a fundamental understanding of the XCT imaging process, including the most common and important influence factors (error sources). Review XCT models for image reconstruction and investigate their effect on measurement uncertainty. Develop methods to measure influence factors and a prototype calibration routine (at this stage artefacts may be designed but not manufactured).

2	**Start: 01/10/2011**	**End: 30/09/2014**	

Deliverable title: Development of performance verification artefacts
Design, manufacture and characterise a small number of verification artefacts. Compare artefacts to traceable CMM systems where possible. Circulate artefacts for comparison with academic and industrial XCT systems. Conduct first-stage NMI comparison of systems.

Project No.	EFM11005	**Price to NMO**	£196k
Project Title	Ultra Precision Manufacturing Metrology (UPMM)	**Co-funding target**	£200k+ per year
Lead Scientist	Richard Leach	**Stage Start Date**	Oct 2011
Scientist Team	Richard Leach, Claudiu Giusca, Chris Jones, Alistair Forbes	**Stage End Date**	Sep 2014
		Est Final Stage End Date	Sep 2017
Sector	50% Process control: 50% Advanced instrumentation	**Activity**	75% NMS infrastructure: 25% Challenge driven R&D

Summary The project will address the needs of next-generation innovative production systems by developing a toolbox of prototype systems to measure surface topography over large areas with high resolution and at high speeds. This will require the development of high accuracy motions systems, high slope topography sensors, sensor hybridisation techniques and data fusion mechanisms. Stage 1 of the project (this proposal) will develop innovation demonstrators and Stage 2 will integrate the demonstrators into production systems.

The Need The UK is considered to be very strong in both scientific research and in the invention of innovative products within emerging sectors. Maximising this wealth generation opportunity will depend on successfully realising next generation production systems, for energy, medical diagnostics, aerospace, space, displays, telecom, semiconductor devices, optics and optoelectronics (Public Service Review: UK Science and Technology 01, 2011). Many emerging sectors (often SMEs in the UK) and products will need large-scale (up to metres) ultra precision (nanometre tolerance) components with complex surface topographies – whilst the manufacturing research is now being addressed, the metrology solutions are not. Without such metrology, quality will be compromised, leading to reduced yield, excess scrap, inefficient use of materials and processes, and a lack of sustainability. As many of the necessary metrology solutions do not yet exist, industry is currently using costly functional testing and trying to make use of instrumentation designed for much smaller scale components. This ambitious and challenging project cannot be funded by any single sector and will require national (and international) effort from industry, academia and government research.

The Solution The solution is to develop, then implement, innovation demonstrators (the 'toolbox') that can be taken up by industry in a range of manufacturing sectors. The demonstrators will include instrumentation for large area scanning, high resolution surface topography measurement, both coarse (tens of micrometres) and fine (tens of nanometres) scanning and sensing, methods for sensor hybridisation and appropriate mathematical and computational infrastructures. Following the identification of suitable technologies and prototype development (first three years), the demonstrators will be installed in a number of industrial manufacturing scenarios, therefore, proving and verifying the technology in UK industry.

Project Description The project is divided into two stages: Stage 1 (first three years) will develop innovation demonstrators for the following technologies (the toolbox): large scale (up to metres), high speed scanning over non-planar surfaces (with slowly varying slopes); high speed optical sensing systems (with high slope measurement capability), sub-micrometre resolution sensing systems (based on optical sensor resolution enhancement, scattering or scanning probe technology); sensor hybridisation techniques (principles to be realised in Stage 2) and data fusion techniques. Stage 2 will verify the toolbox components in industrial scenarios. At all stages of development resultant IP will be licensed to instrument manufacturers for commercial exploitation. The majority of the developments in Stage 1 will be at NPL, with appropriate support from universities through PhDs. UK industry partners will be consulted throughout the duration of the project to ensure that the outputs are relevant and beneficial. Note that the separate parts of the toolbox developed in Stage 1 will be of immediate benefit to UK industry for a number of metrology challenges, but full take up of the whole package will only be demonstrated in-process in Stage 2.

Impact and Benefits The aim of the project is to undertake early stage production research to establish new metrology technologies demanded for effective control of production of emerging products by merging public with private resources to develop highly efficient next-generation metrology solutions. These will exploit breakthrough developments in nanotechnology, instrument design, smart systems integration and reel-to-reel manufacture. The impact will be measured in terms of: economic benefits received by industrial collaborators, number of registered patents and creation of know-how; number of PhDs; the creation of new supply chains and relationships; and number of publications (and their citation rates). Products affected by the project include, for example: 1) next generation displays (flexible or large-scale), activated and animated wall coverings, 3D displays; 2) plastic electronic devices (food packaging, hand held); 3) low cost photo-voltaics; and 4) logistics, defence and security technologies through RFID and IR systems. These emerging products, and the production facilities required to realise them, represent a market of over £335 billion within twenty years, and many high-end manufacturing jobs (Royal Society Report: Hidden Wealth 2009). Further impact stems from an increase in the quality of life through advances in medical devices and treatments, consumer electronics and leisure products. The project will significantly enhance the measurement capability at NPL (enhancing our visibility for collaborative projects and consultancy) and in the UK in general.

Support for Programme Challenge, Roadmaps, Government Strategies The project is in direct response to requirements in the NMS and EMRP Roadmaps for high resolution measurement over large area. The recently completed FP7 project, Co-nanomet, European Strategy for Nanometrology explicitly discusses the need for this work and it is expected that this will be mirrored in future FP7 calls, therefore, facilitating co-funding opportunities. The government strategies in High-Value Manufacturing and Sustainable Energy (see TSB reports) are both focussed on exploiting the UK's ability to design and manufacture innovative products. Maximising this wealth generation mechanism will depend on successfully realising next generation innovative

production systems, including the metrology. The project will also leverage the work conducted under the EPSRC CIMs in Ultra Precision (Cranfield/Cambridge) and Total Machining & Advanced Surfaces (Huddersfield).

Synergies with other projects / programmes

The project has synergy with the previous NMS Areal Measurement & Characterisation project (scanning instrument design, primary traceability), the Micro-probes project (development of optical CMM technologies), AFM projects (instrument development) and FP7 EUMINA*fab*. The project is the natural next-step in areal instrument development and helps to bridge the gap between scanning areal instruments and CMMs. There will also be crossover between this project and the proposed next stage areal project characterisation methods (feature analysis) and between this project and the National Freeform Centre. This proposal is for Stage 1 of a two-stage project. Beyond Stage 2 (integration with manufacturing platforms), the techniques will be extended over larger scales and to higher resolutions and for reel-to-reel manufacture, therefore, supporting the next generation of projects as they arise.

Risks This is a very ambitious project. Many of the hardware solutions (scanning and sensing systems) have been produced for stand-alone instruments that can be slow and do not operate in-line. The novel aspects are in creating fast systems that can be used in-line. There are risks associated when trying to solve the technical issues and in the amount of data that can be produced – it may not be possible to find solutions that are robust or fast enough for use in manufacturing. This risk is mitigated by the two-stage approach where the problems will be solved piecemeal and then integrated into manufacturing systems once they are proven. The formation of an industrial steering group will also help to oversee and mitigate the technical risks.

Knowledge Transfer and Exploitation The outputs of the project will be disseminated via journal and conference publications and through an industrial steering group that will be formed to oversee the project outputs. The outputs will also be taken up in Stage 2 by integration into a number of industrial manufacturing settings. There will also be periodic presentations at NPL Measurement Network and KTN events. Further knowledge transfer will be through the CIM in Ultra Precision seminars and VentureDays series. IP will be licensed to instrument manufacturers for commercial exploitation.

Co-funding and Collaborators The project will receive co-funding through the CIM in Ultra Precision (EPSRC funded) as NPL will oversee all the metrology in this CIM and direct the relevant metrology PhDs (£400k over 5 years). Further co-funding has been won through an FP7 project NANOCleaR (£400k over 4 years) EMRP funding for a sister project (£1m over 4 years, 15 % success, PTB, METAS, VSL), an EPSRC Platform Grant (£50k sub-contract over 4 years, 25 % success), further planned FP7 projects in the 2011 NMP call (£1m, 15 % success), and in kind support from industry in Stage 1 (£200k over 3 years). Collaboration will be through universities of Loughborough (the lead scientist has a visiting chair), Huddersfield, Cambridge, Cranfield, Southampton, Bristol and Stuttgart (this will include several PhDs, masters students and leverage for EPRSC funding). Industrial partners will be sought within Stage 1, but Rolls Royce, Airbus, Messier-Dowty, Boeing, 3M, Honda, Microsharp, Qioptiq, Polytec, Olympus, Epigem, Cinetic Landis, Bruker, Neuteq, Zeiss, Taylor Hobson, Alston, Gooch & Housego and Jaguar Landrover have given support for the project. In Stage 2 direct industry funding will be sought with public support from TSB.

Deliverables – Stage 1: The Toolbox

1	**Start: 01/10/11**	**End: 30/09/14**	

Deliverable title: Development of large scale, high accuracy, high speed, non-planar scanning techniques A prototype scanning system will be designed, constructed and characterised. The system will operate over approximately 500 mm x 500 mm x 50 mm range with 10 nm resolution (to be determined during the design stage). The design stage will incorporate an industrial survey to assess the specification required now and in the future. An uncertainty analysis of the motion system will be produced. At least one instrument manufacturer will be engaged as a commercial partner during this deliverable.

2	**Start: 01/10/11**	**End: 30/09/13**	

Deliverable title: Development of sensing systems and methods for sensor hybridisation and data fusion Following a comprehensive review of available sensing systems, designs will be drawn up for at least two sensing systems: one to measure over large area to relatively low resolution (ten micrometres) and one to measure of a small area to sub-micrometre resolution. Optical methods will be favoured due to their potential for high speed, but mechanical contact sensors are not ruled out at this stage. Following design reviews, prototype sensing systems will be developed and characterised. Uncertainty analyses of the sensors will be produced. Designs will be produced for combining the large and small range sensors developed in D2 into a single hardware package. Following a design review, a prototype hybrid sensor will be developed and characterised in Stage 2. The following will be investigated: methods for handling a large number of data points generated by optical sensors, procedures for registration and fusion of measurement data from different sensors and different measurement parameters, the accuracy of procedures for stitching of measurement fields and methods to enhance the accuracy of less accurate sensors.

Project No.	EFM11006	**Price to NMO**	£482k
Project Title	CoFunding for FP7 NANOclear	**Co-funding target**	This project cofunds an FP7 project valued at £375k
Lead Scientist	Richard Leach	**Stage Start Date**	Dec 2011
Scientist Team	Richard Leach, Claudiu Giusca, Chris Jones, Alistair Forbes	**Stage End Date**	Dec 2014
		Est Final Stage End Date	
Sector	50% Process control: 50% Advanced instrumentation	**Activity**	50% Challenge driven R&D: 50% NMS infrastructure

Summary This project co-funds the FP7 project "Nanoscale Defect Detection Cleaning and Repair for Large Substrates" NANOclear. This is drawn from the parent NMS project "Ultra Precision Manufacturing Metrology" (UPMM). NANOCleaR will pioneer efforts to integrate two exemplar vertical supply chains featuring end-users, leading industrial players involved in supply of metrology, cleaning, repair techniques and thin film production and academic and research groups involved in developing novel metrology, cleaning, barrier production and repair techniques.

The Need The need is to **demonstrate beyond state-of-the-art in-line detection, cleaning and repair of micro-nano-scale defects**, to be integrated into a) production of large-area photovoltaic panels for use in building-integrated systems with demonstrable long life (15-20 years) and b) production of polymer-coated papers used in fibre-based packaging solutions.

These two applications are examples of sectors and products which need large-scale (up to metres) ultra precision (nanometre tolerance) components with complex surface topographies – whilst the manufacturing research is now being addressed, the metrology solutions are not. Without such metrology, quality will be compromised, leading to reduced yield, excess scrap, inefficient use of materials and processes, and a lack of sustainability. As many of the necessary metrology solutions do not yet exist, industry is currently using costly functional testing and trying to make use of instrumentation designed for much smaller scale components. This project requires national (and international) effort from industry, academia and government research.

The Solution The project will address the needs of next-generation innovative production systems by developing a toolbox of prototype systems to measure surface topography over large areas with high resolution and at high speeds. This will require the development of high accuracy motions systems, high slope topography sensors, sensor hybridisation techniques and data fusion mechanisms. The solution is to develop, then implement, innovation demonstrators (the 'toolbox') that can be taken up by industry in a range of manufacturing sectors. The demonstrators will include instrumentation for large area scanning, high resolution surface topography measurement, both coarse (tens of micrometres) and fine (tens of nanometres) scanning and sensing, methods for sensor hybridisation and appropriate mathematical and computational infrastructures. Following the identification of suitable technologies and prototype development (first three years), the demonstrators will be installed in a number of industrial manufacturing scenarios, therefore, proving and verifying the technology in UK industry.

Project Description Metrology developed as described in project EF/2011/06 will be applied to the NANOclear project which will address:

1.Development of an integrated high-speed in-line detection, cleaning and repair solution with production of thin film barriers on plastic using novel in-line high-speed optical sensors, intelligent sampling methods, metrology algorithms, in-situ repair technologies and localised large area cleaning methods.

2. Implementation of process control detection techniques and localised cleaning methodologies for UV cured optical films and for a roll-to-roll Atomic Layer Deposition process. (ALD is known to provide the highest quality barrier)

3. Low-cost, high yield, high-speed production of large area photovoltaics integrated with novel metrology, cleaning and repair systems, combined with roll-to-roll ALD barrier deposition, and better yield of optical film photo-concentrators to provide
product that will last significantly longer than present day plastic panels.

4. Low-cost, high yield, environmentally sustainable roll-to-roll production of plastic coated papers featuring thin-film barriers
for secure, biodegradable packaging solutions.

Impact and Benefits As described in EF/2011/06, with additional benefits resulting from the NANOclear project. The advantage to the NMS of participating in the Nanoclear project is to provide access to NPL to the industrial processes of the committed partners which will provide immediate evidence of the benefits during the lifetime of the project.

The newly developed technologies and processes from NANOCleaR will be easily transferable to other application areas (e.g. displays, lighting, sensors, and other large area electronics) either on the same kind of substrates as envisaged in the project or on other kind of substrates (e.g.glass-substrates, painted functional surfaces). It is expected that the integration of the developed technologies and processes into production lines will be done very quickly by the NANOCleaR industrial partners within the first two years after the project.
The project will significantly enhance the measurement capability at NPL (enhancing our visibility for collaborative projects and consultancy) and in the UK in general.

Support for Programme Challenge, Roadmaps, Government Strategies
As EF/2011/06. In its support to small businesses in emerging sectors, participation in the NANOclear project is in direct support of the government's growth agenda. It provides the NMS with new, accelerated routes for exploitation of NMS funded technology at no cost to the NMS and is fully aligned to the NMS strategy.

Synergies with other projects / programmes
As EF/2011/06.

Risks There is no additional risk to the NMS beyond that declared in project EF/2011/06.

Knowledge Transfer and Exploitation The outputs of the project will be disseminated via journal and conference publications and through an industrial steering group that will be formed to oversee the project outputs. The outputs will also be taken up in Stage 2 by integration into a number of industrial manufacturing settings. There will also be periodic presentations at NPL Measurement Network and KTN events. Further knowledge transfer will be through the CIM in Ultra Precision seminars and VentureDays series. IP will be licensed to instrument manufacturers for commercial exploitation.

Co-funding and Collaborators The NANOclear project will provide £375k grant funding over 4 years. The project is led by the University of Huddersfield and includes industrial and academic collaborators from Austria, Germany, Finland, Switzerland and the Netherlands. Industrial collaborators include Microsharp, Isravision, Kite Innovations and IBS Precision Engineering.

Deliverables – Stage 1: The Toolbox

1	**Start: 01/12/11**	**End: 30/11/14**	
Deliverable title: This is a cofunding project. Details of the deliverables are as specified on project EF/2011/06.			

Project No.	EFM11007	**Price to NMO**	£466k
Project Title	Structured surface metrology	**Co-funding target**	£102k secured from FP7 + £100k+ per year
Lead Scientist	Richard Leach	**Stage Start Date**	Oct 2011
Scientist Team	Richard Leach, Claudiu Giusca, Lakshmi Nimishakavi, Peter Harris	**Stage End Date**	Sep 2014
		Est Final Stage End Date	
Sector	70% Process control: 30% Traceability & uncertainty	**Activity**	50% Challenge driven R&D: 50% NMS infrastructure

Summary

This project is the parent project for Project EF/2012/03 FP7 Project EUMINA FAB. Originally approved at a value of £566k, £100k has been transferred to project EF/2012/03. The scope of the work funded by NMS is unchanged. The project will develop a method for calibrating the transfer function of areal surface topography measuring instruments based on linear systems theory. This will allow, for the first time, an uncertainty value to be associated with an areal topography parameter. The project will also develop methods for characterising structured surfaces using novel feature parameters. The project will build upon the strong work carried out in previous projects in the area of areal surface topography measurement and characterisation.

The Need

Modern manufacturing industry uses engineered surfaces, both stochastic and structured, to change or to control the functionality of a component for increased product efficiency and durability, and to reduce source material and scrap. In this context industry requires traceable areal surface topography measuring instruments and reliable surface texture analysis software to assure design tolerance requirements. A significant number of areal surface topography measuring instruments, largely based on optical techniques, and including analysis software is commercially available. However, implementation of optical instrumentation into production is problematic due to the lack of understanding of the complex interaction between the light and the component surface - studying the transfer function of the instrument could solve this. Currently calibration of the measurement scales of areal instruments is available without any in-depth understanding of the effect of topography measurement into the areal parameters calculation. Reference software has been developed for testing algorithms for field parameters but not for volume and feature parameters that are essential to analyse non-stochastic surfaces. UK manufacturing industry is developed around different branches of precision engineering and high-tech markets that will be the prime beneficiaries of the proposed work. The NMS should fund this project because its general interest will profit UK industry overall and there is no single company that will be able to fund independently such work.

The Solution

The aim of the proposed project is to develop techniques to measure the transfer function of optical instruments that will enable proper exploitation of the current technology consistent with industrial needs, based on the most recent advances in modelling the optical probe interaction with the surface. Development of sound measurement uncertainties associated with areal surface texture parameters that account for the effect of the calibration of the scales and transfer function of the instrument, filtration of the measured topography and parameters calculation assures that parts are manufactured within designed tolerances. Lastly, standard measurement software for volume and feature parameter calculations will verify and quantify the quality of commercial software packages available for analysis of structured surfaces. With these new capabilities NPL will be in a position to offer a world-class measurement service. NPL is uniquely placed to carry out this work: we have existing PhD students in all aspects of the work and have published on the concepts in previous projects.

Project Description (including summary of technical work)

The project consists of three parts. 1) Calibration of the transfer function of optical instrumentation using mathematical models based on linear system theory that accounts for the effect of the interaction between the surface and the optical probe. Inverse modelling will be used to compensate for systematic measurement errors, e.g. due to high slopes. 2) Development of the measurement uncertainty associated with areal parameters based on a model that will consider both the contribution of the scales and that of the transfer function. Special care will be taken to ensure that the systematic effects of the input parameters of the model are isolated from the random effects. This will be followed by the calculation of the uncertainty associated with the areal parameters using the Monte Carlo method for a number of industrial test cases that require comparative and absolute measurements. 3) Standard software will be developed in accordance to ISO 25178 and will use computational algorithms that provide accurate results. The software will be available to use online from the NPL web site. Both industry and academia will be consulted throughout the duration of the project.

Impact and Benefits

This project will deliver the underpinning metrology necessary for manufacturing with deterministic control of surface topography that can improve, e.g. friction, wear, aerodynamics, fuel efficiency, biocompatibility, spectral response, and can allow the engineering of new functions into a product such as self-cleaning glass or colouring without paint. The project will also provide a metrological platform for implementation of areal surface topography measuring instruments into the manufacturing chain by matching the design tolerances with appropriate measurement uncertainties. At the end of the project, NPL will be able to provide a comprehensive measurement and consultancy service for manufacturing with structured surfaces. The impact will be measured in a first stage by the number of academic and industrial partners willing to collaborate and support financially the project (in kind or cash), by the number of accepted peer review journal papers and oral presentations at national and international conferences, by the number of new industrial collaborators and contracts won from non-NMS sources. The project has real technological and scientific relevance and, therefore, a large potential to create a positive impact on people's lives through improvements in fields as diverse as medicine, consumer electronics and the energy conservation.

Support for Programme Challenge, Roadmaps, Government Strategies

The project is in direct response to requirements in the NMS and EMRP Roadmaps for high resolution measurement of structured surfaces. The government strategies in High-Value Manufacturing, Materials, Healthcare and Sustainable Energy (see TSB reports) are focussed on exploiting the UK's ability to design and manufacture innovative products. Maximising this wealth generation mechanism will depend on successfully realising next generation innovative production systems, including the metrology.

Synergies with other projects / programmes

The project has synergy with the previous NMS Areal Measurement & Characterisation project, Areal calibration guides project, the Micro-probes project (development of optical CMM technologies) and FP7 EUMINAfab. The project will be of direct relevance to projects in the Materials and Analytical groups at NPL. The project is the natural next-step in areal surface texture development. There will also be crossover between this project and the proposed UPMM project.

Risks

This is a challenging project in that it pushes the boundary of what can be achieved using areal surface texture measuring instruments and analysis methods. The work with the transfer function requires a high degree of mathematical sophistication but NPL will collaborate with Loughborough University on this who are world-leading in this particular field of optics. The propagation of uncertainty through the complex mathematical functions that form the feature analysis may also be problematic, but again NPL will collaborate with the inventor of this analysis method at the University of Huddersfield.

Knowledge Transfer and Exploitation

The outputs of the project will be disseminated via journal and conference publications and through good practice guides. There will also be periodic presentations at NPL Measurement Network and KTN events. Further knowledge transfer will be through the EPSRC CIMs in Ultra Precision and Total Machining & Advanced Surfaces seminars. The feature analysis software will be available to industry on an NPL hosted web site (alongside the existing field parameters). The outputs of the project will also form input into the ISO 25178 series of standards of areal surface texture. The outputs of the project will be taken up in a range of industrial sectors, from high value manufacturing to archaeology to medicine.

Co-funding and Collaborators

Co-funding from FP7 EUMINA*fab* (£50k per year for 2 years). Co-funding is sought through an FP7 project NANOCleaR (£350k over 4 years, 2nd stage, 50 % success), EMRP funding for a Health project (£400k over 3 years, 15 % success), an EPSRC Platform Grant (£50k sub-contract over 4 years, 25 % success), further planned FP7 projects in the 2011 NMP call (£1m, 15 % success), and in kind support for instrument loans (£200k over 3 years). Collaboration will be through the universities of Loughborough (the lead scientist has a visiting chair), Cardiff, Bradford, Huddersfield, Cranfield, Brunel and Southampton (this will include several PhDs, masters students and leverage for EPRSC funding). Industrial partners will be sought throughout the project, but Taylor Hobson, Bruker, Olympus, NanoFocus, Alicona, Mahr, Polytec, DigitalSurf, Armstrong Optical and Rubert have offered support for the project. Direct industry funding will be sought with public support from TSB.

Deliverables

1	**Start: 01/10/11**	**End: 30/09/14**	

Deliverable title: Calibration of optical instruments using the transfer function

A method of calibrating the transfer function of optical instruments will be developed for various optical surface texture measuring instruments. Initially a sound mathematical model will be developed and used to correct for common errors such as edge effects. The contribution of the transfer function of the instrument to the measurement uncertainty will be investigated.

2	**Start: 01/10/11**	**End: 30/09/14**	

Deliverable title: Reference software for feature parameters

Unambiguous definitions based on ISO standards of the volume and feature parameters will be formulated and reference software for calculating a number of volume and feature parameters will be developed for online access via the NPL web site.

Project No.	EFM11009	**Price to NMO**	£385k
Project Title	Unified micro-co-ordinate measurements	**Co-funding target**	£200k per year
Lead Scientist	Richard Leach	**Stage Start Date**	Oct 2011
Scientist Team	Richard Leach, James Claverley, Alan Wilson, Wenjuan Sun	**Stage End Date**	Sept 2014
		Est Final Stage End Date	Sept 2014
Sector	70% Advanced instrumentation: 30% Traceability & uncertainty	**Activity**	100% NMS infrastructure

Summary

The project will develop a harmonised capability ion micro-coordinate metrology. Tactile systems will be developed and characterised based on probe IP from a previous project. Optical methods for areal surface topography measurement will be enhanced and investigated for true 3D measurement and compared to the traceable output from tactile systems. The outputs of the project will allow micro-coordinate measurements to be utilised in industrial manufacturing. The project will build upon the strong work carried out in a previous project in the area of micro-coordinate metrology and areal surface topography measurement.

The Need

Micro-co-ordinate metrology is required to assist modern manufacturing industries to maintain the accurate and repeatable production and integration of miniature parts to produce products. For almost all industrial inspection purposes, optical micro-co-ordinate measuring systems (such as variable focus, confocal, coherence scanning interferometry) are the preferred solution, due to their non-tactile operation, their ease of use, speed of measurement and easy integration into production lines. However, these optical systems are, as of yet, difficult to verify and calibrate and also subject to a multitude of adverse optical effects. It is, therefore, essential that these optical micro-co-ordinate measuring systems be unified with existing and newly developed calibrated tactile systems to ensure industrial users can be confident on all micro-co-ordinate measurements. Existing tactile micro-co-ordinate measuring systems are expensive (several £100k) and rely on expensive probes (most systems, £1000s, market leader, £600). These probing systems are fast becoming inadequate for co-ordinate metrology of true 3D micro-parts, owing to their lack of sensitivity, damaging interactions and difficulty of use. Tactile micro-co-ordinate measuring systems also lack adequate standards for verification (existing CMM standards, such as ISO 10360, are not applicable). The project aims to bring tactile micro-co-ordinate measuring systems inline with current manufacturing requirements, whilst also focusing on producing a commercially viable product. The project will also develop traceability routes for non-contact micro-co-ordinate measuring systems, which are already being widely used in industry. This work must be completed under the NMS because it is essential that these technologies be unified to ensure industrial users can be confident on all micro-co-ordinate measurements.

The Solution

The project will interface the previously developed NPL vibrating micro-probe with commercial 3D precision micro-positioning platforms to create tactile micro-co-ordinate measurement systems accurate to < 100 nm. These new tactile systems will be fully characterised. Existing non-tactile micro-co-ordinate measuring systems will be characterised and compared against existing tactile systems and the high accuracy systems developed by this project. The accuracy of these non-tactile systems in performing co-ordinate measurements will be determined. From this work, traceability routes for micro-co-ordinate measuring systems, both tactile and optical, will be developed to address the issues in precision manufacturing industry. NPL will further develop its capability in micro-co-ordinate metrology and be able offer a greater suite of traceable micro-co-ordinate solutions to its customers. NPL is uniquely placed to carry out this work: we have existing PhD students in all aspects of the work and have published on the concepts in previous projects.

Project Description (including summary of technical work)

The project will interface the NPL vibrating micro-probe with commercial 3D precision micro-positioning stages (the TriNano by Xpress and the F25 µCMM by Zeiss) and fully characterise their performance. This will also include continued investigation into the state of stylus tip manufacture, including the measurement of the tip form, an essential part of micro-probe operation and use. NPL scientists will complete this with the assistance of collaborators either on site at their research facilities or on site at NPL. At least two optical systems (a variable focus microscope from Alicona and a large area coherence scanning interferometer from Polytec) will be validated for their co-ordinate measuring capability by comparison to traceable tactile measurements. These comparisons will be completed using micro-CMM artefacts that are suitable for both tactile and optical systems.

Impact and Benefits

The high value manufacturing industries, using micro-injection moulding, micro-milling, replication and lithography, currently have limited capabilities for measuring millimetre-scale structures with micro-scale features, either with tactile or non-tactile systems. This project will benefit the high value manufacturing industry by developing and characterising a suite of micro-co-ordinate metrology systems. Metrology is essential for the reduction of dimensional tolerances, which allows the production of more efficient machines and the improvement of their longevity by reducing play or wear. An example is smaller and more efficient injection nozzles in combustion machines, which critically depend on improved dimensional measurement capabilities. Further examples are RF or fibre optic connector components where feature sizes and tolerances require measurement uncertainties at the 0.1 µm level, or small aspherical lenses in digital cameras or mobile phones. An emerging sector is high tech medical products, which very often critically depend on micro-components, e.g. in insulin pumps, cardiac pacemakers, in vivo diagnostic sensors or medical endoscopic imaging systems. The project will directly benefit SMEs in this industry by supporting a measurement service and a knowledge base in micro-co-ordinate metrology. A measurement service will be further developed to calibrate micro-co-ordinate

measuring systems (both tactile and non-tactile) that will allow users to gain confidence in their measurement and to control the quality of their products. This will greatly benefit high value manufacturing industries such as high precision optics, commercial optic moulds, macro and micro bearing surfaces and cam shafts, disposable medical instruments because many in-line measurements are taken using non-contact systems.

Support for Programme Challenge, Roadmaps, Government Strategies

The project is in direct response to requirements in the NMS and EMRP Roadmaps for micro-co-ordinate metrology. The government strategies in High-Value Manufacturing (see TSB reports) are focussed on exploiting the UK's ability to design and manufacture innovative products. Maximising this wealth generation mechanism will depend on successfully realising next generation innovative production systems, including the metrology. The project will also leverage the work conducted under the EPRSC CIM proposal from Cranfield/Cambridge.

Synergies with other projects/programmes

This project directly follows a three-year NMS project developing the NPL vibrating micro-probe. This proposed project has direct links to the proposed 3D AFM (similar technologies and designs are used). The systems developed in this project will be very beneficial to the proposed XCT project and to the proposed Ultra Precision Manufacturing Metrology project, which both need 3D micro-co-ordinate metrology for traceability. Many areas of NPL (materials, optics, analytical, electrical and acoustic) make use of NPL's existing micro-co-ordinate metrology services. This project is also closely linked to the FP7 project, EUMINAfab, which is aimed at lowering the barriers faced by SMEs when trying to exploit emerging technologies in micro and nano-scale manufacturing and characterisation.

Risks

The risk of this project is moderate as it relies on existing expertise at NPL. There is a medium risk associated with the optical micro-CMM calibration, but this is mitigated by a PhD at Loughborough University. There is a risk associated with gaining access to the technical specifications of the Zeiss F25, but this is mitigated by a verbal agreement from Zeiss that access will be granted.

Knowledge Transfer and Exploitation

The project will result in the development of a new, low cost, fully 3D, tactile micro-co-ordinate measuring system, using technology already licensed by NPL. The project will also enhance the capabilities of existing micro-CMMs by integrating the new NPL vibrating probe onto existing micro-CMMs (the Zeiss F25). Manufacturers and users of existing non-contact systems will be able to exploit the new calibration procedures developed by this project, which will include a measurement service for the calibration of micro-co-ordinate measuring artefacts. The project will result in a measurement service to be used by industry. Developments of this project will be reported to suitable conferences and journals and will also be submitted to existing ISO committees to assist in the development of standards aimed directly at micro-co-ordinate metrology.

Co-funding and Collaborators

There are already PhD students completing parts of this project under the auspices of NPL (non-contact micro-CMMs being developed at Loughborough and a precision micro-positioning stage being developed at Eindhoven University). Master students will also be regularly used. In kind contributions from industry for comparison measurements. Co-funding from FP7 – EUMINA*fab* (£50k per year for 2 years) and FP7 – MIDEMMA (€400k over 3 years). Collaborations with instrument manufactures (Alicona, Polytec and others), industrial partners (users of micro-co-ordinate measuring systems, both tactile and optical) and academic partners (from Huddersfield, Loughborough, Brunel, Cardiff and Nottingham).

Deliverables

1	**Start: 01/10/11**	**End: 30/09/14**	

Deliverable title: Tactile micro-co-ordinate metrology

Interface the NPL vibrating micro-probe commercial 3D precision micro-positioning stages and fully characterise the performance of the resulting system. Develop traceability routes from new and existing tactile micro-co-ordinate measurement systems, comparing results across existing tactile techniques. Apply these traceability techniques to existing tactile micro-co-ordinate measuring systems at NPL. Publish results in journal papers.

2	**Start: 01/10/11**	**End: 30/09/14**	

Deliverable title: Non-tactile micro-co-ordinate metrology

Non-tactile systems will be validated for their co-ordinate measuring capability. The suitability of the systems to perform micro-co-ordinate measurements will be verified through direct comparison to traceable measurements taken on tactile micro-co-ordinate measurement systems. Traceability routes developed in Deliverable 1 will be applied to these systems to create a unified micro-co-ordinate measurement capability for the UK. Publish results in journal papers.

Project No.	EFM11010	**Price to NMO**	£152
Project Title	Co-Funding for FP7 MIDEMMA	**Co-funding target**	This project cofunds an FP7 project valued at £150k
Lead Scientist	Richard Leach	**Stage Start Date**	Nov 2011
Scientist Team	Richard Leach, James Claverley, Alan Wilson, Wenjuan Sun	**Stage End Date**	Nov 2014
		Est Final Stage End Date	
Sector	75% High value manufacturing: 25% Traceability & uncertainty	**Activity**	50% Challenge driven R&D: 50% NMS infrastructure

Summary

This project co-funds the FP7 project "Minimizing Defects in Micro-Manufacturing Applications" (MIDEMMA). This is drawn from the parent NMS Project "Unified micro-co-ordinate measurements" MIDEMMA will develop methods for ensuring zero defect manufacturing supported by micro-coordinate metrology. Tactile systems will be developed and characterised based on probe IP from a previous project. Optical methods for areal surface topography measurement will be enhanced and investigated for true 3D measurement and compared to the traceable output from tactile systems.

The Need

Zero defects manufacturing is an aspiration for all modern industries. Producing parts that do not meet the requirements leads to waste, or the need for more expensive equipment for manufacturing and quality control. Large effort has been focused on developing strategies to minimize defects in manufacturing, such as Six Sigma, based on identifying and removing the causes of defects and minimizing variability in the manufacturing process.

The MIDEMMA project aims at contributing to this ongoing effort in optimizing manufacturing processes particularly on micromanufacturing,

The Solution

Technologies need to be developed, and their performance verified, that will improve the competitiveness of the micro-manufacturers in the following ways:

• provide a reduction in process variability by detecting defects as soon as they are generated or predicted to occur.

• allow the use of less expensive machines, that will provide reduced variability through improved monitoring and control.

• allow the use of a less skilled workforce, thanks to acquired process data and the development of smart decision-making tools.

NPL will provide the metrology required to develop these approaches using techniques developed in project EF/2011/10 adapted for this project.

Project Description (including summary of technical work)

1)Workpiece characterization and manipulation - Characterization of raw material characteristics (geometry, material structure), workpiece clamping and manipulation

NPL will develop mechanical and optical sensing techniques for micro-coordinate metrology

NPL will complete the development of a novel micro-scale micro-CMM probe, capable of true 3D point measurement and scanning to an uncertainty below 100 nm. This piezoelectric nickel-based vibrating micro-CMM probe will be verified for isotropic probing, reliable non-contact detection of surfaces and scanning capabilities. This probe will be mounted onto a suitable micro-CMM platform for testing.

New methods for using optical topography instrumentation as a co-ordinate measuring platform will be developed to perform coordinate metrology at the millimetre to micrometre scale. The test instrumentation (variable focus microscopes and laser scanning confocal microscopes) will be refined in terms of the optical physics to translate capability from surface topography analysis to coordinate metrology. Detailed comparisons will be completed between new commercial instrumentation and existing high specification coordinate measuring equipment.

Subsequently, reliable and traceable measurement of workpieces before and after production using micro-manufacturing techniques will be measured to verify the success of defect reducing techniques.

2) Smart decision making tools – Data acquisition, system modelling, efficiency criteria, decision-making strategies, quality assurance and traceability

NPL will examine routes to traceability for all metrology in the project

Suitable methods to qualify and compare the manufacturing processes investigated in this project will be considered. These methods could include evaluation of partners metrology capabilities; calibration of test artefacts to assist in the calibration of metrology installations throughout the consortium and the organisation of a manufacturing round-

robin to verify the initial capabilities of each partner.
The project will interface the NPL vibrating micro-probe with commercial 3D precision micro-positioning stages (the TriNano by Xpress and the F25 µCMM by Zeiss) and fully characterise their performance. This will also include continued investigation into the state of stylus tip manufacture, including the measurement of the tip form, an essential part of micro-probe operation and use. NPL scientists will complete this with the assistance of collaborators either on site at their research facilities or on site at NPL. At least two optical systems (a variable focus microscope from Alicona and a large area coherence scanning interferometer from Polytec) will be validated for their co-ordinate measuring capability by comparison to traceable tactile measurements. These comparisons will be completed using micro-CMM artefacts that are suitable for both tactile and optical systems.

Impact and Benefits

As described in EF/2010/10, with additional benefits resulting from participation in the MIDEMMA project. The advantage to the NMS of participating in the Nanoclear project is to provide access to NPL to the industrial processes of the committed partners which will provide immediate evidence of the benefits during the lifetime of the project.
The success of any Zero-defect or near-zero-defect developments can only be verified though accurate and traceable metrology at all stages of development. NPL's contribution towards traceable tactile and non-tactile metrology on the micro-scale will be essential to verifying the success of any developments in the MIDEMMA project. NPL's support in the area of traceable metrology will enable certain measurements to be taken by the partners; enhancing their capabilities to verify the success of their developments.
At the end of the project new optical and tactile micro-scale CMM technology will be licensed if implemented in commercial instrumentation. Improved calibration and measurement service assuring traceability for measurement instruments with wide dynamic ranges will be available towards the end of the project. Increased knowledge and exposure on new markets and applications will consolidate NPL strategic position in the MNT field.

Support for Programme Challenge, Roadmaps, Government Strategies

As EF/2011/10. In its support to small businesses in emerging sectors, participation in the MIDEMMA project is in direct support of the government's growth agenda. It provides the NMS with new, accelerated routes for exploitation of NMS funded technology at no cost to the NMS and is fully aligned to the NMS strategy.

Synergies with other projects/programmes

As EF/2011/10.

Risks

There is no additional risk to the NMS beyond that declared in project EF/2011/10.

Knowledge Transfer and Exploitation

The project will result in the development of a new, low cost, fully 3D, tactile micro-co-ordinate measuring system, using technology already licensed by NPL. The project will also enhance the capabilities of existing micro-CMMs by integrating the new NPL vibrating probe onto existing micro-CMMs (the Zeiss F25). Manufacturers and users of existing non-contact systems will be able to exploit the new calibration procedures developed by this project, which will include a measurement service for the calibration of micro-co-ordinate measuring artefacts. The project will result in a measurement service to be used by industry. Developments of this project will be reported to suitable conferences and journals and will also be submitted to existing ISO committees to assist in the development of standards aimed directly at micro-co-ordinate metrology.

Co-funding and Collaborators

The MIDEMMA project will provide £150k grant funding over 3 years. The project is led by the IDEKO of Spain and includes industrial and academic collaborators from Belgium, Denmark. Germany, Switzerland and the Netherlands. Industrial collaborators include Microsharp, Isravision, Kite Innovations and IBS Precision Engineering.

Deliverables

1	**Start: 01/11/11**	**End: 01/11/14**	

Deliverable title: This is a cofunding project. Details of the deliverables are as specified on project EF/2011/10.

Project No.	EFM11011	**Price to NMO**	£63k
Project Title	Metrology of small structures	**Co-funding target**	EMRP funding £220k **secured**
Lead Scientist	Andrew Yacoot	**Stage Start Date**	Oct 2011
Scientist Team	Andrew Yacoot, Matthew Tedaldi	**Stage End Date**	Sep 2014
		Est Final Stage End Date	
Sector	100% Advanced instrumentation	**Activity**	100% NMS infrastructure

Summary

This project is the parent project for the EMRP project JRP15i Scatterometry which is described in EF/2011/13. Originally costed at £271k, £220k has been transferred to EF/2011/13 with the remainder remaining in this project. The NPL contribution (in collaboration with PTB) will combine an atomic force microscope (AFM) with an x-ray interferometer (XRI) and an optical interferometer (COXI) to provide a facility for measurement of local variations in the periodicity of gratings used for the verification of models in the scatterometry. Enhancements will also be made to the control system for the x-ray interferometer to improve versatility and increase the range of tasks that can be undertaken using XRI.

The Need

The semiconductor industry has no accepted standard for comparison scatterometry, SEM and AFM measurements. In the optics industry there is a lack of a standardised method for characterisation of diffractive optical microstructures. Improved metrology is needed to characterise and measure sufficiently accurately suitable reference standards. Existing Metrological AFMs are the most suitable method for this task over a short range but are unsuitable for measurements over a range of more than about 100 µm which will be required for this work.

The Solution

The XRI is at present the only non-optical interferometry based method for directly traceable sub nanometre metrology and is therefore immune to the non-linearity problems associated with optical interferometers. By combining the high resolution of the XRI and the long range of the OI together with an improved translation mechanism for the OI a long range (1 mm) high accuracy (<1 nm) displacement platform (COXI) will be developed as a scanning system for an AFM. This will enable the examination of sub nanometre local deviations in grating period over several hundred micrometres; these variations are currently limiting the use of scatterometry. This will provide better measurements of local variations in grating period in relation to the overall period and structure leading to a better calibration artefacts that can be used to validate the models for scatterometry and SEM measurements, performed by other partners in the EMRP project, resulting in more robust process metrology using SEMS and scatterometry.

Project Description (including summary of technical work)

NPL and PTB will integrate an AFM with Z axis metrology into a COXI system. It is likely that a two-crystal XRI system will need to be developed, but initially an uncertainty budget for both the monolithic and two crystal methods will be prepared. A conceptual design for most appropriate system will be produced and be the basis for the full design. In parallel work will be done to enhance several components of the existing XRI platform (power supply for driving pzt, software to allow operation in a dynamic mode, active adjustment of fringe contrast, installation of split channel photomultipliers for quadrature fringe counting). These needs have come to light during the NANOTRACE project and will enhance the performance and versatility of the final instrument. An AFM head will be developed in collaboration with PTB and integrated into the COXI system. Once complete the instrument will be tested and an uncertainty budget prepared before commencing measurements of grating structures.

Impact and Benefits - As per EF/2011/13.

Support for Programme Challenge, Roadmaps, Government Strategies - As per EF/2011/13

Synergies with other projects / programmes - As per EF/2011/13

Risks - As per EF/2011/13

Knowledge Transfer and Exploitation - As per EF/2011/13.

Co-funding and Collaborators

As per EF/2011/13. The EMRP project JRO 15i will provide £220k in grant funding.

Deliverables

This is the remainder a cofunding project. Details of the deliverables are as specified on project EF/2011/13

1	**Start: 01/10/11**	**End: 30/09/14**	**Cost:**

Project No.	EFM11012	**Price to NMO**	£209k
Project Title	Scatterometry - Co-Funding for EMRP JRP15i	**Co-funding target**	This project cofunds an EMRP project valued at £220k
Lead Scientist	Andrew Yacoot	**Stage Start Date**	Oct 2011
Scientist Team	Andrew Yacoot, Matthew Tedaldi	**Stage End Date**	May 2014
		Est Final Stage End Date	
Sector	75% Advanced instrumentation: 25% Traceability & uncertainty	**Activity**	100% NMS Infrastructure

Summary

The project co-funds the EMRP **JRP15i "Metrology of small structure for manufacturing of optical and electronic devices".** The NPL contribution (in collaboration with PTB) will combine an atomic force microscope (AFM) with an x-ray interferometer (XRI) and an optical interferometer (COXI) to provide a facility for measurement of local variations in the periodicity of gratings used for the verification of models in the scatterometry. Enhancements will also be made to the control system for the x-ray interferometer to improve versatility and increase the range of tasks that can be undertaken using XRI.

The Need

The semiconductor industry has no accepted standard for comparison scatterometry, SEM and AFM measurements. In the optics industry there is a lack of a standardised method for characterisation of diffractive optical microstructures. Improved metrology is needed to characterise and measure sufficiently accurately suitable reference standards. Existing Metrological AFMs are the most suitable method for this task over a short range but are unsuitable for measurements over a range of more than about 100 µm which will be required for this work.

The Solution

The XRI is at present the only non-optical interferometry based method for directly traceable sub nanometre metrology and is therefore immune to the non-linearity problems associated with optical interferometers. By combining the high resolution of the XRI and the long range of the OI together with an improved translation mechanism for the OI a long range (1 mm) high accuracy (<1 nm) displacement platform (COXI) will be developed as a scanning system for an AFM. This will enable the examination of sub nanometre local deviations in grating period over several hundred micrometres; these variations are currently limiting the use of scatterometry. This will provide better measurements of local variations in grating period in relation to the overall period and structure leading to a better calibration artefacts that can be used to validate the models for scatterometry and SEM measurements, performed by other partners in the EMRP project, resulting in more robust process metrology using SEMS and scatterometry.

Project Description (including summary of technical work)

NPL and PTB will integrate an AFM with Z axis metrology into a COXI system. It is likely that a two-crystal XRI system will need to be developed, but initially an uncertainty budget for both the monolithic and two crystal methods will be prepared. A conceptual design for most appropriate system will be produced and be the basis for the full design. In parallel work will be done to enhance several components of the existing XRI platform (power supply for driving pzt, software to allow operation in a dynamic mode, active adjustment of fringe contrast, installation of split channel photomultipliers for quadrature fringe counting). These needs have come to light during the NANOTRACE project and will enhance the performance and versatility of the final instrument. An AFM head will be developed in collaboration with PTB and integrated into the COXI system. Once complete the instrument will be tested and an uncertainty budget prepared before commencing measurements of grating structures.

Impact and Benefits

The JRP will enable metrology solutions for currently unsolved crucial challenges. Dimensional metrology of advanced functional structures in the nm-range is especially driven by semiconductor (particularly lithography), optics and sensor manufacturing industries and directly supports development of instrumentation and production in these key industries. Direct and indirect impact will be mainly within the following industrial sectors: mechanical engineering and industry, electrical engineering and industry, process engineering and production technologies and communication technologies and industry and optical engineering and industries. The project stakeholders are major European companies with world markets supplying products that have applications in virtually every sector of life and include ASML, NIST, Heidenhain and Carl Zeiss.

Support for Programme Challenge, Roadmaps, Government Strategies

The work enhances or displacement metrology capabilities at the millimetre to picometre level as well as our SPM capabilities. These areas are identified in our roadmap for micro and nanometrology and improvements in nanometrology are a need highlighted by the highlighted by Royal Society review on nanotechnology

Synergies with other projects / programmes

This project directly builds on the EMRP project Nanotrace (2008-1011), allows NPL to benefit from work done within the EMRP project Nah, (Avogadro constant determination). It complements our AFM work in EM, and will strengthen our length metrology capabilities. It will also improve our sub-nanopositioning capabilities that in turn will benefit all nanometrology projects requiring nanopositioning, e.g. low force, AFM, microthrust.

Risks

These include the loss of key staff, unavailability of suitable accommodation for XRI, damage to XRI and partners failing to deliver on schedule.

Knowledge Transfer and Exploitation

NPL will be leading the Impact work package for the EMRP. Since NPL is leading the Impact work package for several EMRP projects, it will be adopting a co-ordinated approach to avoid duplication of effort.

To ensure the relevance of this project to stakeholders and to enable communication and coordination of activities with them, leading European manufacturers and academics are involved through the REG proposals and through collaborations with the stakeholders identified in the letters of support. There will be regular meetings of a Stakeholder Committee that will also be open for new stakeholders.

Throughout the life of the project there will be a dedicated website.
Project results will be disseminated, through standardisation bodies such as ISO. The consortium will organise a workshop within the final year of the project, inviting key international speakers and presenting the major outcomes of the project. The partners in this project will publish their work through peer-reviewed papers and conference presentations. To further disseminate the scientific outcome of this project, training activities through participation of key researchers at relevant workshops and training courses will be undertaken.

Co-funding and Collaborators

EMRP project JRO 15i Scatterometry for the manufacturing of electronic and optical devices. The XRI work will be done in close cooperation with PTB. In the overall project, partners include, PTB, CMI, MIKES, NMI VSL, Carl Zeiss, Heidenhain, SIOS.

Deliverables: Scientific outputs of EMRP project

1	**Start: 01/10/11**	**End: 30/05/2014**	

Deliverable title: Impact outputs of EMRP project. Develop and Ultra-high stability platform **for the x-ray interferometer.**

This includes, building links with stakeholder community via the formation of a stakeholder committee, presentation of work at relevant conferences, setting up of a project web site and an open project web site.
Enhancements to XRI to include quadrature and dynamic operation (deliverable: working instrument)
Uncertainty budget and conceptual design for single and two-crystal XRI constructions (deliverable: report)
Detailed design and construction of a platform for accommodating an AFM (deliverable: instrument)
Development of a compact AFM head being capable of measuring in both, contact and non-contact modes (PTB are leading this partner with minor input from NPL) (Deliverable: instrument)

Input into design of test standard (deliverable: test standard)

Verification of performance; initial measurements will be made to verify the performance of each component of the system and then the performance of the whole system will be verified. This will require sample gratings with known periods albeit known over a small range. This information can be fed into a final uncertainty budget based on actual measurements. (Deliverable uncertainty budget)

Measurements of grating structures and comparison with other methods
The local period of grating samples produced within the project are to be measured over micrometre distances prior to translation over distances of several hundred micrometres. This will allow local values of grating period to be mapped over a 1 mm range. (deliverable: set of measurements)
for contractual and administrative purposes, this project will be split into a £208k matching co-funding project, with the balance contained in a separate project

Project No.	EFM11013	**Price to NMO**	£341k
Project Title	AFM Metrology to support UK nanoscience	**Co-funding target**	£200 k from EMRP
Lead Scientist	Andrew Yacoot	**Stage Start Date**	October 2011
Scientist Team	Andrew Yacoot, Matthew Tedaldi	**Stage End Date**	September 2014
		Est Final Stage End Date	September 2014
Sector	100% Traceability & uncertainty	**Activity**	60% NMS infrastructure: 40% Challenge driven R&D

Summary

There are several aspects of this project all working towards providing a metrological infrastructure for AFMs enabling reliable, traceable measurements to be made using both metrological and commercial AFMs at NPL, universities and in industry. These aspects include, a new head for the metrological atomic force microscope, (MAFM), strategies for faster scanning including intelligent AFM sampling, the assessment of crystalline standards as nanometre calibration standards and a fundamental understanding of the properties and theory of AFM operation and how they affect instrument performance. The project will result in greater confidence in AFM metrology, best practice of operation, input to ISO standards, greater efficiency of use and lower measurement uncertainty.

The Need

There are several hundred AFMs in use in the UK in areas as diverse as micro manufacturing, healthcare, defence, aerospace, photonics, materials science, biotechnology, pharmaceutical and agriculture. The majority are not calibrated and give inaccurate results. The NPL Metrological AFM (MAFM), via calibrated transfer standards, provides a guarantee of traceability for UK AFM users. Many additional factors (tip shape, tip sample interactions, operating parameters) affect AFM performance. A fundamental study is required to improve reliability and give greater confidence in these instruments. AFMs and in particular metrological AFMs have slow image updating rates (typically 0.01 Hz). With the increase in object sizes, new strategies and characterized transfer standards are required for intelligent sampling that targets the region of interest. To meet future requirements of nanotechnology, The CCL Working Group on nanometrology has proposed feasibility studies to assess the potential of crystalline standards as calibration standards at the nanometre and sub nanometre level. These standards need to be traceably measured and their long term stability determined. All this work is necessary to underpin future developments in AFM such as 3D AFM. The need for this work is also recognized at a European level and is aligned to four EMRP Potential research topics submitted in collaboration with other NMIs. The current MAFM head is no longer supported by the manufacturer and is in urgent need of replacement.

The Solution

The construction and characterization of an NPL designed AFM head for the metrological AFM that is compatible with the current MAFM platform. An investigation of tip sample interactions and their effects on dimensional metrology and more accurate determination of AFM tip shape and tip wear. The characterization of three dimensional (3D) AFM transfer standards using the MAFM and intelligent sampling strategies will increase data acquisition rates. A UK intercomparison using MAFM calibrated step heights and gratings to highlight problems associated with uncalibrated AFMs used in the UK.

Project Description (including summary of technical work)

A comparison will be organized and made open to UK AFM Users. A new head for the metrological AFM will be developed. The improved NPL interferometer system will be used to servo control the MAFM stage, rather than the intrinsic capacitance sensors. This will allow equally spaced data points to be acquired and the direct compensation of system drift. This development will enable better characterization of the scanning stage and the mapping of local stage errors and uncertainty in stage position. Routines for intelligent data sampling and fast data acquisition will be developed. A methodology will be developed for the calibration of 3D artefacts in collaboration with the artefact manufacturer so that their calibration can be offered by NPL.

4 The effects of tip sample interactions on lithographically produced structures will be continued, via the PhD student at Manchester.

Impact and Benefits

The AFM is the most widely used tool in the nano world with applications including imaging, manipulation and measuring, all of which will be underpinned by the improve metrology from this project. The proposed work aligns to requirements for AFM metrology highlighted in the recent EU funded Co-NanoMet project and will deliver improved AFM metrology for the UK that leads to compliance with ISO and quality assurance. Specifically: the

availability of more valid and robust AFM measurements for users in all sectors that use AFMs, input into future ISO standards via a better understanding of basic AFM performance and of tip sample interactions. The calibration of crystalline standards will provide a set of directly measurable nano transfer standards. The developments in fast scanning AFM and three-dimensional standards are a precursor to the development of 3D AFM.

Support for Programme Challenge, Roadmaps, Government Strategies

The Royal Society has highlighted the critical need for improved nanometrology. This project will enable the UK to contribute and take the lead in developing ISO standards in this area. ISO TC201/SC9 (SPM), TC229 (nanotechnologies) and TC213 (dimensional) have highlighted the need for valid methods and standards in dimensional metrology and AFM tip shape measurements.

Synergies with other projects / programmes

The work build on work from previous AFM projects within Engineering Measurement, aids the NMS project on optical interferometry and will link in with proposed EMRP projects on (i) tip sample interactions, (ii) low force metrology, (iii) fast scanning AFMs, and (iv) traceability for crystalline standards. The work on fast scanning AFM will be done in collaboration with the Analytical Science team via an EMRP project. The crystalline standard work will benefit from work done within EMRP projects NANOTRACE and Scatterometry as well as making use of the x-ray interferometry facility at NPL.

Risks

Damage to equipment, lack of available staff, lack of suitable laboratory for the XRI

Knowledge Transfer and Exploitation

Refereed publications, UK and international conferences presentations, good practice guide, ISO standards. Increased industrial awareness of AFM metrology leading to further collaboration. Dissemination through IMPACT work packages in EMRP projects. There is potential for a workshop at NPL after the industrial comparison.

Co-funding and Collaborators

The following organisations have indicated their willingness to support the project (outside of any EMRP), Queensgate Instruments, PTB, CMI, University of Manchester (current PhD student), University of Ilmeanu (Germany), M2C (supplier of 3D calibration standards). In addition further collaboration will be possible if the EMRP applications within the New technologies call are successful.

Deliverables

1	**Start: 01/10/1011**	**End: 30/09/2014**	

Deliverable title: Enhanced Metrological AFM

Deliverables include a new AFM head, routines for fast scanning and intelligent data sampling, a report/paper on comparison of AFM tip shape determination methods, improved knowledge of tip sample interactions, routines for examination of 3D calibration artefacts. A report on UK comparison of AFM measurements.

Project No.	EFM11033	**Price to NMO**	£ 205k
Project Title	Traceable Dynamic Measurement of Mechanical Quantities - Co-Funding for EMRP JRP20i	**Co-funding target**	This project cofunds an EMRP project valued at £171k
Lead Scientist	Andy Knott	**Stage Start Date**	Oct 2011
Scientist Team		**Stage End Date**	Sept 2014
		Est Final Stage End Date	
Sector	50% High Value manufacturing: 50% Process Control	**Activity**	70% NMS infrastructure: 30% Challenge R&D

Summary: This project cofunds the EMRP JRP20i "Traceable Dynamic Measurement of Mechanical Quantities". This is drawn from the parent NMS project GS001 FR05 "Dynamic Pressure Traceability for industrial Measurement ". This has been placed in Contract ENG&FLOWKB_NMS-EFM11 due to its extended end date.

The Need: In aerospace, medicine, production, transport or process controls, measurements are generally performed under dynamic conditions and often by use of automated systems. In addition, increasingly complex measurement configurations require the characterisation and the realisation of mechanical multi-component measurements. Traceable dynamic measurements should cover periodic and shock-like excitation for different measurands with large range of amplitude and frequencies, with decreasing uncertainty. High-speed data acquisition and modelling are necessary to develop advanced dynamic and/or multicomponent measurements.
With important applications in car industries, in engineering, in petrochemical and pharmaceutical industries, but also for elaborations of specific materials, the developments of new high pressure technologies and standards are required.

The Solution:
At present there are no traceable validated methods for generating known dynamic pressure signals that can be used to calibrate reference transducers. This project will carry out the novel research required to allow traceability to be achieved, including specifically the use of shock tubes as calibration tools and methods of modelling shock tube waveforms and other dynamic pressure signals.

New systems capable of generating specific pressure waveforms will be designed, commissioned, and used to calibrate industrial transducers against the reference transducers characterised in the primary systems. Dissemination of the results of the proposed research will not be possible without such developments.

Project Description (including summary of technical work):
The aim of the project is to create dynamic pressure standards as follows:
Primary Dynamic Pressure Standard - A shock tube based system capable of generating pressure steps of known magnitude and dynamic content will be developed – these steps will be used to provide primary traceability for fast-acting pressure transducers. The effect of diaphragm design, boundary layer formation, and temperature variations on the duration and integrity of the step, together with equipment vibration on the sensor output, will be investigated. Part of the commissioning of the system will involve comparisons with existing Cranfield gun tunnel and other international facilities, both at NMIs and within industrial laboratories. The performance of a range of transducers and associated instrumentation within the system will be characterised to ensure its fitness for purpose.
Secondary Dynamic Pressure Standard - The existing pressure generator will be developed into a national secondary pressure standard, taking traceability from the primary standard via high quality reference transducers. The functionality of the system will be enhanced, enabling a high frequency pressure waveform to be superimposed on a steady state or slowly varying pressure level, to help meet the requirements of the gas turbine industry.

Impact and Benefits: The NMIs and stakeholders participating in this project will benefit directly. NMIs will be able to provide new primary dynamic calibration services. The industrial stakeholders will employ the results for their development of new transducers or commercial calibration systems specifically designed for dynamic calibration. Specifically in pressure measurement, benefits are seen as follows.
1. In-cylinder pressure measurement in combustion engines is a highly dynamic measurement task. Completion of the dynamic pressure measurements work package in this JRP will make possible the design of more efficient engines which has direct **environmental** impact. One could expect reduction of CO_2 emissions and in fuel consumption with associated **financial** savings. Reduction of CO_2 emissions can also be viewed as a social impact by improving air quality.

2. Providing accurate dynamic pressure signals improves efficiency of test procedures and hence reduction of resource consumption (**environmental** and **financial** impact), and it helps to increase the safety in areas such as aviation and road transport due to more reliable test procedures.

Support for Programme Challenge, Roadmaps, Government Strategies:

As per project FR05 "Dynamic Pressure Traceability for industrial Measurement". Participation in this EMRP project provides the NMS with new, accelerated routes for exploitation of NMS funded technology at no cost to the NMS and is fully aligned to the NMS strategy.

Synergies with other projects / programmes:

As per project FR05 "Dynamic Pressure Traceability for industrial Measurement".

Risks:

As per project FR05 "Dynamic Pressure Traceability for industrial Measurement".

Knowledge Transfer and Exploitation:

As per GS001 FR05 with additional activity as an EMRP project, the outputs of which will be made publicly available through publications of scientific papers and internet-based, downloadable software. Exploitation of knowledge through the international standardization and communication to industrial community.Results will be available to the project partners immediately, followed by industrial companies, other international NMIs and end users.

Co-funding and Collaborators: The EMRP project will provide £171k over three years. The consortium is led by PTB and includes LNE, MIKES, CEM, SP, INRIM and Tubitak. Industrial support has been achieved from Porsche, VW, Hottinger Baldwin Messtechnik and Scandura Instrumentation

Deliverables

1	**Start: 01/10/11**	**End: 30/09/12**	

Deliverable title: This is a cofunding project. Refer to deliverables on Project FR05

Project No.	EFM11016	**Price to NMO**	£400k
Project Title	HiTeMS – Co-funding for EMRP 28i	**Co-funding target**	£340k
Lead Scientist	Graham Machin	**Stage Start Date**	01 Sep 11
Scientist Team	Graham Machin, Jon Pearce, Claire Elliot, Dave Lowe	**Stage End Date**	31 Aug 14
		Est Final Stage End Date	31 Aug 14
Sector	40% High value manufacturing: 35% Process control: 25% Traceability & uncertainty	**Activity**	50% Challenge driven R&D: 50% NMS infrastructure

Summary

The measurement of temperatures above 1000 ºC is both difficult and yet vital for the success of a wide range of industrial processes (e.g. aerospace/space (~1300 - 3000 ºC), nuclear fuel production and essential nuclear safety testing (~1800 ºC->2500 ºC), refractory metals production (2500+ ºC), silicon carbide, carbon/carbon composites (to >2800 ºC) and iron, steel, glass and ceramics manufacture (1100 to 2000 ºC)). The overall objective of this project is to develop a suite of methods and techniques for improving the measurement of high temperatures in industry on a broad front in a coherent and comprehensive way.

The Need

The state of the art in industry is the use of type N thermocouples (<1250 ºC), type R, S or B thermocouples <1700 ºC, and W/Re temperature refractory thermocouples are used above that. Non-contact thermometry is used over the whole range. All thermocouples are known to drift, often unpredictably, leading to the need for regular scheduled replacement. For example, W/Re drift quickly (>50 ºC), embrittle in place and cannot be routinely removed for re-calibration. Non-contact thermometers usually control industrial processes through a window that often experiences progressive contamination and cannot be easily changed. Both issues can lead to processes running too high, leading to higher emissions and excess energy use and the need for costly process shut-down. This project aims to make step change improvements in high temperature measurement for the benefit of all enterprises where high temperature processing is important. This work covers a broad spectrum of enterprises, and requires high-level metrological expertise and as such is best carried out by an NMI.

The Solution

In short this project will:

1) Produce working demonstrator self validating sensors to 2000 ºC through the incorporation of known temperature references within special thermocouples – this is a capability never demonstrated before at these extreme temperatures
2) Development of the methodology for *in-situ* correction of radiation thermometers viewing through contaminating windows. A known "driftless" temperature reference (a high temperature blackbody) will be used to develop a highly stable radiance against which the transmission of a progressively contaminated window will be determined.
3) New metrological capability for the low uncertainty assessment of reference functions of high temperature thermocouples. This is a significant undertaking as currently no capability exists for this assessment in Europe.

Project Description (including summary of technical work)

Deliverable 1: High temperature fixed point (HTFP) materials will be identified and crucibles designed and constructed. Ingots will be cast and a metrological assessment including the assignment of a traceable temperature performed. These will form one of the temperature references required for deliverable 2 [other temperature references provided by HiTeMS project partners].
Deliverable 2: Construction of cohort of four non-standard Ir-Ir/Rh thermocouples, including annealing and selection of appropriate insulation. Two aged according to agreed process and then determine the thermovoltage at the HTFPs (deliverable 1 at NPL) and intermediate temperatures (by HiTeMS partners). This is repeated to assess the stability of the reference function and assign a realistic uncertainty. New capability for the low uncertainty determination of non-standard thermocouple reference functions at high temperatures of which NPL's HTFPs (deliverable 1) will be a critical part.
Deliverable 3: Materials compatibility studies for contact thermometers and the construction of miniature HTFPs for self-validation studies ~2000 °C . Compatibility tests of self validating MIMS thermocouples with integrated miniature HTFP crucibles at temperatures ~2000 °C, including assessment of improvement of traceability possible using these thermocouples.
Deliverable 4: Design & construction of *in-situ* of HTFP for self-validation studies. Measurement of window transmission using HTFP and development of a novel correction technique for industrial non-contact temperature measurements through windows.

Impact and Benefits

Deliverable 1&2: Establishment of new capability for the determination of reference functions for non-standard thermocouples at high temperatures. Since no such dedicated capability exists, this leads to significant advance beyond the state of the art. The lack of reference functions restricts uptake, even though they could be of great use in specialist industries. Exotic thermocouples have poorly determined reference functions with uncertainties ~5-10 ºC, the aim is to radically improve this to ~1-2 ºC.
Deliverable 3: Self-validating contact thermometry sensors for above 2000 °C. There are no high temperature sensors with self-validating capability at these extremes. The outcome of this WP is to have qualified methods that will make a x10 improvement in high temperature thermometry, from current levels of 20–50 ºC uncertainty when using W/Re thermocouples.
Deliverable 4: Novel correction methods for non-contact thermometry to > 2500 °C. Many industrial processes are controlled using radiation thermometry. This often necessitates viewing the process through a window that is progressively getting dirty; this can often lead to errors >50 ºC too low. Here we develop validation methods based on HTFPs that can potentially be

implemented *in-situ*. By implementing this approach optimal process control can be maintained.

Support for Programme Challenge, Roadmaps, Government Strategies

This project directly addresses the overall target of the E&F Programme: temperature roadmap of "Step change improvement in high temperature thermometry in harsh environments". This is done in support of advanced manufacturing in for eg aerospace, metals production and processing, improved energy efficiency through better process control (and so lower carbon emissions), improving competitiveness through optimising energy use, improved product quality and facilitating zero waste manufacture.

Synergies with other projects / programmes

The temperature team is embarked on an ambitious long-term programme of research to improve high temperature thermometry on a broad front from the top NMI level of scale realisation and dissemination to practical thermometry in industry by for example thermocouples and radiation thermometers. Projects that are currently underway that this work is directly dependent upon are: High temperature fixed points (HTFPs) for the new high temperature scale (TH9), Next generation thermocouples to 1500 °C (TH8) and Self validating, ultra-high temperature and novel thermocouples (TH11). The overall aim of this project is to make NPL the European hub for industrial high temperature measurement solutions.

Risks

This is a challenging three year programme of work – because it is partly dependent upon the HiTeMS consortium partners. This risk is reduced by having multiple NMIs to supply the requisite facilities/expertise.

Main technical risks are: 1) The thermocouples chosen are not stable enough to develop stable reference function. Mitigated by a) experts in thermocouple construction in project b) choice of a well known non-standard thermocouple c) limiting top temperatures to only those necessary. 2) Miniature HTFPs not compatible with any thermocouples to 2000 °C. Mitigated by a) using materials experts knowledge at NPL, b) if necessary limiting the top temperature to less than 2000 °C.

Knowledge Transfer and Exploitation

Dissemination will be through papers and conference presentations. Three conferences offer excellent opportunities; these are Temperature Its Measurement and Control in Science and Industry (TS2012), Metrologie 2013 and Tempmeko 2013. Annual reports will be made on the progress of this project to Euramet TCT and CCT. At least one lecture/year will be given at major tradefairs and trade magazine articles will be written eg in Power and Process Engineering. Finally, a project specific website (for HiTeMS) will be developed and hosted by NPL. Beneficiaries are the many companies that measure high temperatures.

Co-funding and Collaborators

The co-funding for this project comes in two kinds. £320k cash over three years from the EMRP HiTeMS project.

There is also in-kind cofunding in time, supply of materials and facility access from collaborators with the HiTeMS project eg Johnson Matthey will supply Rh/Ir thermocouple wires (worth £10-20k), others will undertake on-site testing using their facilities. Collaborators with the EMRP project include 9 NMIs and unfunded industry partners CEA, E+H, GDF and MSS.

Deliverables

1	**Start: 01/09/11**	**End: 31/08/14**	

Deliverable title: New ultra-high temperature high temperature fixed points (HTFPs) for thermocouple assessment

This will cover the construction of two HTFPs above 1500 °C, for determining metrological quality reference functions of non-standard high temperature thermocouples (required for deliverable 2). These will be two from the following HTFPs; Pt-C (1738 ºC), Cr_3C_2-C (1826 ºC) or Ru-C (1953 ºC). HTFPs, at these temperatures, have never been used before for thermocouple reference function assessment. *Evidence*: Two HTFP fixed points above 1500 °C with technical paper describing performance submitted

2	**Start: 01/09/11**	**End: 31/08/14**	

Deliverable title: Establishment of facility for metrological reference functions of non-standard high temperature thermocouples.

The aim is to determine low uncertainty reference functions of non-standard thermocouples, (using Ir-Ir/Rh[1] as a case study) between 1100°C and ~2000 °C. The HTFPs developed in deliverable 1 will be used, in part, to determine the reference function of these thermocouples. *Evidence*: Two papers published describing a) facility for reference function determination b) reference function of Ir-Ir/Rh thermocouples

3	**Start: 01/09/11**	**End: 31/08/14**	

Deliverable title: Self-validating thermocouple demonstrators developed to 2000 °C

The aim of this work is to develop reliable self-validating contact thermometry sensors for establishing traceability up to ~ 2000 °C. Two miniature HTFPs usable with MIMS thermocouples will be constructed and their performance investigated by applying repeated melting/freezing cycles including long-term measurements in a furnace. *Evidence*: Paper describing results of study of two self validating MIMS thermocouple demonstrators up to ~2000 °C

4	**Start: 01/09/11**	**End: 31/08/14**	

Deliverable title: Development of a novel correction technique for industrial measurements through contaminating windows.

This task is a proof of concept study to use HTFPs to determine the window transmission change and develop a correction algorithm to be used *in-situ*. *Evidence*: Submitted paper describing experiments, results and correction algorithm

[1] Wires supplied FOC by Johnson Matthey

Project No.	EFM11018	**Price to NMO**	£232k
Project Title	Improved air temperature traceability – Co-funding for EMRP 02e	**Co-funding target**	
Lead Scientist	Stephanie Bell/Michael de Podesta	**Stage Start Date**	Oct 2011
Scientist Team		**Stage End Date**	Sep 2014
		Est Final Stage End Date	
Sector	50% Process control; 40% Traceability & uncertainty: 10% Climate change	**Activity**	100% NMS infrastructure

Summary – This project, in its entirety, is used as the co-funding project for EMRP JRP02e "Metrology for pressure, temperature, humidity and airspeed in the atmosphere"
NPL will become a centre of excellence for traceable air temperature measurement, linked to meteorological and climate research communities. An extended air temperature calibration capability, to be built on existing services.

The Need User needs for improved air (gas) temperature measurements and traceability are detailed in *NPL REPORT ENG 11*. Applications include air conditioning; climate research; processing, storage and testing of diverse products; chemical engineering, various areas of metrology, fuel gas transportation, stack emission monitoring and monitoring of environments generally. Better accuracy is needed in precision metrology applications, such as dimensional metrology and dew-point generation (gas temperature is critical for accurate humidity generation and measurement, especially at a range of flows and pressures). Climate science requires temperature measurements in a wide range of conditions from nearly still air-to-air moving at 100 ms^{-1} and with a range of humidities.

Current State of the Art (NPL and elsewhere)
Air temperature sensors are prone to influences such as self-heating, thermal/solar radiation, stem conduction and other heat transfer problems, which tend to be worst in gas media.
There is considerable UK air temperature expertise (e.g. Reading University, and *Facility for Airborne Atmospheric Measurements* (FAAM)), but the measurements are problematic and lack sound metrological traceability. Difficulties are particularly acute for airborne measurements on sondes and especially aircraft, where additional thermodynamic and aerodynamic corrections are needed. The effect of condensation on existing sensors is critical. The *Global Climate Observing System* (GCOS) report into the requirements for reference measurements for climate (GCOS-112, April 2007) states:
"Shortcomings in the…current upper-air measurement network greatly limit the accuracy and detail of observations needed to specify how climate has varied…This deficit impacts our ability to accurately predict climate change, and hence has potentially serious consequences in areas of high relevance to society…There is no clear consensus that the technology to deliver such monitoring of … even solely temperature and humidity … from the surface to at least the middle stratosphere currently exists." At present, air temperature sensors are typically calibrated by immersion in stirred liquid baths to obtain the smallest uncertainties. They are then used in free air, with little or no allowance for errors caused by usage in different thermal media. The impact of the difference in heat exchange between liquid and gas can be up to several tenths of a degree.
NPL and others carry out some temperature calibrations in air, but without control of key variables that should inform calibration, characterisation and use of air temperature sensors.

The Solution In indoor ambient/laboratory regimes, the requirement is understood. This can be met by providing air temperature sensor calibrations that are relevant to conditions of use of thermometers in a range of gaseous media, where there may be variations in flow, pressure, thermal radiation and other gas conditions not represented in liquid calibration baths. Results would be used to raise awareness of thermometer performance and measurement uncertainties in air or other gases.
For atmospheric monitoring, specialised solutions to air temperature measurement and traceability will be proposed. These must take account of: Continuity with historic approaches to ground-based observations of air temperature, and the challenging measurement conditions of aircraft-borne measurement. As a first step, a study will be completed to identify how to correctly address these problems.

Project Description (including summary of technical work) The project comprises 2 work areas:
Development of an improved facility for temperature calibration in air, with the ability to vary airflow rates and other parameters while maintaining thermal equilibrium. Gas sample housings and/or radiation shields, and air velocity measurements will be introduced to provide previously unknown detail of temperature sensor performance.
Dissemination of results to promote adoption of appropriate methods and uncertainties for air temperature sensors.
Participate in EURAMET Project 1061 *Comparison of air temperature sensor calibrations.*
Study of two aspects: 1) Theoretical modelling of heat transfer between a thermometer and flowing gas under various conditions. 2) Study capturing UK user needs, taking account of pre-existing technologies, and suggesting future work packages with optimal impact.

Metrology Capability to be delivered

A facility for temperature calibration and testing in air, separately or in conjunction with humidity calibration. Air temperature range at least 0 °C to 65 °C with the ability to vary conditions of airflow (from 0 to at least 3 m s^{-1}) and potential to vary some or all of: thermal radiation, flow regime (turbulent/laminar), and possibly other parameters. A modelling capability will also be developed to address points such as hydrodynamic corrections due to pressure drop and viscous heating of moving air.

Impact and Benefits More reliable air temperature measurements and calibrations with realistic uncertainty relevant to gas environments for demanding applications in laboratories, industry and research. Impact will include improved confidence in meteorological measurements and improvements in understanding of important climate phenomena such as global warming, and cloud formation and stability.

Within the project time frame, we propose to provide extra data to existing customers on a trial basis – free to the user. This will increase awareness, provide immediate benefit, and explore the market for "smarter" air temperature calibrations. If this work can contribute to reliable observation of global warming, there are enormous economic and life quality benefits.

Support for Programme Challenge, Roadmaps, Government Strategies *Support for Programme Challenge*

Programme Challenge: Environmental Sustainability: Provide measurement technologies that support the ability to monitor the environment and mitigate climate change. "Measurements for the Environment" is an NPL priority area — with strategic focus on 'traceable and efficient measurements for climate change'.

Government Strategy: Environmental sustainability sector: Climate change, Pollution control and monitoring. High value manufacturing sector: Low carbon. Underpinning metrology: A trusted and internationally harmonised system of measurement to underpin the economy, regulation, quality of life, science and innovation

Synergies with other projects / programmes Both new measurement capability and theoretical modelling are relevant to all humidity projects e.g. C 'Multi-gas multi-pressure humidity calibration'

Risks Technical risk – improved air temperature facility is novel: few NMIs only are putting similar provisions in place. **Mitigation**: Cooperation inter-NMI and with instrument companies.

Study may show weather/climate monitoring problems to be intractable. **Mitigation**: Option to stop weather/climate work after study/modelling.

Knowledge Transfer and Exploitation Enhanced NPL calibration service for temperature calibration in air, and possibly other improved humidity standards. Potential dissemination of techniques and services to other (UKAS) calibration labs. Feedback to customers, makers of climatic/calibration chambers, and suppliers of air temperature sensors. Journal/conference publication and proposed workshop meeting (with Reading University).

Co-funding and Collaborators Reading University's *Walker Institute for Climate System Research* brings access to world leading meteorological expertise. *Facility for Airborne Atmospheric Measurements* at Cranfield FAAM: gives access to an airborne test facility and links to the main research teams throughout the UK. Collaboration in EMRP Project 1061 (approx 15 European NMI participants) studying the issues around calibration of air temperature sensors. Collaboration also expected from instrument suppliers and will also liaise with high-level users of air temperature measurements, and calibration labs.

Deliverables

1	**Start: 01/10/2011**	**End: 30/09/2014**	

Description: Description: Develop facility for temperature calibration in air with ability to vary parameters such as airflow to enable characterisation of performance of air temperature sensors. Investigate/compare the performance of the most common types of air temperature sensor in varying conditions.

Evidence: An improved air temperature calibration facility that will provide information on the performance of probes in varying conditions. Report of findings for sensors.

2	**Start: 01/10/2011**	**End: 30/09/2014**	

Description: Theoretical report & modelling work. This study will show how to establish traceability from the indicated thermometric reading to thermodynamic temperature in flowing air regimes of interest.

Assessment of user requirements. Study capturing user requirements for range of air conditions and measurement technologies for climate and weather observations. Suggestions for future work packages with optimal impact.

Evidence : Two NPL reports. Presentation at meeting of project partners. Proof of concept experiments using ultrasonic anemometer will also be carried out.

Project No.	EFM11034	**Price to NMO**	£97k
Project Title	Practical acoustic thermometry – TH1 Part B	**Co-funding target**	£70k
Lead Scientist	Michael de Podesta	**Stage Start Date**	October 2012
Scientist Team	Radka Veltcheva, Gavin Sutton, Robin Underwood	**Stage End Date**	September 2014
		Est Final Stage End Date	
Sector	40% Energy generation: 30% Advanced instrumentation: 30% Traceability and uncertainty	**Activity**	100% NMS infrastructure

Summary –NPL will develop a new temperature sensing technology which meets the need for durable thermometry in harsh environments, particulalry at high temperature and in radioactive environments. The project was originally approved at 2011 Decision Conference (as TH1). Subsequent to the award of the EMRP NOTED project, TH1 was restructured to provide cofunding, leaving deliverable 4 to be set up as this separate project. This project will be delivered alongside the Noted EMRP project and the combined outputs are described here.

The Need

The long term monitoring of the temperature measurement of radioactive waste is currently a problem with no solution. Next generation nuclear power plants need temperature sensing to 1200 °C, this technique would fulfil that need being insensitive to the hostile radioactive environment. Another application concerns the deployment of Solid Oxide fuel cell power plants currently being planned. These require, 1°C temperature drift over 5 years. There are many other examples in which industrial processes depend critically on temperature in which calibration costs could be reduced, and robustness & accuracy improved

The Solution

From –266 °C to 250 °C, acoustic thermometry is the most accurate technique of primary thermometry ever devised. Developed in the 1980s at NPL and NIST and now in development at several NMIs (NPL, NIST, LNE, INRIM) its current implementations use specially crafted resonators confined to laboratory use as a calibration reference. The systems are used to calibrate PRT's, which 'carry' the temperature scale in practice. However, the acoustic thermometry technique is not used in practice in any industrial or scientific environment.

At NPL we have conducted preliminary experiments. These trials have necessarily been incomplete but indicate that practical sensors are possible. Specifically, close to room temperature, millikelvin temperature resolution is achievable. Operation up to 700°C has been demonstrated (with unknown uncertainty) and measurements to over 1000 °C are probably achievable.

The solution is to build on the current understanding of acoustic thermometry and construct a device, which can be used practically at a wider range of temperatures and at lower cost while retaining many of the advantages of acoustic thermometry i.e. sensitivity and a simple physical principle of operation. This can be done by exploiting the ability of tubes (metal, plastic or ceramic) to act as acoustic waveguides. The speed of sound through the waveguide (as measured by the time-of-flight of a sound pulse) is a measure of the average temperature along the length of the waveguide. The waveguide (typically 10 mm diameter) can be many metres long and bent smoothly around any object. A second waveguide (or reflections from a discontinuity in the interior of the waveguide) can be used to extract localised timing/temperature information. Thermal expansion of the waveguide can be either measured with microwaves or inferred from known data. Waveguide attenuation can be measured and used to apply a small correction to the measured speed.

We will build and calibrate a prototype device capable of operating from 0 °C with an upper temperature target of at least 1000 °C with an uncertainty below 1 °C and a measurement resolution of <0.1 °C across this range. Long term stability tests will be undertaken by comparison with one or more calibrated thermocouples.

Project Description (Practical Acoustic Thermometer parts A and B)

- Theoretical work with acoustics modelling & development of multi-path correction technique called the Maximum Length Sequence (MLS) algorithm
- Construction of demonstrator incorporating MLS algorithm
- Long term stability test of acoustic thermometer through extended exposure to high temperatures
- Identification of Industrial Partners

- Construction of prototype customised for use at partner site.
- Report with exploitation plan

Impact and Benefits

Many specific benefits of a robust temperature measuring device with low uncertainty and low calibration overhead. As mentioned above, likely initial beneficiaries will be in radioactive waste handling and other heavy industrial processes.

This technique aims at taking a primary thermometry method, acoustic thermometry, and turning it into a practical temperature sensing method. It will be of value for users for whom confidence in temperature measurement is critical to their application, and for whom pre-emptive sensor calibration and replacement is a significant burden, or even not possible. For example, if this technique were implemented in a radioactive environment, there would be no sensor to be replaced and calibration would not be required. In the case of storage of radioactive waste where it might be hoped to store waste indefinitely, this technqiue would allow remote temperature monitoring without any need for degradable sensors or electronics to be placed in the radioactive environment. In an industrial environment, the sensor is enormously more robust than a PRT or and would not need to be calibrated after initial installation.

Support for Programme Challenge, Roadmaps, Government Strategies

Energy generation and utilisation: Need for technologies that facilitate a secure sustainable energy supply. Advanced Manufacturing: Accelerate the shift to high-value manufacturing

Energy Generation & Supply sector: Low carbon energy, and affordable and efficient energy supply. High value manufacturing sector: Low carbon, and demand led innovation.

Synergies with other projects / programmes

The project exploits knowledge & personnel from the 'NMS Pathfinder Programme' working on measurement of the Boltzmann Constant and Acoustic thermometry. It also exploits knowledge from 'NMS Acoustic and Ionising Radiation Programme'.

Risks

Preliminary work has reduced the risk of a major technical flaw, but it may be that such a flaw still exists. At low temperatures we have not yet implemented the MLS algorithm. At high temperatures we may uncover unusual phenomenon associated with non-linear averaging of the time-of-flight, or problems akin to refractive index matching where propagation on the waveguide may be affected by steep temperature gradients.

We believe there are technical solutions to these problems, but delivery or anticipated ranges of operation may be affected.

It may not be possible to find project partners with suitable projects.

Knowledge Transfer and Exploitation

The project has many possible routes for exploitation beyond papers and possible IP. If successful, the best strategy would be to find a industrial instrumentation company to either licence the technology or to partner with in some other way.

Co-funding and Collaborators

A bid (for £60k) has been submitted to the EMRP – Energy call for acoustic thermometry to be used for in-pile temperature validation studies. In addition, in the latter stages of this project, we would expect industrial partners to make a considerable in kind contribution. This project activity is included in a proposed research topic (PRT) entitled "Novel dissemination routes for temperature" submitted to the EMRP SI Broader Scope 2011 call.

Project partners have not yet been identified. Possible partners would include the *Nuclear Decommissioning Agency* and *Sellafield*. Preliminary contacts have been made with both these organisations.

Other organisations with a need for robust temperature measurement will be sought in the fields of chemical engineering.

Deliverables

1	**Start: 01/10/2012**	**End: 30/09/2014**	

Description: Aid uptake of acoustic thermometry through the development of a demonstrator acoustic "dry block calibrator" prototype for calibrating/comparing conventional contact thermometers with an acoustic technique in the range 0 °C to 100 °C.

Evidence: Existence of the prototype

Project No.	EFM11036	**Price to NMO**	£383k
Project Title	Co-funding for EMRP S07 MeP Kg	**Co-funding target**	£282k (EMRP) + £1.5m (for other partners + EMRP)
Lead Scientist	Stuart Davidson	**Stage Start Date**	1 June 2012
Scientist Team	James Berry, Michael Perkin	**Stage End Date**	31 May 2015
		Est Final Stage End Date	
Sector	50% traceability & uncertainty, 50% extension of SI	**Activity**	90% NMS Infrastructure; 10% International obligations

Summary

The unit of mass, the kilogram, is the last of the seven base units of the International System of Units (SI) to be defined in terms of a material artefact rather than by relation to an invariant of nature. Progress is being made towards a redefinition in terms of the Planck constant (h), realised via the watt balance and Avogadro experiments. The work outlined here addresses the requirements for NPL (and other NMIs) to put in place a practical means of implementing traceability to the redefined kilogram and continuing to maintain the national mass scale and provide traceable calibrations for end users.

The Need

The development of a practical means of traceability between a new definition and the (current) mass scale is necessary both for the initial fixing of a value of the Planck constant with relation to current scale (the International Prototype Kilogram) in order to redefine the mass unit and for the dissemination of the unit following redefinition with reference to the fundamental realisation (in vacuum). Both the watt balance and Avogadro experiments are designed to realise the kilogram under vacuum conditions. The current definition of the unit is realised via the International Prototype Kilogram (IPK), which is kept and used in air. In order to set the value of the Planck constant (*h*) with relation to the current mass scale a means of linking the mass of the IPK in air with a mass in vacuum must be realised. Once the Planck constant is fixed and the kilogram is redefined the unit of mass will be realised in vacuum via the watt balance and Avogadro experiments. It is therefore also necessary to consider traceability from the realisation in vacuum to the mass scale in air. Both the fixing of *h* and the subsequent dissemination of the redefined unit must be achieved at the lowest possible level of uncertainty to maximise the benefit of the redefinition to the mass user community.

The Solution

- To develop and evaluate artefacts suitable to provide maintenance and dissemination of a redefined kilogram
- To provide appropriate procedures and techniques for the mass transfer between vacuum and air
- To evaluate surface parameters and dynamic changes on the artefact surface between vacuum, air and selected gas atmospheres
- To evaluate the mass stability of artefacts with a focus on the storage, cleaning and transport methods used
- To identify and evaluate the uncertainty components inherent in the mise-en-pratique and in their propagation through the dissemination chain.

Project Description (including summary of technical work)

- Develop and evaluate artefacts suitable for the determination of the Planck and the Avogadro constants to provide traceability to the IPK and for the maintenance and dissemination of a redefined kilogram
- Provide appropriate procedures and apparatus for the mass transfer between in-vacuum experiments (watt balance apparatus and vacuum mass comparators) and to in-air experiments (comparison with the IPK and dissemination of the unit to end-users)
- Evaluate the mass stability of suitably stored mass artefacts and develop the metrological infrastructure for the (medium term) maintenance of the mass unit and its dissemination based on different realisations (via a pool of artefacts which may be held at a number of NMIs and key comparisons)
- Develop and adapt surface analysis techniques (e.g. X-Ray Photoelectron Spectroscopy, (XPS), Ellipsometry, Contact Angle Spectrometry, (CAS)) and overlayer models for the accretion of contamination on mass standards (including silicon spheres)
- Develop and validate methods to allow the reproducible cleaning of primary mass standards such as the use of UV activated ozone and gas plasma techniques.
- Identify and evaluate the uncertainty components inherent in the mise-en-pratique and their propagation through the dissemination chain for the kilogram and its multiples and sub-multiples

Impact and Benefits

The outputs of the project will include new procedures and apparatus and next generation mass standards which will allow the implementation and dissemination of the redefined kilogram. This will allow the benefits of the redefinition to be fully realised and ensure the continuity of the mass scale for the end user community. If current trends are followed, in future there will be a growing demand for more accurate mass calibrations which can only be satisfied with reliable traceability to the redefined kilogram at a level of uncertainty commensurate with the requirements of the end users (calibration laboratories, accreditation bodies, legal metrology, high-end industrial users such as pharmaceutical, power generation and aerospace are examples).

Support for Programme Challenge, Roadmaps, Government Strategies

The mass scale underpins Programme Challenge, Roadmaps, and Government Strategies in most key areas. Specifically the redefinition of the kilogram and its successful implantation is key to the future development of the SI. High value manufacturing particularly in areas such as pharmaceuticals relies on the accurate realisation of the mass unit and the dissemination and sub-division of the scale to the milligram level and below. The area of quantitative environmental monitoring relies on the dissemination of the mass scale for a wide range of gas and particulate measurements. Continuity of the mass scale following redefinition is critical for all technical areas which require traceability to the SI unit of mass (force, pressure, humidity, materials measurement, acoustics, biotechnology).

Synergies with other projects / programmes

The work underpins other key areas of NPL's research and measurement services (see above). Synergies with surface studies (ellipsometry and XPS) in the materials area, surface finish (AFM and white light scattering) and low force measurements in the length area.

Risks

This is a highly innovative project involving many partners from different disciplines and organisations. The major risks with this project is that the International partners do not deliver allocated tasks to schedule – this is mitigated by regular contact and appointment of suitable workpackage leaders and by the fact that critical deliverables can be delivered by more than one partner.

Knowledge Transfer and Exploitation

Outputs from this project will be disseminated in the following ways:

- Establishment of stakeholder committee
- Publication of at least 10 peer reviewed papers
- Publication of at least 10 articles in trade journals or popular media
- Presentations at least 9 conferences or technical meetings
- Good practice guide on weighing in vacuum
- Good practice guide on storage of mass standards
- Guide to the impact of the redefinition of the kilogram for end users
- Establishment of JRP website with public access and secure areas

Co-funding and Collaborators

Co-funding has been achieved through the EMRP 2011 call. Project consortium members (those who will accede to the JRP contract) include the following national measurement institutes (NMIs): CEM, CMI, CNAM, DFM, LNE, METAS, MIKES, MIRS, PTB, UME, SMU, and UME. Additionally there is a proposed Researcher of Excellence Grant recipient from the University of Ilmenau. Additionally INRIM and NRC have entered into formal collaboration as unfunded partners for the JRP and the BIPM, Mettler-Toledo, Sartorius and Häfner are registered as collaborators.

Deliverables

1	**Start: 01/06/12**	**End: 31/05/15**	

Deliverable title: Develop a practical means of disseminating the new kilogram

NPL will;

Act as coordinator for the EMRP collaborative project and manage and coordinate the delivery of the JRP

Act as work package leader for WP 4: Evaluation of the mass stability of artefacts with a focus on storage, cleaning and transport methods.

Act as workpackage leader for C6 WP 6: Creating Impact

Characterise new mass artefacts using instrument indentation, AFM measurements, ellipsometry and XPS

Investigate air-vacuum-inert gas transfer methods and analyse effects gravimetrically and with XPS

Design, produce and evaluate apparatus for artefact storage and transfer under vacuum/inert gas

Coordinate an investigation of new cleaning methods for primary mass standards and produce best practice guides

Coordinate a comparison of primary mass standards between vacuum mass comparators and watt balance apparatus

Produce technical papers (at least 4) good practice and general guides and technical presentations.

Project No.	EFM11037	**Price to NMO**	£309k
Project Title	Co-funding for EMRP s12 NOTED	**Co-funding target**	£268k secured
Lead Scientist	Jonathan Pearce	**Stage Start Date**	1 June 12
Scientist Team	Graham Machin, Radka Veltcheva, Claire Elliott, Jayne Gray, Michael de Podesta, Gavin Sutton, Robin Underwood, Richard Rusby	**Stage End Date**	31 May 15
		Est Final Stage End Date	
Sector	100% Extension of SI	**Activity**	100% NMS Infrastructure

Summary

This project is focused on the development of new advanced techniques for providing improved traceability to the kelvin to support its wider and simpler dissemination to the users. The project comprises 3 parts:

- Impurity modelling: The base realisation of the temperature scale, ITS-90, is by contact thermometry using standard platinum resistance thermometers (SPRTs). Development of a method for substantially reducing uncertainty in SPRT calibration service via a numerical method based on the physics of freezing for characterising the effect of impurities.
- Development of a new temperature sensing technology which meets the need for durable thermometry in harsh environments, particularly at high temperature and in radioactive environments.
- Investigation of Au/Pt thermocouples as a replacement of high temperature platinum resistance thermometers (HTPRTs). To be the acknowledged world-leading NMI in our chosen areas of thermocouple thermometry research.

The Need

- **Impurity model**: Top level traceability to reliable temperature is essential for the proper functioning of a modern economy. The first step in reliable temperature measurement in the UK is NPL's realisation of the ITS-90. The largest uncertainty in this realisation arises from the impurities in the pure material fixed points – this is the limiting factor.
- **Practical Acoustic Thermometry (PAT)** : To improve secondary calibrations of contact thermometers, a means of calibration against a thermodynamic temperature sensor is needed eg an acoustic thermometry. This is required to eliminate the numerous problems with precision and traceability of dry-block calibrators.
- **Au/Pt:** ITS-90 scale transfer is a problem between the Al (660 °C) and Ag (962 °C) points currently realised using a HTPRT. KCs not possible using HTPRTs as evidenced by recent Euramet KC[2]. CCT (May 2008) stated active research needed "to improve interpolation devices from Al to Ag to be more robust than HTPRTs."

The Solution

- Impurity model: A radical solution to the problem of reducing the uncertainty due to the impurity content without the need for unreliable chemical analyses. The solution is a practical model derived from a new detailed physics based microscopic model, to determine the impurity content from the shape of the fixed point freezing curve.
- PAT: To improve secondary calibrations of contact thermometers, construction of a secondary 'wet block' calibrator with an inbuilt acoustic thermometer immersed in the liquid that never needs recalibrating. This provides a liquid bath for comparison calibrations against a primary thermodynamic temperature sensor.
- Au/Pt thermocouples are the most likely sensor to replace HTPRTs. These are currently manufactured commercially but achieving optimum performance is not yet understood. The target is a factor of 5 uncertainty improvement.

Project Description (including summary of technical work)

- Impurity model: Development of a numerical model to quantitatively characterise the influence of impurities on the freezing curves of pure materials based on the physics of freezing. Following this, a practical means of correcting SPRT calibrations will be instigated. The team has a strong track record in numerical modelling[3].
- PAT: Construction of demonstrator, with potential to provide primary temperature measurement as an alternative to conventional secondary standard dry block calibrators, initially in the temperature range 0 °C to 100 °C.
- Evaluate suitability of Au/Pt thermocouples aiming to be competitive with HTPRTs by comparing cohorts of both.

Impact and Benefits

- Impurity modelling: This is a core NMI activity and services many different sectors of the UK economy from industrial users to the service sector such as healthcare. Provision is through dissemination of the correction

[2]D. Heyer *et al:* "**Final report on EUROMET.T-K4: Comparison of the realizations of the ITS-90 at the freezing points of Al (660.323 °C) and Ag (961.78 °C)"** *Metrologia* **45** Technical Supplement (2008) 03003

[3]e.g. Evaluating uncertainties in interpolations between calibration data for thermocouples, J.V. Pearce, P.M. Harris, and J.C. Greenwood, Int. J. Thermophys. 31, 1517 (2010), Thermal modelling of fixed points for contact thermometry, J.V. Pearce, D.H. Lowe, D.I. Head, and G. Machin, Int. J. Thermophysics, 250, 29 (2008)

method directly to end users, and supply of high level calibrations and calibrated artefacts to ISO17025 laboratories.
- PAT: Beneficiaries will be in secondary calibration laboratories. It will also be of value for users for whom confidence in temperature measurement is critical to their application, to have a primary thermometry comparison calibrator.
- Au/Pt: Evaluate better sensors (Au/Pt thermocouple) to replace unsatisfactory HTPRTs for scale realisation, rsulting in a simplified, reduced cost service with better stability – this will also enable high level key comparisons that are currently not possible because of poor performing HTPRTs[1]

Support for Programme Challenge, Roadmaps, Government Strategies
- Impurity modelling: All sectors – in particular roadmap challenge "World class realisation and dissemination of ITS-90".
- "step change improvement in high temperature thermometry" and "Au/Pt thermocouple quantified as alternative to HTPRTs". Supports challenges in Drivers: "energy", "underpinning metrology" and "advanced manufacturing".

Synergies with other projects / programmes
- Impurity model: Augments an underpinning capability that links with projects: e.g. provision of contact and non-contact thermometry standards, thermocouple developments; Boltzmann constant and acoustic thermometry.
- PAT: Exploits knowledge & personnel from projects on measurement of the Boltzmann Constant and Acoustic thermometry. Exploits knowledge from 'NMS Acoustic and Ionising Radiation Programme'.
- Au/Pt: Au/Pt development is a stated objective of CCT and will be done cooperatively with EU partners.

Risks
- PAT: Preliminary work has reduced the risk of a major technical flaw, but it may be that such a flaw still exists.
- Au/Pt: Inability to overcome technical challenges of Au/Pt to approach HTPRT capability.

Knowledge Transfer and Exploitation
- Impurity model: At least two refereed papers describing the methodology, access to model via e.g. web. Ad-hoc consultancies in contact thermometry, provision of calibrated artefacts i.e. temperature sensors and fixed points.
- PAT: The project has many possible routes for exploitation beyond papers and possible IP. A successful outcome will be the granting of a licence to an industrial instrumentation company.
- Au/Pt: At least two refereed publications. Improved and new UKAS calibrations. This project develops innovative knowledge at NPL and provides the foundation for consultancies/JIPs. Licence NPL know-how to commercial supplier/s of thermocouples. Promotion through "sensors KTN" and/or trade journal articles.

Co-funding and Collaborators (This is already a co-funding project)
Impurity model: External materials science collaborators are Prof John Hunt (Oxford University) and prof Peter Lee (Diamond and Manchester University) who will provide advice during the project.
PAT: Project partners are manufacturers of calibration equipment who make dry well calibrators. A goal is to involve them to make a prototype device with the acoustic thermometer incorporated during the lifetime of the project.
Au/Pt: UK manufacturers: CCPI, Isotech (potential licencees). External collaborators: LNE, PTB, NMIJ, possibly CEM, NMIA

Deliverables

1	**Start: 01/06/12**	**End: 31/05/15**	
Impurity model: Numerical model of the influence of impurities on the freezing curve of pure fixed point materials. This will be a model which is fit to experimental freezing curves, and the impurity concentration is parameterised. Evidence: Numerical model, publication, submission to CCT working group for wider dissemination and collaboration. A UKAS accredited calibration service for SPRTs with lower uncertainties.			
2	**Start: 01/06/12**	**End: 31/05/15**	
Practical acoustic thermometer: Aid uptake of acoustic thermometry through the development of a demonstrator acoustic "dry block calibrator" prototype for calibrating/comparing conventional contact thermometers with an acoustic technique in the range 0 °C to 100 °C. Evidence: Existence of the prototype and a plan for post project exploitation.			
3	**Start: 01/06/12**	**End: 31/05/15**	
Au/Pt: Evaluate leading Au/Pt thermocouples and compare with HTPRTs. Undertake comparison with careful evaluation of key uncertainty sources. Evidence: take up of this approach in favour of HTPRTs			

Project No.	EFM11038	**Price to NMO**	£ 83k
Project Title	Co-Funding for TSB Project "High Resolution Nanopositioning**"**	**Co-funding target**	This project cofunds a TSB project at £105k
Lead Scientist	Andrew Yacoot	**Stage Start Date**	Apr 2012
Scientist Team		**Stage End Date**	Mar 2014
		Est Final Stage End Date	
Sector	100% High value manufacturing	**Activity**	100% Challenge driven R&D

Summary: This project cofunds the TSB project "High Resolution Nanopositioning". This is drawn from the parent NMS project GS001 NA06 "Next Generation High Precision NPL Interferometer". Year 1 of this project is described in GS001 CF7

The Need: Increasing hard disk drive (HDD) production volumes and increasing data density places considerable pressure on the overall positioning systems for production test equipment, which is already at the limits of what can be achieved. The next generation of HDD heads and test equipment needs a step change in positioning capability. For the existing UK supply chain to remain competitive it needs to utilise the technology with the highest precision available.

The Solution: The project aim is to develop a prototype piezo driven nano-positioning stage with the neccessary step change in performance as a technology enabler for the hardware used to test the read/write heads required for the next generation of HDDs. The improvements will include increased accuracy, speed of response, and bandwidth with an extremely low noise floor. This will be achieved by integrating a new innovative force feedback control mechanism into the piezo stage.

The low noise positioning accuracy requires the development of a new high precision metrology system based on improved interferometric techniques currently funded by NMS through project NA06. This will provide interferometry at noise levels<10 pm, and the development of low noise fringe counting electronics. The nano-positioning stage will be integrated into a current generation of head test rig and its performance assessed. The improved positioning performance is essential for the development of the next generation test equipment. The improved nano-positioning stage will be applicable in a broad range of nanotechnology applications such as metrology, microscopy and fabrication. The project supports long term growth objectives of the partners in test equipment and nano-positioning markets

Project Description (including summary of technical work):

The objectives are to integrate a force feedback (FF) sensor system, into a flexure based nano-positioning system to enable a step change in noise, speed of response and distance of travel for application in the HDD test industry. NPL will:

1. Investigate options and develop detailed metrology requirements and provide a technical appraisal of metrology solutions.
2. Develop and test methodology to measure positioning with very low noise.
3. Implement a low noise fringe counting system with non-linearity correction developed for Optical Interferometry
4. Design and construct mechanical platform for measurement system
5. Manufacture prototype piezo stage & confirm performance characteristics
6. Install and test piezo stage in representative conditions and assess performance
7. Evaluate and report performance to TSB.

Impact and Benefits: Prior to the bid submission QG and NPL have discussed a number of aspects relating to dimensional nanometrology and nanopositioning and have identified several areas for future collaboration. The success of the TSB bid enables them to strengthen their collaboration. In addition, potential metrological collaborations have been identified with Xyratex, stimulating future potential UK R&D investment in the UK. The stimulation of the development of the interferometer, provides a national metrology lab instrumentation capability for broader industrial application with a ww market potential. The TSB funding will enable QG's to maintain their investment in R&D to occur, whilst continuing to invest in their business growth. QG's product sales are extensively built on bespoke solutions, requiring significant engineering resource. Without the funding the development of the new nano-positioners will consequently occur at a slower pace potentially missing the opportuntity within the new HDD test equipment market.

A successful project will provide NPL and NMS with a powerful case study describing how the support of the NMS can enable wealth creation through a supply chain by the exploitation of science operating at the frontiers of what is currently possible in dimensional measurement.

Support for Programme Challenge, Roadmaps, Government Strategies:

As per project NA06 “Next Generation High Precision NPL Interferometer”. In its support to small businesses in high value sectors, participation in this TSB project is in direct support to the Government’s growth agenda. It provides the NMS with new, accelerated routes for exploitation of NMS funded technology at no cost to the NMS and is fully aligned to the NMS strategy.

Synergies with other projects / programmes:
As per project NA06 “Next Generation High Precision NPL Interferometer”

Risks:
As per project NA06 “Next Generation High Precision NPL Interferometer”

Knowledge Transfer and Exploitation:
Generally as per project NA06 “Next Generation High Precision NPL Interferometer”. The final report from the TSB project will result in a case study of the benefits of precise measurement to an industrial supply chain.

Co-funding and Collaborators: The TSB project will provide £105k grant funding over 2 years. The project is led by Queensgate instruments, manufacturer of nanopositioning equipment, and includes Xyratex, a hard drive test equipment manufacturer and a contribution from the University of Newcastle in Australia.

NMS Deliverables

1	**Start: 01/04/12**	**End: 30/04/14**	

Deliverable title: Enhancements to the NPL plane mirror differential optical interferometer

- **Modelling of interferometer performance**
  Model performance of Jamin and the effects of different illumination sources, optical imperfections and alignment errors on non-linearity on interferometer performance.
  Literature study to identify recent work on fringe correction followed by implementation and testing of newly developed algorithms for more efficient non-linearity compensation to assess their potential for real time fringe correction.
- **Description: Hardware and software for fringe counting and error compensation**
  Development of an FPGA based signal optimisation and fringe counting system both as a stand alone unit and incorporated into commercially available FPGA cards. Both systems will be capable of working in real time and will provide on board correction for non-linearity.
- **Description: Development of input optics and experimental verification interferometer performance**
  Development of different input optics eg telescope and fibre well as methods for compensation of intensity and polarization (in fibre) variations.
- **Description: Measurements against XRI** Investigation and measurement of non linearity and effects of different configurations using x-ray interferometer to verify the models developed in WP 1 and the cards developed in WP2
- Comparison with state of the art heterodyne optical interferometer system with non linearity removal.verify the models developed in WP 1 and the cards developed in WP2
- Comparison with state of the art heterodyne optical interferometer system with non linearity removal.

Evidence:

- A complete model of the effects of alignment errors and imperfect optics on performance of Jamin. Results presented in an NPL report to form the basis of a paper on completion of the project.
- A stand alone fringe counting card with on board real time correction for non-linearity and a similar system based on a commercially available card.

Paper reporting results Guidelines on configuration and use of Jamin interferometer.

Project No.	EFM11022	**Price to NMO**	£117k
Project Title	Au/Pt thermocouples	**Co-funding target**	£70k
Lead Scientist	Graham Machin	**Stage Start Date**	1 October 2012
Scientist Team	Jonathan Pearce, Jayne Gray, Clare Elliott and Radka Veltcheva	**Stage End Date**	31 May 2015
		Est Final Stage End Date	
Sector	10% High value manufacturing; 80% Uncertainty & Traceability; 10% Process control	**Activity**	80% NMS infrastructure; 20% Long term SI

Summary – This project was deliverable 3 of previous project TH08 approved at 2011 Decision Conference and as such the project text covers the scope of the whole thermocouple development plan of Pt/Pd and Au/Pt. This project will be delivered alongside the Noted EMRP project and the combined outputs are described here.
Step improvements in high temperature thermocouple thermometry measurement over the next 5 years in the whole measurement chain from NMI to *in-situ* industrial measurements, from ~660 °C to at least 1500 °C. To be the acknowledged world-leading national measurement institute for thermocouple thermometry research.

The Need

The thermocouple is the most widely used industrial temperature sensor. Despite this there remain many outstanding issues that need to be addressed such as *in-situ* sensor drift. Some needs are:
Industrial: Advanced manufacturing needs improved thermometry (e.g. heat treatment of aerospace components at >1300°C). Next generation nuclear power plants need improved temperature sensing. Improved *in-situ* measurement will reduce energy use and lead to optimum production ("zero-waste").
NMI: Development of reliable construction and calibration of high performance Pt/Pd and Au/Pt thermocouples for scale transfer. ITS-90 between the Al (660 °C) and Ag (962 °C) points currently realised using a HTPRT. KCs not possible using HTPRTs as evidenced by recent Euramet KC[4]. CCT (May 2008) stated active research needed "to improve interpolation devices from Al to Ag to be more robust than HTPRTs."

The Solution

NPL is leading a multi-national research programme into developing robust Pt/Pd thermocouples and HTFPs[5,6] for low uncertainty calibration and scale dissemination to 1500 °C (participants NPL, LNE, PTB, NMIJ). Au/Pt thermocouples are the most likely sensor to replace HTPRTs. Currently manufactured but achieving optimum performance not yet understood, target ~x5 uncertainty improvement to compete with HTPRTs.
Develop necessary construction methodology for Pt/Pd and Au/Pt thermocouples to be world leading. Understand, quantify and solve performance limitations to above sensors. Establish HTFPs for routine thermocouple calibration to 1500 °C, including new Fe-C (1153 °C). Demonstrate the superiority of HTFP method to established wire-bridge method. Develop optimum interpolation algorithms.

Project Description (including summary of technical work)

Establish homogeneity measurement and optimum thermoelement wire annealing facilities. Establish interpolation for lowest uncertainty scale realisation.
Complete Euramet 857 project (comparing Pd-C and Pt/Pd thermocouple performance). Undertake a comparative study of wire-bridge versus HTFP calibration of representative batch of thermocouples. Construct and compare Fe-C fixed point with LNE.
Evaluate suitability of Au/Pt thermocouples aiming to be competitive with HTPRTs. Compare cohort of Au/Pt thermocouples with HTPRTs to demonstrate improved performance. If necessary, develop in-house Au/Pt construction methodology to improve on commercial sensors.

Metrology Capability to be delivered

World leading construction, characterisation and calibration capability for ultra-high performance robust Pt/Pd and Au/Pt thermocouples. World-class facilities for thermocouple inhomogeneity reduction and characterisation. Lowest uncertainty ISO17025 (UKAS) accredited calibration service of pure thermoelement thermocouples

Impact and Benefits

[4] D. Heyer *et al:* "Final report on EUROMET.T-K4: Comparison of the realizations of the ITS-90 at the freezing points of Al (660.323 °C) and Ag (961.78 °C)" *Metrologia* **45** Technical Supplement (2008) 03003
[5] HTFP = High Temperature Fixed Points (above Cu)
[6] Machin, G., "**Realising the benefits in improvements in high temperature measurement**", *Acta Metrologica Sinica*, 29, p. 10-17, 2008, Invited keynote lecture at Tempbeijing 08

This project will:

- Meet identified industrial requirements for improved thermocouple thermometry
- Develop new robust sensors for scale dissemination to industrial laboratories and potentially *in-situ* in industrial processes with lower uncertainties and improved reliability
- Evaluate better sensors (Au/Pt thermocouple) to replace unsatisfactory high temperature platinum resistance thermometer (HTPRT) for scale realisation – this will enable high level key comparisons that are currently not possible because of poor performing HTPRTs[1]

Beneficiaries include UK high value manufacturing sector e.g. heat treatment of aerospace components require access to improved temperature measurement (already benefited through initial developments, reducing waste in heat treatment of hot zone blades). Carbon emissions minimised through improved temperature measurement (optimised energy use). UK has strong temperature sensor manufacturing base and they will gain competitive advantage through first access to NPL developed know-how.

Support for Programme Challenge, Roadmaps, Government Strategies

This project directly meets the programme challenges of "step change improvement in high temperature thermometry" and "Au/Pt thermocouple quantified as alternative to HTPRTs". Supports programme challenges in Drivers: "energy", "underpinning metrology" and "advanced manufacturing".

Advanced manufacturing (cutting edge improvement in high temperature measurement). Sustainable production (optimised energy use through improved temperature control, lower emissions, zero waste). Underpinning metrology - step change improvement

Synergies with other projects / programmes

The Pt/Pd part of this project is reliant upon the "New high temperature scale by high temperature fixed points". These two projects, together with non-contact high temperature scale provision make the UK international leaders in high temperature metrology. This project informs "Ultra-high temperature self-validating thermocouples" which will develop capability for UK requirements arising in 5+ years. The Au/Pt thermocouple development work is a stated objective of CCT and as such will be done cooperatively with EU partners – possibly part funded through an EMRP project.

Risks

This project is ambitious in its scope. Key risks include failure of HTFPs to be reliable calibration artefacts at 1500 °C. Inability to overcome technical challenges of Au/Pt to approach HTPRT capability.

Knowledge Transfer and Exploitation

At least five refereed publications. Sale of low uncertainty Pt/Pd thermocouples and HTFPs, improved and new UKAS calibrations. This project develops innovative knowledge at NPL and provides the foundation for consultancies/JIPs. Licence NPL know-how to commercial supplier/s of thermocouples. Promotion through "sensors KTN" and/or trade journal articles.

Co-funding and Collaborators

Agreed at least 3 FTE/year in-kind from Euramet partners. PhD student, funded by NIMT, at Surrey. Possible JIP &/or licence agreement with thermocouple manufacturer. A bid made to EMRP – Energy, was successful (MetroFission) and this supports deliverable 2 the use of HTFPs for thermocouple calibrations. Deliverable 3 activity is included in a proposed research topic (PRT) entitled "Novel dissemination routes for temperature" submitted to the EMRP SI Broader Scope 2011 call.

UK sensor manufacturers: CCPI (agreed licencee), Isotech (potential licencee). External NMI collaborators are: LNE, PTB, NMIJ and possibly CEM NMIA, NRC

Deliverables

1	**Start: 01/10/2012**	**End: 31/05/2015**	

Description: Evaluate leading Au/Pt thermocouples and compare with HT-PRTs. Characterise world-class Au/Pt thermocouples, undertake experiments to develop optimum annealing and calibration procedure. Calibrate at least 3 HTPRTs to provide ITS-90 base. Construct comparator for optimum comparison of the two sensor types. Undertake comparison with careful evaluation of key uncertainty sources. Develop in-house construction of Au/Pt thermocouples to improve on commercial sensors if needed. Development of optimised interpolation algorithms for best exploitation of both Pt/Pd and Au/Pt thermocouple types.

Evidence: a) Refereed paper reporting results. b) Briefing document to CCT on suitability of Au/Pt as replacement interpolating sensor for HTPRT.

Project No.	TS003408 (previously 4.8)	**Price to NMO**	£800,000
Project Title	Cofunding for EMRP 17e Traceable Radiometry for Remote Measurement of Climate Parameters project (optical element)	**Co-funding target**	£760,000 (in place)
Lead Scientist	Dr Nigel Fox	**Stage Start Date**	OCT-2011
Scientist Team	Dr Andrew Levick, Dr Emma Woolliams, Dr Theo Theocharous, Agnieszka Bialek, Ruth Montgomery	**Stage End Date**	SEP-2014
		Est Final Stage End Date	2014
Sector	100% Environmental Sustainability	**Activity**	100% NMS infrastructure

Summary

Under the framework of the European Metrology Research Programme Joint Research Project (JRP) ENV04 'European Metrology for Earth Observation and Climate (MetEOC)', this project will establish greater coordination and focus more effort on the underpinning metrology, to realise practical, efficient, cost effective, "fit for purpose" traceability for the European EO community. Particularly:

• Satellites require improved uncertainty and traceability through all stages of data production: pre-flight and post-launch calibration and validation and all the intermediate processing steps,

• Data interoperability across the full electro-magnetic spectrum; maintaining and improving the uncertainty available from primary standards and facilities.

• Evolution of laboratory-based metrology, field metrology, and space metrology.

This project is co-funded by the European Metrology Research Programme Joint Research Project (JRP) ENV04 'European Metrology for Earth Observation and Climate (MetEOC)'.

The Need

Remote monitoring of the Earth system is crucial to enable better stewardship of the environment to provide the information to policy makers developing appropriate mitigation strategies for climate change. Global observations can only be made from space, and although such observations are being made, the harsh and challenging environment of space limits the uncertainty currently attainable. In the specific case of climate this is often a factor of 10 larger than required by the community. The drive for reduced uncertainty and the need to combine data from a variety of sources has placed "traceability" at the top of space agencies and GEO (Group on Earth Observation) community's agenda. The goal of GEO to establish a Global Earth Observation System of Systems (GEOSS) by 2015 is recognition that no single nation or region has the resources provide a full global earth observing system with the accuracy needed for climate.

The Solution

This project will establish greater coordination and focus more effort on the underpinning metrology, to realise practical, efficient, cost effective, fit for purpose traceability for the European EO community. Particularly;

• Satellites require improved uncertainty and traceability through all stages of data production: pre-flight and post-launch calibration and validation and all the intermediate processing steps,

• Data interoperability across the full electro-magnetic spectrum; maintaining and improving the uncertainty available from primary standards and facilities.

• Evolution of laboratory-based metrology, field metrology, and space metrology.

Project Description (including summary of technical work)

Within the framework of the EMRP JRP ENV04, this project will establish new transfer standards and methods to improve accuracy and traceability (by factors between 2 to 10) for:

• Laboratory based (air and vacuum) pre-flight calibration of optical and microwave imaging cameras

• In-flight (on-board) calibration for optical imagers and atmospheric limb sounders

• Surface based "test-sites" for the post-launch calibration and validation of land and ocean imaging radiometers

• Models and algorithms to improve performance and traceability of level 2 (L2) land products

• Prototyping techniques to establish an "SI traceable benchmark measurements from space". This will underpin the upgrade of current sensors, and enable a global climate observing system

Impact and Benefits

Although this project focuses on the remote sensing community and the needs of climate, this JRP will identify detailed requirements for the future and build partnerships to ensure full use is made of all relevant European metrological expertise. This will include organisations not eligible for funding under the current EMRP, co-aligning where possible with other related projects within Europe and elsewhere.

To build a long-term evolving and sustainable set of capabilities, infrastructure and expertise with minimal

duplication requires a “European centre of excellence“, and a subsequent goal from this JRP is the establishment of a virtual European Metrology Centre for Earth Observation and Climate (EMCEOC). If this were established it would encompass the metrological aspects of all Earth Observation application domains and provide a “one-stop-shop“ to support the needs of those in industry and academia engaged in the calibration and validation of Earth Observation instrumentation and associated products.

Support for Programme Challenge, Roadmaps, Government Strategies

Extend scope to establish SI traceability for Oceans; Faster uptake of outputs through establishment of prototype services as international demonstrators; Commence work on validation of models/algorithms used to process sensor signals into real bio/geo-physical parameters. Quality assurance of evidence to support environmental monitoring and enables collection of climate quality data to inform Government strategies.

Synergies with other projects / programmes

QI at pixel of image linked to project 2.2 and also existing and likely future SSfM programme. CSAR will provide the international reference standard for photovoltaic efficiency- project 4.4. Ocean colour traceability will build on transfers standards under development in Project 2.2. Operational land imager test site use and adapt mathematical models developed in Project 2.2. Microwave metrology requirements are addressed under linked project 4.10.

Risks

Many of the target outputs from this programme are highly challenging and full success will depend on contributions from collaborators. However, traceability in this field is so immature that even incremental gains in accuracy or even improved confidence in the processes through the robust analysis that will occur within this project will be seen as a success by the EO community.

Knowledge Transfer and Exploitation

The results of this JRP will be widely disseminated through peer-reviewed papers, trade journals, news articles, conference presentations, Good Practice Guides and 3 case studies (covering validation of “forest carbon” estimates and uncertainty analysis) that will be used to provide training on how to evaluate uncertainties in EO systems. The JRP will also provide metrological advice for EO applications and climate via a helpline, and provide advice and technical input to standards organisations, including supporting the evolution and implementation of international EO specific standards such as QA4EO. Additionally Stakeholder workshops will be held to establish roadmaps of priority metrology need for the EO sector. All activities will be promoted on the JRP website.

Co-funding and Collaborators

Matching co-funding funding provided by EMRP under ENV04 ‘European Metrology for Earth Observation and Climate (MetEOC)’. Funded JRP consortium members include PTB, INRIM, JRC, LNE, AALTO, MIKES & WRC-PMOD. Unfunded JRP consortium members include Bergische Universität Wuppertal (BUW Germany), Deutsches Zentrum f. Luft- und Raumfahrt e.V. (DLR Germany), Forschungszentrum Juelich GmbH (FZJ Germany), and Geodeettinen Laitos (FGI Finland).

Deliverables

1	**Start: 01/10/2011**	**End: 30/09/2014**	

Deliverable title: Management, coordination and completion of EMRP JRP ENV04 MetEOC

Evidence: The project aims to harmonise the European metrology infrastructure within the earth observation community and work towards a European Metrology centre for earth observation and climate. To achieve this the project is focused on developing the following themes:

- Pre-flight Laboratory-based Calibration Standards and Methodologies
- On-board Calibration Standards
- Establishing In-flight Traceability through Reference Standard Measurements and Test-sites
- An ‘NMI in Space’ for Benchmark Measurements of Climate

In addition, the project will create impact through uncertainty training, best practices, influencing international standards and stakeholder interaction.

NPL will design and test a prototype Polarising Transfer Radiometer (PTR) capable of capable of in flight calibration of Traceable Underpinning Terrestrial and Helio Studies (TRUTHS). The Cryogenic Solar Absolute radiometer (CSAR) will be calibrated and its performance as primary standard for TRUTHS demonstrated.Drawing on PTR and CSAR, the project will demonstrate the spectrally traceable calibration of TRUTHS.

Project No.	TS003409 (previously 4.9CF)	**Price to NMO**	£64,000
Project Title	Cofunding for EMRP 17e Traceable Radiometry for Remote Measurement of Climate Parameters project (microwave element)	**Co-funding target**	£60,000 (in place)
Lead Scientist	Richard Dudley	**Stage Start Date**	OCT-2011
Scientist Team	Richard Dudley , Mira Naftaly	**Stage End Date**	SEP- 2014
		Est Final Stage End Date	2016
Sector	100% Environmental Sustainability	**Activity**	100% NMS infrastructure

Summary

This project provides co-funding for the microwave part of the EMRP 'Traceable Radiometry for Remote Measurement of Climate Parameters' collaborative project (ref ENV 17). The overall EMRP project includes one NMI partner. In this project we will make the first steps in building International confidence in climate change predictions through the validation of atmospheric temperature observations in the mm-wave band. Data from microwave instruments complement optical measurements by providing temperatures for different sections of the atmosphere. Specifically, the project will assist the process of defining the requirements and capability required for the calibration of satellite and airborne microwave radiometers. The instruments operate from 30 - 200 GHz, but may rise in future years as high as 600 GHz.

The project will support the NMO project by enabling representation and discussion with groups outside Europe to assist in determining the most critical pre-flight calibration and operational calibration schemes. The processes will require discussions with international organisations, NIST, NASA and the Chinese Space Agency for example, to define the most appropriate experimental solutions. At this stage the validation of black body calibration targets appears to have the greatest potential impact and this project will be used to publicise and advance the European solutions globally.

The Need

Improved calibration methodologies will lead to increased measurement resolution, improving the accuracy and confidence of climatic predictions. Quoting Brown et al from JPL, "Detailed pre-launch calibration and characterisation is crucial for understanding observed calibration differences in orbit'. Accurate measurement of temperature trends in the lower atmosphere is crucial to understanding and predicting climate change. Documents such as the 2006 US Climate Change Science programme on 'Temperature Trends … and steps for reconciling differences', and the "Achieving Satellite Instrument Calibration for Climate Change (ASIC)" series of workshops have shown the need for improved calibration strategies for future satellite missions

The Solution

A two-stage solution is required to address the future calibration requirements of microwave radiometers:

- Work with the international players to develop a standardised procedure and documentation for pre-launch calibration. Enable traceability between all future microwave radiometers missions.

Develop new measurement systems, procedures and uncertainties for key aspects of the microwave radiometer instrument, building on studies and work to date

Project Description (including summary of technical work)

The task will focus on improving and validating the calibration of satellite radiometers by combining European expertise in microwave and terahertz measurements for materials, power and blackbody radiation. A key activity to build European metrology capability in the use of Microwave sounders is to gain practical experience with existing sensors. This project will work with international meteorological and space agencies to understand measurement issues and work towards better calibration. The will increase engagement between the metrological and meteorology communities and improve the quality of satellite radiometry, deliver quantifiable benefits for the work of climate monitoring in the project's timeframe.

Impact and Benefits

The debate on whether climate change is real continues, and has recently intensified by press reports that question the evidence base. Often the levels of predicted climate change manifest as trends close to or below the accuracy and resolution of the instrumentation. Improving the pre-launch calibration of future satellite missions will reduce the measurement uncertainties, increase the sensitivity, and provide greater confidence to

the public and governments in the evidence base.			
Support for Programme Challenge, Roadmaps, Government Strategies Supports the programme's environmental sustainability objective, providing measurement technologies that underpin the ability to monitor environment and analyse the effects of climate change.			
Synergies with other projects / programmes Tightly linked to project 4.10 – Satellite Microwave Sounders . Strong links to project 4.8, the larger 'optical element' part of EMRP 17e Traceable Radiometry for Remote Measurement of Climate Parameters.			
Risks Many of the longer –term outputs are challenging and full success will depend on contributions from collaborators. However, traceability in this field is immature so incremental gains in accuracy or even improved confidence in the processes through the robust analysis that will occur within this project will be seen as a success by the EO community.			
Knowledge Transfer and Exploitation An internationally agreed metrology strategy for microwave radiometers will be developed and disseminated at conferences and though publications. The project team will engage with stakeholders needing to characterise instruments for ground and aircraft based remote sensing to engage them with this project from the outsets			
Co-funding and Collaborators Co-funding is confirmed 45.6% from EMRP. Funded JRP consortium members include PTB, INRIM, JRC, LNE, AALTO, MIKES & WRC-PMOD.			
Deliverables			
1	**Start: Oct 2011**	**End: Sept 2014**	
Deliverable title: Cofunding for EMRP 17e Traceable Radiometry for Remote Measurement of Climate Parameters project (microwave element) Evidence : A feasibility study for traceable calibration of Microwave sounders including the establishment of a European and international roadmap and action plan for the calibration of microwave sounders for future earth observation missions.			

Support to NMS Infrastructure

The following projects provide essential support to the maintenance of metrology capability and are normally contracted in advance on a 12 monthly extension. .

Project No.	EFM11024	**Price to NMO**	£321k
Project Title	Force standards - maintenance and development	**Co-funding target**	Services income
Lead Scientist	A Knott	**Stage Start Date**	01 Oct 13
Scientist Team		**Stage End Date**	30 Sep 14
		Est Final Stage End Date	
Sector	100% Traceability & uncertainty	**Activity**	100% NMS Infrastructure

Summary
This project will provide internationally recognised traceability for the UK force scale.

The Need
Maintain the UK's national force standards up to 30 MN- these are used to give traceability to industrial customers, either directly or via UKAS-accredited laboratories. The force facilities at NPL require regular monitoring, cross checking, and internal calibration, as well as standard mechanical and electrical maintenance.

The Solution
The NMS Core-Facilities, consisting of bespoke systems, are SOA for the UK.
Maintain the UK's national force standards up to 30 MN- these are used to give traceability to industrial customers, either directly or via UKAS-accredited laboratories. The force facilities at NPL require regular monitoring, cross checking, and internal calibration, as well as standard mechanical and electrical maintenance.
Metrology Capability to be Delivered
High accuracy facilities and specialised services will be provided for the dissemination of traceable force and materials testing standards through the following facilities:
Deadweight machines – 50N, 500N 2.5kN, 20kN, 120kN and 1.2MN,
Servohydraulic machines – 3MN, 5MN, 12MN and 30MN,
Strain cylinder verification,
Extensometer calibration rigs,
DC ratio meters,·

Project Description (including summary of technical work)
Maintain measurement hardware and software for delivery of force measurements and calibrations. Succession planning and training/development of staff to ensure continuity of service. Development of improved measurement practice and measurement procedures. Maintenance of UKAS accreditation for the measurement services. Continual review of facilities maintained to ensure relevance to UK industry and science base.

Impact and Benefits
Force is regularly measured in a wide range of industrial sectors, to determine parameters such as material strength, cable tension, centre of gravity, engine thrust, and aerodynamic efficiency - the required uncertainty of the force measurement is critical in many applications.
The major benefit of this work is that a route to traceable force measurements will continue to be available to the large number of industrial companies who require it. The impact will vary between sectors - for example, the ability to validate the performance of engine test rigs will enable the aerospace industry to certify the performance of engines to lower uncertainties, leading to reductions in environmental impact and increases in revenue. NPL provides the UK verification for strain cylinders used to verify concrete cube testing machines, thereby enabling construction standards to be met.

Support for Programme Challenge, Roadmaps, Government Strategies
The access to nationally available force standards will prevent UK companies from suffering competitive disadvantage resulting from the need to source measurement traceability from other countries, with the associated time and transportation costs, and possible language difficulties. It will also ensure that national access to technical advice is maintained and that the UK will continue to be in a strong position to contribute to international developments in the area.

Support advanced manufacturing industries, such as aerospace, automotive and medical devices, where force/load monitoring is critical to product quality and regulatory requirements. Provide the traceability that underpins health and safety legislation such as Lifting Regulations

Synergies with other projects / programmes

The NPL facilities provide support to the dynamic force project and support some of NPL's Materials programme

Risks

Low – many facilities are ageing and may require excessive attention to continue operations; opportunities to invest in new facilities or to divest activities should be pursued to mitigate this risk.

Knowledge Transfer and Exploitation

Measurement services delivering over 400 certificates per year. Underpinning facilities to support EMRP work. Availability of large scale testing facilities for hire by UK industry.

Co-funding and Collaborators

Measurement services income

Approximately 30 companies commission force calibrations directly with NPL each year. Some of the key customers are major UKAS accredited labs and instrument suppliers (such as Instron, MDS, Zwick, Dennison Mayes) who work with NPL to improve their metrology capabilities and disseminate NPL developed technology.

Deliverables

1	Start: 01/10/13	End: 30/09/14	

Description: Force facilities: essential support - Oct 13 - Sep 14

Ongoing activities will be performed to maintain confidence in the forces generated by the range of standard machines - these activities will include calibration of the hydraulic machines, cross checking over machines' common force ranges, monitoring of drift over time, and mechanical / electrical maintenance of the range of equipment.

Evidence: Maintain NPL force capabilities and issue approximately 300+ calibration certificates annually to UKAS laboratories, instrument manufacturers and engineering companies.

Project No.	EFM11025	**Price to NMO**	£128k
Project Title	Maintenance of the national standard of mass and development of a method for the practical implementation of the redefined kilogram	**Co-funding target**	Services income
Lead Scientist	S Davidson	**Stage Start Date**	01 Oct 13
Scientist Team		**Stage End Date**	30 Sep 14
		Est Final Stage End Date	
Sector	70% Traceability & uncertainty; 30% Extension of SI	**Activity**	50% NMS Infrastructure 50% Statutory & Policy

Summary

This project involves the maintenance and dissemination of the current UK national standard of mass and undertakes the research necessary to ensure that NPL can maintain the UK mass measurement capability following the future redefinition of the SI unit of mass.

The Need

Originally contracted at £231k, funding has been transferred to provide co-funding for EMRP S07 MeP Kg. Remaining funding covers maintenance tasks only.

Ensure that UK primary mass scale is realised and is internationally accepted to facilitate trade. The re-definition of the kilogram will allow the (theoretical) realization of the unit at any NMI and will address issues with the stability of an artefact-based definition. Work is already underway to find a method to redefine the kilogram in terms of a fundamental constant - the Crystal Density (Avogadro) project and the Watt balance experiments. Both projects involve the realisation of a kilogram in vacuum and have major implications for how the unit is maintained and disseminated at the national level.

The Solution

UK primary mass scale traceable to BIPM.

Maintenance and dissemination of the UK mass standard involves the maintenance and assessment of NPL's kilogram mass comparators, the annual comparison of primary platinum-iridium mass standards with the national standard.

Metrology Capability to be Delivered

Key to preparing for a new definition of the kilogram and to the implementation and continued maintenance of the mass scale after re-definition is a method to compare, maintain and disseminate the re-defined kilogram. A methodology for the maintenance of the mass scale between realisation using standard artefacts, stored and used in such a way as to optimise long term stability

Project Description (including summary of technical work)

Annual comparison of platinum-iridium kilograms with the UK's standard of mass. The calibration of artefacts for the direct measurement of air density and the maintenance of equipment for the indirect determination of air density, and the dissemination of the kilogram from platinum-iridium primary standards to stainless steel working standards. Participation in international intercomparisons.

Impact and Benefits

This project will maintain the UK's primary standard of mass and establish equipment, measurement techniques and procedures for maintaining traceability for the UK mass scale and prepare for the redefinition of the kilogram. Improvement to the way in which the kilogram is realised and maintained will be beneficial to the mass scale in the UK and will allow NPL to offer the low uncertainties which are already required by a number of laboratories within the UK In future the number of laboratories requiring such uncertainties will increase and this work will ensure that NPL is in a position to meet these requirements. In order to achieve the redefinition of the kilogram a way of connecting the (theoretical) realisation of the kilogram, via the Watt balance or Avogadro experiments, with the practical mass scale needs to be developed. Ensures the traceability of the UK mass scale to support implementation of the UK Weights and Measures Act and ensure the redefinition of the kilogram can be practically realised as a standard

Support for Programme Challenge, Roadmaps, Government Strategies

Maintenance of the mass scale in the UK and underpinning efforts to redefine the kg.

Underpin trade and trading standards through NWML (in support of the UK Weights and Measures Act).

Synergies with other projects / programmes

Other scientific work within NPL (Boltzmann constant redefinition, Watt balance, Small Force, moisture in materials) relies on this work to provide critical measurement traceability and expertise, as does the work of other scientific areas within NPL (force, humidity, radiation, acoustics, environmental monitoring, biotechnology).

Risks

Low

Co-funding and Collaborators

Measurement services income

Several NMI s within the EURAMET area and Worldwide are collaborating with NPL in the research areas associated with this project. Collaborating laboratories will include PTB, METAS, LNE, SP, CEM, KRISS and SPRING. The BIPM are also interested in collaborating with NPL in support of its mass programme.

Deliverables

1	Start: 01/10/13	End: 30/09/14	

Description: National Kg Standard - Oct 13 - Sep 14

The annual comparison of platinum-iridium kilograms with the UK's standard of mass. The calibration of artefacts for the direct measurement of air density and the maintenance of equipment for the indirect determination of air density, and the dissemination of the kilogram from platinum-iridium primary standards to stainless steel working standards. Continuing investigation the effect of transferring weights between air to vacuum, the effects of surface condition of weights, optimum cleaning processes.

Evidence:

Annual calibration of the UK's primary, secondary and working kilogram standards and assessment of primary kilogram mass comparators.

Project No.	EFM11026	**Price to NMO**	£216k
Project Title	Mass and Density Standards	**Co-funding target**	Services income
Lead Scientist	S Davidson	**Stage Start Date**	01 Oct 13
Scientist Team		**Stage End Date**	30 Sep 14
		Est Final Stage End Date	
Sector	100% Traceability & uncertainty	**Activity**	100% NMS Infrastructure

Summary

This project provides internationally recognised traceability for the UK mass scale in the range from 1 mg up to 25 kilograms and both solid and liquid density.

The Need

In order to provide a measurement service at the level required by the mass and density area, other NPL users, UKAS laboratories and industry a suite of measurement facilities must be maintained.

The Solution

Maintain UK primary mass scale traceable to BIPM. Maintenance and dissemination of the UK mass standard involves the maintenance and assessment of NPL's kilogram mass comparators, the annual comparison of primary platinum-iridium mass standards with the national standard.

Mass standards traceably calibrated to better than OIML Class E1 level are only available in Europe from NPL and PTB. This project will disseminate the mass scale from 1 milligram to 25 kilograms by sub-division and build up from the national standard kilogram by the calibration of platinum-iridium and stainless steel weight sets in the range 1 mg to 25 kg and the maintenance and verification of a suite of balances and mass comparators.

The NMS Core-Facilities in density, consisting of bespoke systems, are State of the Art in the UK. These include Four solid density measurement systems covering the range 10 grams to 25 kilograms will be maintained and regularly assessed. A hydrostatic weighing apparatus providing traceability to solid density standards of silicon and Zerodur will be maintained to provide primary traceability for liquid and solid density measurements to the lowest level of uncertainty. NPL also maintains a facility for the measurement of solid density by in air measurements critical for the calibration of porous and reactive samples. A facility for calibrating small liquid density samples and powder samples will also be maintained.

Project Description (including summary of technical work)

Maintain measurement hardware and software for delivery of mass and density measurements and calibrations. Succession planning and training/development of staff to ensure continuity of service. Development of improved measurement practice and measurement procedures. Maintenance of UKAS accreditation for the measurement services. Continual review of facilities maintained to ensure relevance to UK industry and science base. Participation in international intercomparisons.

Impact and Benefits

UKAS laboratories in the UK require their mass standards traceably calibrated to better than an OIML Class E1 level which is a service only offered by NPL and PTB in Europe. This project will also provide reference level calibrations for UKAS for audit purposes (again only available at NPL and PTB in Europe). Additionally, the UK Weights and Measures Act statutorily requires NWML to maintain both imperial and metric standard weight sets in the range 1 mg to 25 kilograms and have them calibrated against the UK national standard. A wide range of industrial users also rely on the accuracy of calibration that this work facilitates. These include the pharmaceutical, oil and gas and nuclear industries. These and other areas of UK industry also rely on the training, comparisons, knowledge transfer meetings and consultancy services that this project allows NPL to provide. There are 36 UKAS accredited laboratories within the UK all of which are traceable to NPL and these laboratories perform over 200 000 calibrations per annum.

An accurate knowledge of density is an essential parameter for the evaluation of the best uncertainty values of reference standard weights, volume standards and other artefacts, and is therefore critical for the maintenance of NPL's mass standards. In the UK, all laboratories that maintain mass standards calibrated to class E1 or better require traceable density measurements at an uncertainty level only obtainable at NPL. Apart from standards laboratories, other end users requiring low uncertainty density measurements include the pharmaceutical, materials, biomedical, nuclear, automotive and aerospace industries. This work underpins the calibration of primary mass standards both for NPL and for external customers, which include UKAS accredited laboratories, NWML (in support of the UK Weights and Measures Act) and other NMIs. The flexibility of NPL's facilities and level of expertise allows calibration of non-standard samples, critical for pharmaceutical, biomedical, nuclear, automotive and aerospace industries.

Support for Programme Challenge, Roadmaps, Government Strategies

Maintenance of the mass scale in the UK and underpinning efforts to redefine the kg. Density measurements critical to the maintenance of the mass scale in the UK and the underpinning of efforts to redefine the kg.
Underpin trade and trading standards through NWML (in support of the UK Weights and Measures Act).

Synergies with other projects / programmes

Other scientific work within NPL (Boltzmann constant redefinition, Watt balance, Small Force, moisture in materials) relies on this work to provide critical measurement traceability and expertise, as does the work of other scientific areas within NPL (force, humidity, radiation, acoustics, environmental monitoring, biotechnology). Projects on the maintenance of the UK national standard of mass and on the dissemination of the mass scale for 1 mg to 25 kg also rely on the output of this project.

Risks

Low – many facilities are ageing and may require excessive attention to continue operation; opportunities to invest in new facilities or to divest activities should be pursued to mitigate this risk.

Co-funding and Collaborators

Measurement services income
The National Weights and Measures Laboratory collaborate with NPL on the build up of the mass scale by provision of mass calibration facilities above 10 kilogram. NPL provide NWML with expertise and mass standards to allow the extension of their mass scale up to 500 kg. NPL has also collaborates with other UK calibration laboratories on research in this area (for example the calibration of magnetically permeable weights) to allow establishment of best practice for non-routine measurements

Deliverables

1	Start: 01/10/13	End: 30/09/14	

Description: Mass and Density Standards - Oct 13 - Sep 14
Sub-division of the mass scale from 1 kilogram to below 1 milligram. Build up of the mass scale from 1 kilogram to 25 kilograms. Participation in key and supplementary comparisons organised by the CCM and EURAMET.
Provision of a solid density measurement facilities for samples from 5g to 25 kg. Provision of liquid density measurement facilities. Participation in Key and Supplementary Comparisons organised by the CCM (CCM.D-K3) and EURAMET where appropriate
Evidence:
Maintain UKAS/MRA accreditation of NPL of the NPL mass service and realisation of the UK mass scale.

Project No.	EFM11028	**Price to NMO**	£86k
Project Title	Pressure Facilities	**Co-funding target**	Services income
Lead Scientist	B Waller	**Stage Start Date**	01 Oct 13
Scientist Team		**Stage End Date**	30 Sep 14
		Est Final Stage End Date	
Sector	100% Traceability & uncertainty	**Activity**	100% NMS Infrastructure

Summary
This project will support UK industrial requirements in pressure, through representation on international committees and ensuring internationally acceptable traceability is available. The NMS Engineering and Flow Programme no longer supports activity in the area of static pressure, but it is important that UK interests continue to be represented on international metrology and standardisation committees (eg CEN, BSI, EURAMET, CCM) by experts of international standing. Without this there is a serious risk that UK industry will be disadvantaged in new written standards and may not receive feedback on new technical developments.

The Need
The strong UK based pressure and vacuum industry continues to require internationally acceptable traceability with world-class uncertainties that allow it to trade internationally and provide year-on-year improvements to instrumentation

The Solution
NPL maintains internationally accepted pressure scales in the following ranges: Hydraulic pressure 0.5 MPa – 500 MPa, Pneumatic pressure 3.5 kPa – 20 MPa.. The pneumatic scale underpins a service for the calibration of electronic barometers.
Traceable measurements will be provided by NPL on a commercial basis with the NMS programme funding international comparisons required to satisfy the Mutual Recognition Agreement and also secondments to other NMIs.

Metrology Capability to be Delivered
UKAS accredited pressure scales in the following ranges: Hydraulic pressure 0.5 MPa – 500 MPa, Pneumatic pressure 3.5 kPa – 20 MPa. A secondary barometer calibration service for NPL and commercial customers.

Project Description (including summary of technical work)
NPL will participate in any international comparisons required to maintain its CMC entries in the pressure field. Participation will continue in the Consultative Committee for Mass (CCM) Pressure Working Group and relevant EURAMET committees. Internal cross comparison of measurement standards will ensure the availability of the pressure scales in the following ranges: Hydraulic pressure 0.5 MPa – 500 MPa, Pneumatic pressure 3.5 kPa – 20 MPa., and barometry.
Internal cross comparison of measurement standards will ensure the availability of the pressure scales in the following ranges: Hydraulic pressure 0.5 MPa – 500 MPa, Pneumatic pressure 3.5 kPa – 20 MPa., and barometry. Participation in appropriate international intercomparisons. Updating equipment and procedures to maintain capability.

Impact and Benefits
The measurement of pressure remains of importance to a range of industrial sectors (most notably aerospace, automotive, instrumentation manufacture, general engineering and oil and gas).

Support for Programme Challenge, Roadmaps, Government Strategies
To underpin the requirements for accurate pressure standards for engineering & flow measurements to support regulations for, and to provide a sound basis for, cost-effective and reliable measurements.
The measurement of pressure remains of importance to a range of strategically important industrial sectors (most notably aerospace, automotive, instrumentation manufacture, general engineering and oil and gas). Pressure measurement is essential for process and flow control in many sectors. Pressure safety regulations require traceable pressure scales

Synergies with other projects / programmes

Underpins dynamic pressure projects. The barometry service is essential for delivery of laser interferometer calibrations provided by frequency standards group

Risks
Low

Knowledge Transfer and Exploitation
The Engineering Measurement Awareness Network (EMAN) and the NMS publications will be the prime routes for dissemination from this project. Both vehicles will be used to transfer best practice to UK end-users.

Co-funding and Collaborators
Commercial calibration customers.
NPL will work on this project with accredited laboratories, instrument suppliers and other NMIs to ensure the best possible dissemination of the output.

Deliverables

1	Start: 01/10/13	End: 30/09/14	

Description: Pressure facilities 2013-2014
Evidence:
UKAS accredited pressure scales in the following ranges: Hydraulic pressure 0.5 MPa – 500 MPa, Pneumatic pressure 3.5 kPa – 20 MPa.
Maintain a secondary barometer calibration service for NPL and commercial customers.
Maintain UK CMCs.

Project No.	EFM11029	**Price to NMO**	£535k
Project Title	Dimensional Facilities: Essential Support	**Co-funding target**	Services income
Lead Scientist	D Flack	**Stage Start Date**	01 Oct 13
Scientist Team		**Stage End Date**	30 Sep 14
		Est Final Stage End Date	
Sector	80% Traceability & uncertainty: 20% Process control	**Activity**	100% NMS Infrastructure

Summary
Provides the internationally recognised traceability for the UK dimensional scale required to support national and international trade, technology innovation and manufacturing.

The Need
The project aims to provide efficiently maintained core facilities and metrology expertise, offering the high-accuracy dimensional capabilities demanded by UK industry. Ongoing reviews of dimensional measurement requirements will be used ensure that capabilities supported continue to meet the needs of UK industry. The main beneficiaries of the NMS dimensional facilities include transport, automotive, aerospace and defence. Although it is difficult to think of any industrial sector that does not benefit from traceability established by this project

The Solution
The NMS Core-Facilities, consisting of bespoke systems (e.g. primary length bar interferometer, Metroscope, ID machine) and state of the art commercial instrumentation, are in many cases SOA for the UK (or Europe) or close to this level. These equipment are used to provide world-leading dimensional measurement traceability that impacts on just about every aspect of life, for example high-level research activities (e.g. nano technology and MEMS devices), high precision manufacturing and pharmaceuticals.
These essential facilities will be maintained so that they continue to meet the needs of UK industry and the specifications in the relevant UKAS schedule and the calibration and measurement capabilities declared under the Mutual Recognition Arrangement (MRA). Maintenance of expertise at NPL will facilitate the provision of high quality advice to UK industry and the development of measurement solutions for bespoke requirements
High accuracy facilities and specialised services will be provided for the dissemination of traceable dimensional standards through characterisation and calibration of:
End standards: gauge blocks, length bars and step gauges,
CMMs and CMM verification artefacts
Roundness and diameter, reference thread and plug gauges (including API),·
Imaging standards: Stage micrometers, high precision optical scales, image analyser graticule, optical grid plates, diffraction gratings,·
Optical components: lenses, optical flats,
Angle standards and autocollimators ·
Surface texture and step heights, micro and nano standards,
Laser trackers and tracers

Project Description (including summary of technical work)
Maintain measurement hardware and software for delivery of dimensional measurements and calibrations. Succession planning and training/development of staff to ensure continuity of service. Development of improved measurement practice and measurement procedures. Maintenance of UKAS accreditation for the measurement services. Continual review of facilities maintained to ensure relevance to UK industry and science base. Participation in relevant international intercomparisons.

Impact and Benefits
The NPL facilities provide the fundamental support to innovative NMS projects and provide direct traceability into industry, which permits 100,000's UKAS certificates to be produced annually.

Support for Programme Challenge, Roadmaps, Government Strategies
Provides underpinning traceability routes to the realisation of the metre, thereby facilitating globally competitive trade through advanced manufacturing, engineering and assembly at accuracy levels demanded by society.
Support advanced manufacturing industries, such as aerospace, automotive and medical devices, where precision engineering is critical to product quality and regulatory requirements. Without the traceability provided by NPL, engineering tolerances and manufacturing advances will not be achieved.

Synergies with other projects / programmes

The NPL facilities provide the fundamental support to innovative NMS projects within the Engineering and Flow programme and elsewhere in the NMS (e.g. Redefinition of the Boltzmann constant in Pathfinder, Radiation standards). Supports many areas of the Programme through traceability routes to the SI metre.

Risks

Low – many facilities are ageing and may require excessive attention to continue operations, opportunities to invest in new facilities or to divest activities should be pursued to mitigate this risk.

Knowledge Transfer and Exploitation

Measurement services delivering over 400 certificates per year. Underpinning facilities to support EMRP work. Development of training materials for Dimensional framework course. Delivery of bespoke measurement solutions to UK companies

Co-funding and Collaborators

Measurement services income

Approximately 100 companies commission dimensional calibrations directly with NPL each year. Some of the key customers are major UKAS accredited labs and instrument suppliers (such as Taylor Hobson, Hexagon Metrology, Mitutoyo, Tru Thread, Pyser) work with NPL to improve their metrology capabilities and disseminate NPL developed technology.

Deliverables

1	Start: 01/10/13	End: 30/09/14	

Description: Dimensional facilities: essential support - Oct 13 - Sep 14

Support core facilities and expertise: Maintain facilities and procedures so that they meet the specifications in the UKAS schedule and the calibration and measurement capabilities declared under the Mutual Recognition Arrangement (MRA). Participate in international intercomparisons to demonstrate capability. Review future requirements for dimensional measurement facilities providing recommendations for investments in new facilities or divestment of capability in support of rolling formulation.

Evidence: Maintain NPL dimensional capabilities and issue approximately 400+ dimensional calibration certificates annually to UKAS laboratories, instrument manufacturers and engineering companies.

Project No.	EFM11030	**Price to NMO**	£275k
Project Title	Humidity – Provision of standards	**Co-funding target**	Services income
Lead Scientist	S Bell	**Stage Start Date**	01 Apr 13
Scientist Team	M Stevens, P Carroll, J Wilkinson, K Douglas	**Stage End Date**	30 Sep 14
		Est Final Stage End Date	
Sector	100% Traceability & uncertainty	**Activity**	100% NMS Infrastructure

Summary

Maintenance of a world-leading national humidity standard meeting UK needs for traceable humidity calibrations for industry, services and innovation. A leading influence nationally and internationally, increasing and disseminating knowledge in humidity measurement and standards.

The Need

Humidity influences the properties of gases, and has wide ranging effects on materials. Standards for humidity provide traceability for measurements that affect a wide variety of industries and consumers. Humidity measurements are needed in production of foods and packaging, pharmaceuticals, energy (fuel cells, nuclear, and conventional power). They are needed in climate research, weather, building management, healthcare, and product testing.

Humidity traceability particularly supports UKAS-accredited humidity calibration labs, environmental test houses, suppliers of pure gases and gas dryers, and hygrometer manufacturers.

The Solution

NPL provides probably the most comprehensive scope range, and accuracy of national humidity standards worldwide, and leads developments in scope of these standards. New capabilities added this programme will further meet user needs. Approximately 10 national humidity standards derive humidity traceability from NPL. Measurement traceability in ranges supporting humidity measurements in a wide variety of industrial conditions.

Metrology Capability to be delivered

Dew-point standards –90 °C to +90 °C. Relative humidity standards 1 %rh to 98 %rh at air temperatures –40 °C to +100 °C. Primary mixing ratio. Other derived humidity quantities. Temperature calibration in air. Mobile measurement and calibration capability. New capabilities supported in this programme – calibration of water vapour flux (TEWL skin water loss) instruments, humidity in air at pressure up to 10 bar, and in selected non-air gases at atmospheric pressure. Ongoing UKAS accreditation. International equivalence demonstrated through measurement key comparisons.

Project Description (including summary of technical work)

Provide, maintain, update, incrementally improve standards. Maintain traceability of supporting measurements. Upgrade data handling. Continuously improve calibration methods, keeping up with developments in humidity instrumentation. Meet quality, safety and environmental requirements. Integrate new capabilities supported in this programme –humidity at pressure, and in non-air gases, moisture in materials and calibration of water vapour flux (TEWL) instruments. Maintain accreditation and consider extensions of scope to cover new capabilities. Measurement key comparisons for demonstration of proficiency and international equivalence. Progress entry of capabilities into BIPM CMC database. Knowledge transfer though advice, visits, committees, publications, other channels

Impact and Benefits

Reliable humidity measurements, assured by measurement traceability, underpinning environmental and process control for a vast range of processes and products.

Traceability to NPL is well recognised internationally. This particularly supports UK companies which are strong exporters of equipment and services for supply and measurement of high purity and industrial process gases

Support for Programme Challenge, Roadmaps, Government Strategies

Underpinning metrology. Supports measurements and instrumentation for advanced manufacturing process control; study and reduction of climate change; healthcare

Energy (measurements for reductions in energy consumption). Sustainability (confidence in climate change data, via reference methods). Healthcare (assurance of consistent delivery across the NHS through good measurement practice). Maintains leading international status of UK NMI

Synergies with other projects / programmes

Synergy with all other humidity and moisture projects in this NMS programme. Links also with:
trace moisture element of VAM Project GA04.

Innovation Programme Project T05 on humidity and gas temperature in hydrogen fuel cells

Risks

(1) Continuity of provision depends on key equipment and staff. Mitigation: Sufficient back-up equipment and cross-training. (2) Level of uptake of new types of calibration unknown (for humidity at pressure and in non-air gases, and for TEWL). Mitigation: Possible market survey, launch, publicity. Review of uptake and customer feedback.

Knowledge Transfer and Exploitation

Some 200 NPL humidity calibrations per year. Fan-out of humidity traceability via some 14 UKAS-accredited labs. Other projects and contracts stemming from NPL general humidity capability. Knowledge transfer through advice, training, committees, MfI and other consultancy etc.

Co-funding and Collaborators

Calibration service income from some 200 calibrations per year. Cooperation with other NMIs (intercomparison of measurements, technical information exchange, potential guest workers). Cooperation towards outputs of national an international committees, conferences, journal publications. Contribution from hygrometer suppliers in forms of: occasional instrument loans or discounts to NPL; referral of customers to NPL; contribution to and publicity for NPL KT events; two-way technical dialogue and information sharing.

Trace moisture range (down to a few nmol/mol) is provided in conjunction with NPL Analytical Science Division. Other cross-NPL teaming as required. Close working with hygrometer companies.

Deliverables

1	Start: 01/04/13	End: 30/09/14	

Description: Operation of UK humidity standards, actively disseminating traceability for humidity through calibrations of hygrometers. Services include new facilities for humidity calibrations in air at pressure and in non-air gases, moisture in materials and TEWL (skin water loss). Demonstrate consistency between humidity standards internationally and across NMS programmes.

Maintaining and incrementally improving the effectiveness and efficiency of techniques and equipment in use for the standards. Continuing UKAS accreditation. Consider/obtain extensions of scope to UKAS accreditation.

Evidence: Provision of primary humidity standards and dissemination of traceability, with UKAS accreditation maintained.

Project No.	EFM11031	**Price to NMO**	£340k
Project Title	Contact thermometry - provision of standards	**Co-funding target**	Services income
Lead Scientist	J Pearce	**Stage Start Date**	01 Apr 13
Scientist Team	J Gray, K Alston, R Veltcheva, C Elliott, G Machin	**Stage End Date**	30 Sep 14
		Est Final Stage End Date	
Sector	100% Traceability & uncertainty	**Activity**	90% NMS Infrastructure; 10% International obligations

Summary

Deliver a leading contact thermometry calibration service via:
The defined ITS-90 points Ar to Ag, efficient and effective calibration capability of platinum resistance thermometers (PRTs) with lowest target uncertainties in Europe
Fit for purpose comparison methods
Noble metal thermocouples to higher temperatures the Pd-C and Pd wire bridge temperatures

The Need

Top level traceability to reliable temperature is essential for the proper functioning of a modern economy. Many industrial processes would not function without reliable thermometry. This project aims at providing user-friendly access to a world class realisation of the current teperature scale, ITS-90. Provision of top level traceability to ISO17025 accredited laboratories.

The Solution

NPL has a very long tradition of being one of the leading European laboratories in temperature measurement. Its realisation of ITS-90 is equivalent or better than many EU NMIs as demonstrated by its performance in previous key comparisons.
Continued provision of current capability but with a) incorporation of new improved services from other research and development projects b) active participation in key comparison that would demonstrate our leading contact thermometry capability.

Metrology Capability to be delivered

Calibration capability of PRTs/HT-PRTs from the Ar to Ag point. Calibration and provision of noble metal thermcouples from 0 °C to 1492 °C (Pd-C) (and Pd-wire bridge). Certification of fixed-point cells against the national reference cells. All services to be ISO17025 accredited. Demonstration of international equivalence through participation in CCT led KC.

Project Description (including summary of technical work)

Provision of working national standard ITS-90 defining fixed points. PRT calibration capability including bridges, standard resistors, furnaces and PRTs. Measurement capability for thermocouples such as DVMs, furnaces, fixed points and homogenity characterisation capability. KC protocol development and implementation with KC partners.

Impact and Benefits

This is the base realisation of the current temperature scale, ITS-90 by contact thermometry. This is a core NMI activity and as such services many different sectors of the UK economy from industrial users to the service sector such as healthcare. Provision is generally through the supply of high level calibrations and calibrated artefacts to ISO17025 accredited laboratories both in the UK, Europe and worldwide.
Routine access to UK-based, world-class, traceable, validated calibrations of contact thermometry sensors; thermocouples, SPRTs, HTPRTs and I-PRTs, over a wide range of industrially relevant temperatures.

Support for Programme Challenge, Roadmaps, Government Strategies

Impacting all sectors where temperature measurement is important - but in particular roadmap challenge "World class realisation and dissemination of ITS-90"
Environmental sustainability, High value manufacturing (both impossible without reliable temperature measurement). Healthcare, energy generation and underpinning metrology.

Synergies with other projects / programmes

This project provides an underpinning infrastructure and capability for that links with the projects: e.g. provision of non-contact thermometry standards, thermocouple developments; in pathfinder Boltzmann and acoustic thermometry, primary radiometry.

Risks

(1) Continuity of provision depends on key equipment and staff. Mitigation: Sufficient back-up equipment and cross-training. (2) Level of uptake of new types of calibration unknown (for humidity at pressure and in non-air gases, and for TEWL). Mitigation: Possible market survey, launch, publicity. Review of uptake and customer feedback.

Knowledge Transfer and Exploitation

Ad hoc consultancies in contact thermometry, training in contact thermometry techniques, provision of UKAS ISO17025 assessors, provision of calibrated artefacts i.e. temperature sensors and fixed points

Co-funding and Collaborators

Income from ISO17025 accredited services for contact thermometry. In-kind from the KC participants.

External participants in the KC among whom will be NIST, PTB, LNE, NMIJ, NIM, INRIM, NRC, VSL

Deliverables

1	Start: 01/04/13	End: 30/09/14	

Description: UKAS accredited [or internationally validated, through KCDB/cmc entries] dissemination facility for PRTs, and thermocouples up to 1500 °C.
Provide top-level traceability to ITS-90 via ITS-90 fixed-points and top-level calibrations for SPRTs and low uncertainty calibrations for noble metal thermocouples.
This facility comprises primary level fixed-points, an ensemble of water triple point cells, a set of standard PRTs and world-class resistance bridges (e.g. F900). This capability will be provided at the NPL CMC entry uncertainty – or better for special requirements.

Evidence: UKAS accredited calibration service for SPRTs, HTPRTs and noble metal thermocouples: Pt/Pt-Rh, Pt/Pd
Participation in relevant comparisons.

Project No.	EFM11032	**Price to NMO**	£370k
Project Title	Radiation thermometry - provision of standards	**Co-funding target**	Services income
Lead Scientist	H McEvoy	**Stage Start Date**	01 Apr 13
Scientist Team	D Lowe, V Montag, R Simpson, G Machin	**Stage End Date**	30 Sep 14
		Est Final Stage End Date	
Sector	100% Traceability & uncertainty	**Activity**	90% NMS Infrastructure 10% International obligations

Summary
To maintain NPL's world leading position in radiation thermometry through the provision of non-contact thermometry standards over the temperature range from -40 °C to 3000 °C, and demonstrated through the results of international research projects. The thermometry standards will benefit increased numbers of users and manufacturers of radiation thermometry equipment via more accessible calibration services.

The Need
Radiation thermometry calibration facilities are required to demonstrate that equipment is operating correctly within the required specifications and uncertainty and is fit for purpose. This capability is required by radiation thermometry users as well as UK manufacturers to enable them to remain competitive in the global market. It is also required to underpin high temperature research and international project work so that NPL remains one of the leading NMIs.

The Solution
Radiation thermometry facilities exist in different NMIs worldwide, with NPL one of leading three. This is in terms of both capability (e.g. ability to calibrate up to 3000 °C) as well as being at the forefront in leading-edge, high temperature research.
Provision of non-contact thermometry standards facilities to cover the full range from –40 °C to 3000 °C, over wavelengths from 0.4 um to 14 um for the calibration of radiation thermometers, blackbody sources, thermal imaging systems and tungsten ribbon lamps. Ongoing improvement activities to both reduce the cost of provision and increase the outreach of the technology, to benefit the widest range of UK radiation thermometry users and manufacturers.

Metrology Capability to be Delivered
World-recognised, top-level, UK-based radiation thermometry facilities, covering the temperature range from –40 °C to 3000 °C and offering internationally-competitive levels of calibration uncertainty.

Project Description (including summary of technical work)
Provision of non-contact thermometry facilities to cover the temperature range from -40 °C to 3000 °C - these will provide a world leading calibration service for radiation thermometers, blackbody calibration sources, thermal imagers, tungsten ribbon lamps and infrared medical thermometers and will underpin NPL's involvement in leading-edge research and collaborations in radiation thermometry. Efficiency savings will be identified and implemented, both to improve cost-effectiveness in providing the facilities for the UK, and to benefit a greater number of calibration service users.

Impact and Benefits
Top-level radiation thermometry facilities, offering calibration uncertainties at the lowest level, will benefit radiation thermometry users across all industrial sectors through improved measurement and will enable UK equipment manufacturers to remain competitive in the world market in terms of capability and achievable calibration uncertainty
Top level facilities offering highly competitive calibration uncertainties result in improved performance in manufacturing and industrial process control resulting in better energy efficiency, and reduction in waste and greenhouse gases. The facilities will underpin research and international collaboration projects enabling NPL to demonstrate its competence and enabling it to maintain its world-leading position. Greater access to National Standard facilities benefit users and manufacturers of radiation thermometry equipment through more accessible services. They also impact on quality of life and medical care.

Support for Programme Challenge, Roadmaps, Government Strategies
Energy generation and transmission – emissions reduction

Environmental sustainability – resource efficiency, pollution and waste reduction
Healthcare – diagnostics
Underpinning metrology – standards
The project supports: the built environment sector (e.g. in the areas of energy efficiency and reduction of energy use); the high value manufacturing sector (world-leading measurement services result in more effective and competitive trade and manufacturing, along with greater process control, improved efficiency and reduction of waste); the underpinning metrology sector (trusted and harmonised system of measurements, and globalisation of science and technology through international collaborations).

Synergies with other projects / programmes
This project provides the essential background facilities for for the Engineering programme project 'HTFP radiation thermometry', some underpinning for "Next generation thermocouples" and has strong synergy with the 'thermography' project.

Risks
This project relies mainly on well-established technology, expertise and facilities the risks are therefore relatively low.

Knowledge Transfer and Exploitation
Calibration work and contracts are carried out for both UK and Overseas users and manufacturers. This ultimately benefits a large number of users, as a result of the 'fan out' via accredited calibration laboratories in the UK and NMIs in other countries. For example, NPL provides traceability to Land Instruments International, a UK manufacturer (and a world leading supplier of) of infrared thermometry systems (annual equipment sales of ~£22 million [2006]). That traceability enables Land to provide an objective accredited calibration service to its customers. Additionally, thermocouple users benefit via the provision of high temperature calibration services involving metal-carbon eutectics, which were developed and subsequently calibrated using radiation thermometry facilities.
Better accessibility to calibration services as a result of proposed efficiency savings will increase the number of direct beneficiaries. The facilities are also required to underpin international collaboration and research work and participation in future key comparisons.

Co-funding and Collaborators
Income via measurement services, consultancy and other third-party contracts.

Equipment manufacturers and other third parties via consultancies and contracts.

Deliverables

1	Start: 01/04/13	End: 30/09/14	

Description: Provision of non-contact temperature standards
Non-contact thermometry facilities for the temperature range from –40 °C to 3000 °C will be available for the calibration of radiation thermometers, blackbody sources, thermal imaging systems, tungsten ribbon lamps and medical infrared thermometers, offering top-level calibration uncertainties according to our UKAS scope. The facilities will also be available for international project and research collaborations.
Participation in the Euramet cmc review of radiation thermometry capabilities.
Evidence:
1) Provision of high temperature non-contact thermometry standards for the temperature range from 1000 °C to 3000 °C;
2) Provision of low to medium temperature non-contact thermometry standards for the temperature range from –40 °C to 1000 °C.

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Contract ENG&FLOWKB_EFM-12

This section contains a list of the new projects approved at the June 2012 Decision Conference and subsequently included in the NMS contract ENG&FLOWKB_NMS-EFM12.

Summary of Project costs and timescales

Proposal No	Title	Price (£k)	Start date	End date
EFM12002	Filter Radiometry	185	Oct 12	Sep 15
EFM12003	Maintenance of the national standard of mass and development of a method for the practical implementation of the redefined kilogram	145	Oct 14	Sep 15
EFM12008	Co funding for EMRP 05s Sub Nano	239	Oct 12	Sep 15
EFM12009	Co funding for EMRP MechProNo	264	Sep 12	Aug 15
EFM12010	Cofunding for UKSA QA4EO Secretariat	50	Oct 12	Mar 14
EFM12011	High temperature fixed points (HTFPs) for the new high temperature scale – TH9 Part B	152	Oct 12	Sep 15
EFM12012	Co-funding for EMRP “InK”	360	Oct 12	Sep 15

Project No.	EFM12002	**Price to NMO**	£185k
Project Title	Filter Radiometry	**Co-funding target**	
Lead Scientist	Emma Woolliams	**Stage Start Date**	1 October 2012
Scientist Team	Graham Machin, Martin Dury, Dave Lowe, Helen McEvoy	**Stage End Date**	30 September 2015
		Est Final Stage End Date	
Sector		**Activity**	

Summary

This project will provide the radiometric traceability for thermodynamic temperature measurement using filter radiometry. In a previous project we developed the Thermodynamic Optical Radiometer (THOR) for highest accuracy determination of the temperature of high-temperature fixed-point (HTFP) cells using filter radiometry. In a parallel related project (EMRP-InK) we will lead the international programme that will assign definitive thermodynamic temperatures to a set of HTFPs. This will involve our own measurements of those fixed-points made with THOR.

In this project we 'bridge-the-gap' between those two activities in order to ensure that NPL emerges as world leading in these important activities. Within this project we will determine the optimum methods for using THOR to measure fixed-point cells, we will carry out additional calibrations of THOR to obtain the best possible accuracies and we will investigate additional sensitivities of the fixed-points.

The Need

The new *mise-en-pratique* for the definition of the kelvin (*MeP*-K) enables, for the first time, thermodynamic temperature to be realised and disseminated directly at the extremes of temperature [for this project that means >1300 K]. This is a radical departure from the accepted practice of the last 85 years where temperature has been established and disseminated in terms of a defined temperature scale[7]. The *MeP*-K approach is better because true thermodynamic temperature will be realised and disseminated, permanently breaking the dependency upon a defined scale and linking directly to the kelvin, which will soon be redefined in terms of the Boltzmann constant.

This project, along with the EMRP – InK project, will ensure NPL attains a world leading position in realising and disseminating thermodynamic temperature rather than the defined scale in this temperature range. High temperature measurement is important for a wide variety of industries, including iron and steel, nuclear fuel manufacture, glass and ceramics, to name but a few.

The international project to assign thermodynamic temperatures to a set of high temperature fixed points (HTFPs) is the most challenging application of primary filter radiometry. The project will test, and prove, the capabilities of the world's leading national measurement institutes under particularly challenging circumstances. As project leaders, NPL will both lead the world community in this endeavour and at the same time objectively demonstrate our renewed and leading filter radiometry capability. Since the most challenging practical application of filter radiometry is Earth Observation, we anticipate that successful leadership of this project will have contingent benefits to our Earth Observation activities, in particular highlighting our strengths compared to competing NMIs such as PTB and NIST.

The Solution

- Ensure that we have the processes in place to use THOR as effectively as possible with HTFPs
- Ensure that THOR maintains its calibration throughout the HTFP work
- Ensure that we carry out additional tests to determine the uncertainties associated with the thermodynamaic temperature as accurately as possible

Project Description (including summary of technical work)

- Investigate different alignment approaches, and sensitivities to stray light of THOR used with a HTFP furnace. Also test the sensitivity of THOR to transportation between its calibration laboratory and the furnace laboratory.
- Investigate the sensitivity of HTFPs to previous-freeze rate using THOR as the calibration instrument. This work will be of international interest and will be written up in a paper.

[7] The current defined scale is the International Temperature Scale of 1990 the ITS-90

- Carry out calibrations of THOR before and after each measurement round for the InK project and make additional copper point measurements during each measurement round.
- Calibrate THOR at different ambient temperatures in order to understand its sensitivity to temperature. Also determine other uncertainty budget sensitivity coefficients experimentally.

Impact and Benefits

This project will enable the benefits of WP1 in InK to be achieved at the highest levels. It directly supports the realisation and dissemination of the kelvin, allowing, for the first time, thermodynamic temperature to be supplied to the end-user. It directly supports and will provide key input into the new *MeP*-K. This will support both fundamental temperature metrology and also its industrial application, particularly for where long term reliable high-temperature values are required. The project will also provide a rigorous test and demonstration of primary filter radiometry, the key radiometric technique that underpins both radiometric derived quantities and Earth Observation.
Finally, once thermodynamic temperatures have been assigned to the HTFPs, they can be used as reference points to establish a very low uncertainty, relatively low cost, radiance scale both in NMIs and also in industrial laboratories. The latter will benefit greatly in that the temperatures realised will be thermodynamic (and hence permanent and unchanging) and will give access to scale realisation uncertainties similar to those available in NMIs.

Support for Programme Challenge, Roadmaps, Government Strategies

International and national thermometry roadmaps require the dissemination of thermodynamic temperature at high temperatures within the timeframe of this project. To maintain and grow NPL's internationally-leading position in this activity, gained by NPL chairing both CCT-WG5 and the Euramet TC-T Strategy Group, it is essential that we are able to do both the thermometry and radiometry required by this programme to a world-class level. Improved filter radiometry is also an essential part of the Optical Radiation and Photonics Capability roadmap.

Synergies with other projects / programmes

This project continues the work of project 113847 TS00320203 'Improved detectors and detector scales'. That project designed, built and calibrated a new filter radiometer, which was made for the purpose of determining the thermodynamic temperature of high temperature fixed-point (HTFP) cells with the lowest possible uncertainties.
This project supports EMRP InK and its NMO co-funding project EF/2012/06.

Risks

This project is low-risk. It builds on work already completed in the NMS Detector Based Scales project and it feeds into the higher-risk InK project. This project provides the testing to lower the risk of the InK project.
The main residual risk is damage to the THOR instrument.

Knowledge Transfer and Exploitation

This project is high-level metrology and the stakeholders are the international temperature community. The project outputs will therefore be most effectively disseminated through attendance at the main international conferences, particularly Tempmeko 2013 and Newrad (2014?). In addition there will be a paper published in an appropriate peer-reviewed journal. As part of InK there is a projected international workshop at the Royal Society and this project underpins that important dissemination activity. This work will also facilitate the development of several briefing documents to the CCT and/or CCPR.

Co-funding and Collaborators

This project supports the outcome of the InK project, which involves thirteen NMIs and one stage 2 REG (Royal Holloway). The InK project, even before it begins, is already being seen as the international temperature community's most significant project this decade.

Deliverables

1	**Start: 01/10/12**	**End: 30/09/15**	

Deliverable title:

- Complete uncertainty budget for HTFP measurement with THOR based on experimental determination of sensitivity coefficients, including lab-based stray-light, transportation sensitivity and sensitivity to detector/filter temperature.
- Submit a paper on the sensitivity of HTFP cells to the rate of previous freeze
- Calibrate THOR before and after each round of NPL measurements for InK

Project No.	EFM12003	Price to NMO	£145k
Project Title	Maintenance of the national standard of mass and development of a method for the practical implementation of the redefined kilogram	Co-funding target	Services income
Lead Scientist	S Davidson	Stage Start Date	01 Oct 14
Scientist Team		Stage End Date	30 Sep 15
		Est Final Stage End Date	
Sector	70% Traceability & uncertainty; 30% Extension of SI	Activity	50% NMS Infrastructure 50% Statutory & Policy

Summary

This project involves the maintenance and dissemination of the current UK national standard of mass and undertakes the research necessary to ensure that NPL can maintain the UK mass measurement capability following the future redefinition of the SI unit of mass. This project forms the host project in 2014-5 for co-funding project EMRP project Si07 Mis en Pratique new KG NMS/EFM11036

The Need

Ensure that UK primary mass scale is realised and is internationally accepted to facilitate trade. The re-definition of the kilogram will allow the (theoretical) realization of the unit at any NMI and will address issues with the stability of an artefact-based definition. Work is already underway to find a method to redefine the kilogram in terms of a fundamental constant - the Crystal Density (Avogadro) project and the Watt balance experiments. Both projects involve the realisation of a kilogram in vacuum and have major implications for how the unit is maintained and disseminated at the national level.

The Solution

UK primary mass scale traceable to BIPM.

Maintenance and dissemination of the UK mass standard involves the maintenance and assessment of NPL's kilogram mass comparators, the annual comparison of primary platinum-iridium mass standards with the national standard.

Metrology Capability to be Delivered

Key to preparing for a new definition of the kilogram and to the implementation and continued maintenance of the mass scale after re-definition is a method to compare, maintain and disseminate the re-defined kilogram. Such a "mise-en-pratique" will need to include:·A means of directly comparing the results of Watt balance and Avogadro experiments via the transfer of mass artefacts,·A protocol for the transfer of mass standards between vacuum and air or inert gas developed to minimise the effect of the transfer on mass stability and to optimise the repeatability of the process·,A methodology for the maintenance of the mass scale between realisation using standard artefacts, stored and used in such a way as to optimise long term stability

Project Description (including summary of technical work)

Annual comparison of platinum-iridium kilograms with the UK's standard of mass. The calibration of artefacts for the direct measurement of air density and the maintenance of equipment for the indirect determination of air density, and the dissemination of the kilogram from platinum-iridium primary standards to stainless steel working standards. Continuing investigation the effect of transferring weights between air to vacuum, the effects of surface condition of weights, develop cleaning processes. Participation in international intercomparisons.

Impact and Benefits

This project will maintain the UK's primary standard of mass and establish equipment, measurement techniques and procedures for maintaining traceability for the UK mass scale and prepare for the redefinition of the kilogram. Improvement to the way in which the kilogram is realised and maintained will be beneficial to the mass scale in the UK and will allow NPL to offer the low uncertainties which are already required by a number of laboratories within the UK In future the number of laboratories requiring such uncertainties will increase and this work will ensure that NPL is in a position to meet these requirements. In order to achieve the redefinition of the kilogram a way of connecting the (theoretical) realisation of the kilogram, via the Watt balance or Avogadro experiments, with the practical mass scale needs to be developed. This work builds on NPL's knowledge base in the areas of vacuum weighing and storage, surface analysis of mass standards (and silicon artefacts) and mass cleaning. The impact will be realised by maintaining NPL's

position as the leading NMI in this area and putting us in a position to coordinate the efforts of other NMIs on this work in particular within Europe via EURAMET.
Ensures the traceability of the UK mass scale to support implementation of the UK Weights and Measures Act and ensure the redefinition of the kilogram can be practically realised as a standard

Support for Programme Challenge, Roadmaps, Government Strategies
Maintenance of the mass scale in the UK and underpinning efforts to redefine the kg.
Underpin trade and trading standards through NWML (in support of the UK Weights and Measures Act).

Synergies with other projects / programmes
Other scientific work within NPL (Boltzmann constant redefinition, Watt balance, Small Force, moisture in materials) relies on this work to provide critical measurement traceability and expertise, as does the work of other scientific areas within NPL (force, humidity, radiation, acoustics, environmental monitoring, biotechnology).

Risks
Low

Co-funding and Collaborators
Measurement services income
Several NMI s within the EURAMET area and Worldwide are collaborating with NPL in the research areas covered by this project. Collaborating laboratories will include PTB, METAS, LNE, SP, CEM, KRISS and SPRING. The BIPM are also interested in collaborating with NPL in support of its mass programme.

Deliverables

1	Start: 01/10/14	End: 30/09/15	

Description: National Kg Standard - Oct 14 - Sep 15

The annual comparison of platinum-iridium kilograms with the UK's standard of mass. The calibration of artefacts for the direct measurement of air density and the maintenance of equipment for the indirect determination of air density, and the dissemination of the kilogram from platinum-iridium primary standards to stainless steel working standards. Continuing investigation the effect of transferring weights between air to vacuum, the effects of surface condition of weights, optimum cleaning processes.
Evidence:
Annual calibration of the UK's primary, secondary and working kilogram standards and assessment of primary kilogram mass comparators.

Project No.	EFM12008	Price to NMO	239k
Project Title	Co funding for EMRP 05s Sub Nano	Co-funding target	191k (already secured)
Lead Scientist	Andrew Yacoot	Stage Start Date	01 Oct 12
Scientist Team	Andrew Yacoot, Ian Robinson, Matthew Tedaldi, John Mountford	Stage End Date	30 Sep 15
		Est Final Stage End Date	
Sector	100% Traceability & Uncertainty	Activity	100% NMS Infrastructure

Summary

The work forms part of the EMRP project SUBNANO that will meet the growing requirement for the broader dissemination of the SI unit of length at the sub-nanometre level. This will be achieved with the development of state of the art techniques for sub nanometre length metrology by improving and cross verifying the metrology of x-ray interferometers, capacitance sensors and Fabry Perot interferometers. This leads naturally to the investigation of potential portable transfer standard for verifying the performance sub nanometre displacement measuring instrumentation outside of the pure NMI environment.

The Need

Displacement measurements with sub-nanometre uncertainties are essential for the further development of the international system of physical units, the SI. Moreover, the rapid development of precision manufacturing and semiconductor industry nowadays requires position measurements with sub-nm accuracy. The industrial need for dimensional metrology at the sub nanometre level is highlighted by the ITRS Roadmap 2009 “Metrology methods must routinely measure near and at atomic scale dimensions”. It additionally states that “no single metrology method or technique can deliver all demanded information. Therefore, in order to be able to compare the results of various dimensional metrology tools and methods meaningfully, parameters beyond repeatability and precision need to be addressed. Each measurement application requires consideration of the need for … absolute accuracy (traceability to absolute length scale).” In addition, dual pattern technology requires from 2015 on an image placement below 1 nanometre [http://www.itrs.net/Links/2009ITRS/2009Chapters_2009Tables/2009Tables_CROSSCUT_A.xls, table 2009_MAT4A].Currently, positioning in semiconductor industry is controlled by capacitive sensors as well as optical interferometers. Given this is a strong need by the semiconductor industry for traceable sub-nm length measurements, both capacitance sensors and optical interferometers have to be investigated to fulfil these needs which will be addressed by this JRP. Beyond the specific example of semiconductor industry, similar needs of traceable measurements are found in a broader field of manufacturing with precision equipment (e.g. nano- or photonic technologies) or high-end instrumentation (e.g. space science) and by NMIs themselves in supporting traceable calibration of artefacts such as transfer standards for atomic force microscopy using metrological AFMS. *Indeed the recent EU funded survey of industrial metrology requirements for Nanotechnology highlighted the need for more accurate dimensional metrology [Leach et al, 2011 Nanotechnology 22 (2011) 062001].

The Solution

These industrial needs will be considered in this project by referencing capacitive sensors and optical interferometers as used by the industry to the highest accuracy reference systems (x-ray interferometers) at the NMIs.

Project Description (including summary of technical work)

The EMRP project has three techncial workpackages; Optical interferometry, capacitnce sensors and instrumentation development. NPL’s contribution is: the measurement of the permance of capacitance sensors against the x-ray interferometer, measurment of the effects of waveront curvature on optical interferometry, the development a robust quadrature fringe counting system for the x-ray interferometer, review options for transfer standards, development of prototype transfer standard and management of the instrumentation workpackage.

Impact and Benefits

The projects aims to develop improved traceability of dimensional nanometrology in high end instrumentation used at NMIs and in high tech industries e.g. semiconductor, lithography, and nanopositioning industries as well as other industries with challenging requirements such as the space instrumentation industry that requires a once only calibration that must be valid for the lifetime of the instrument.

This knowledge will result in standardised and validated measurement methods for calibrating precision instruments; will enhance the quality assurance of national metrology institutes, the calibrations they perform for customers and will improve ultimate quality of the products manufactured in Europe.

Support for Programme Challenge, Roadmaps, Government Strategies

The work supports the EMRP roadmap. And the UK NMO roadmaps for length metrology and SI fundamental metrology

Synergies with other projects / programmes

The project is partially funded by EMRP and builds on work done within the EMRP NANOTRACE project

Risks

Damage to x-ray interferometer, loss or unavailability of key staff

Knowledge Transfer and Exploitation

Calibration of capactiance sensors will be of benefit to manufactures such as Queensgate, MicroEpsilon and IBS. Their eextensive customer bases crossing many industrial sectors will benefit from the outputs from this project e.s space, semiconductors, precision displacement. In addition the wavefront modelling carried out by other partners can be applied to the NPL interferometer and used to benefit its users across NPL and those who rely on measurment services that obtain traceability via the NPL interferometer.

Co-funding and Collaborators

EMRP funding, collaborators: PTB, VSL, CMI, UME, MIKES, INRIM, TU Delft, Queensgate

Deliverables

1	Start: 01/10/12	End: 30/9/15	

Description: Successful completion of EMRP project which includes:

Evidence:

Interfaces for capacitive sensors to allow alignment with the XRI and where necessary mounting on the XRI produced Nov 2013

Sets of measurements, comparing performance of capacitive sensors with XRI, and determining agreement with theoretical models developed in WP1.3 of EMRP project completed Mar 2015

Paper presenting results submitted to refereed journal April 2015

Sub x-ray fringe positioning capability of x-ray interferometer based on quadrature x-ray fringe detection developed Nov 2013

High resolution drive system for x-ray interferometer capable of picometre resolution developed Nov 2013

Paper about quadrature fringe counting and sub fringe positioning submitted to a peer reviewed journal for publication May 2014

Management of workpackage 3 of EMRP project Jun 2015

Support of impact workpackage with contributions to papers in refereed journals and conference presentations Jun 2015

Project No.	EFM12009	Price to NMO	£264k
Project Title	Co-funding for EMRP n12 MechProNo	Co-funding target	£138(Already secured)
Lead Scientist	Andrew Yacoot	Stage Start Date	01 Sept 2012
Scientist Team	Matthew Tedaldi, Jason O'Neill, John Mountford, Nigel Jennet	Stage End Date	31 Aug 2015
		Est Final Stage End Date	
Sector	100% Traceability	Activity	100% NMS Infrastructure

Summary

The is work forms part of the EMRP project MechProNo which aims to develop metrological traceability for the measurement of the mechanical properties (adhesion, stiffness, elasticity and hardness) of nano-objects, such as nanoparticles, nanowires and nanoscale structures and composite materials. The Engineering Measurement role is to enhance the Tip Sample AFM in order to investigate the effects of AFM tip properties, the traceability of force of the AFM tip and to make measurements on nanostructures.

The Need

Nano-objects such as nanoparticles and nanotubes have shown extraordinary mechanical properties like very high stiffness and very high tensile strength. This makes them very attractive for applications, e.g. in steel, glass and concrete, light-weight materials, coatings, where the mechanical properties of materials have to be improved. A great variety of composite materials benefiting from the inclusion of nano-objects has been developed and increasingly will be developed. Therefore in order to "design" nanomaterials with new capabilities the accurate knowledge of the mechanical properties of nano-objects, like elasticity (target uncertainty 20 %), hardness (target uncertainty 10 %), and yield strength as function of diameter, length, internal structure, etc. is mandatory. These nano-objects will be examined with AFM and work is required to ensure that AFM metrology is capable of supporting these measurements of nano-objects.

The Solution

AFM is the instrument of choice for studying nano-objects since it combines high lateral and normal resolution and facilitates the determination geometrical parameters like diameter, length, shape. In addition it can be used to perform measurements of mechanical properties such as adhesion, stiffness, modulus and hardness, too. A systematic approach is required to address the issues affecting AFM metrology of nano-objects that includes series of measurements made in a controlled fashion on a metrological AFM.

Project Description (including summary of technical work)

Improved optical interferometry and an improved fibre interferometer system will be installed in the WWAFM. MEMS based actuators developed by PTB will be tested on the WW-AFM with a view to development of a traceable calibration of the cantilever's normal spring constant. The properties of the AFM tip will also be investigated and procedures will be developed to determine the AFM tip radius, tip form, contact area and the wear of the tip. A combination of blind tip estimation and Legendre Transforms will be used to determine tip shape. Nanoscale structures will be used to investigate effects due to different materials (chromium lines on glass). For this, optimised samples with selected materials will be used to enhance adhesion effects.

Impact and Benefits

Overcoming today's limits related to the precise and accurate values of the mechanical properties of nano-objects is very relevant for the research institutes, industry and universities. The impact of the JRP is related to the provision of improved methodologies to measure different nano-objects, e.g. nanoparticles, nanowires as well as nanocomposite materials, by improving techniques of AFM. The results of the JRP will be transferred to industry by case studies, tutorial and workshop. Within the tutorial the tools and the techniques to calibrate cantilevers of AFM will be directly demonstrated to Collaborators and to interested stakeholders.

Support for Programme Challenge, Roadmaps, Government Strategies

This work falls within the EUROMET, CO-NANOMET and NMO roadmaps for improved dimensional metrology and a better understanding of tip sampleinteractions and their effects on AFM dimensional metrology

Synergies with other projects / programmes

EMRP funding for this project has been secured.

Risks

Damage to AFM or nanoindentation apparatus, loss or un availability of key staff

Knowledge Transfer and Exploitation

Within the project ERMP coordinator will organize workshops for interested parties, case studies with industry. Results of the project will be disseminated via prublications, conferences and good practice guides.

Co-funding and Collaborators

EMRP funded project, collaborators, PTB, CMI, MIKES, BAM			
Deliverables			
1	Start: 01/09/12	End: 31/08/15	
Description: Successful completion of NPL Engineering Measurement contribution to EMRP project MechProNo **Evidence:** Improved optical detection system installed in WW-AFM (M12) Setup for WW-AFM tested (M18) Software for combined Blind-tip and Legendre Transform available (M12) Draft on AFM tip characterization technique available (M15) Report on AFM tip characterization techniques(M18) Software for combined Blind-tip and Legendre Transform available(M12) Nano-objects measured by CD-tips (M15) Geometries of beam like structures determined (M18) Report on influence of adhesion effects on size determination of nano-objects prepared (M24) Contribution to Impact workpackage via conference presentations and refereed papers.			
2	Start: 01/09/12	End: 31/08/15	
Description: Successful completion of NPL Materials Division contribution to EMRP project MechProNo **Evidence:** Method for tethering nanoparticles for measurement (M15) Contributions to “Best practice” for measuring mechanical properties of samples with IIT (M25) Contributions to FE modelling activities (M36) Contribution to Impact workpackage via conference presentations and refereed papers.			

Project No.	EFM12010	**Price to NMO**	£50k
Project Title	International QA4EO Secretariat	**Co-funding target**	£50k (in place)
Lead Scientist	Nigel Fox	**Stage Start Date**	01 July 2012
Scientist Team	Niall Origo	**Stage End Date**	30 June 2014
		Est Final Stage End Date	
Sector	100% Environmental Sustainability	**Activity**	100% KT

Summary
This project will support the development and implementation of the Quality Assurance Framework for Earth Observation through provision of a dedicated QA4EO Secretariat. The project is delivered collaboratively with 50% matching funding from the UK Space Agency (UKSA).

The Need
The Quality Assurance Framework for Earth Observation (QA4EO) was established via as a Committee on Earth Observation Satellites (CEOS)'s Working Group on Calibration and Validation (WGCV) initiative, in response to the Group on Earth Observation (GEO) vision for a Global Earth Observation System of Systems (GEOSS) – GEO task DA-09-01a. The aim is to produce an operational framework to facilitate interoperability and harmonization of GEO systems. This strategy is based upon a set of operational guidelines derived from best practices for implementation by the community. Four dedicated QA4EO workshops have been held since its inception to bring together experts from around the world. Discussions held at and around the workshops led to the drafting of the QA4EO principles and a set of associated guidelines.

Efforts have continued towards QA4EO implementation within CEOS through the workings of the WGCV but further work is required to help demonstrate benefits and practical implementation. Similarly, the GEO task DA-09-01a requires QA4EO implementation throughout GEOSS and this wider remit provides an even greater challenge that is beyond the working vision of the WGCV and its space focus. The QA4EO Secretariat will provide focus and momentum to support the implementation of QA4EO throughout GEOSS and CEOS space agencies.

The Solution
This project will provide a dedicated secretariat to support the further development, promotion and uptake of the Quality Assurance Framework for Earth Observation. The secretariat role requires a technical understanding of the QA4EO guidelines and the requirements of the CEOS and GEO user communities. The secretariat will work directly in support of the international QA4EO task group and help to establish detailed technical case studies to demonstrate impact and benefit.

Project Description (including summary of technical work)
The QA4EO Secretariat will serve as a point of contact for QA4EO, both directly and through a dedicated web site (www.qa4eo.org). The secretariat will also provide support and coordination of activities on behalf of the QA4EO task team. Specific activities to include**:**

- Maintain and update the QA4EO web site (www.qa4eo.org) as a central information and resource point for the user community.
- Act as primary contact point for QA4EO and process request for information
- Coordinate QA4EO guidelines and procedure peer reviews
- Draft and edit official QA4EO documentation
- Coordinate the activities of the QA4EO task group
- Provide organisation and logistics planning for international QA4EO workshop(s)
- Support the development of case studies illustrating benefits of traceability

Impact and Benefits
QA4EO has been endorsed by CEOS as a contribution to facilitate the GEO vision for a Global Earth Observation System of Systems (GEOSS). The aim of GEOSS is to deliver comprehensive and timely knowledge / information products worldwide to meet the needs of its nine "societal benefit areas". This can only be achieved through the synergistic use of data derived from a variety of sources (satellite, airborne and in situ) and the coordination of the resources and efforts of the GEO members.

To accomplish this vision, starting from a system of disparate systems that were built for a multitude of applications,

requires the establishment of an internationally coordinated operational framework to facilitate interoperability and harmonisation. The success of this framework, in terms of data, is dependent upon the successful implementation of two key principles: 1. Accessibility / Availability and 2. Suitability / Reliability. Success also requires effective communication of these principles to all stakeholders.

The critical importance of the development of climate services as part of UK space strategy is dependent on some form of QA service which will ultimately result from the uptake of QA4EO. Calls within current and future EU research programmes are looking for the development of operational QA services to meet the needs of climate which may be undertaken and delivered with key input from an NMI such as NPL.

Support for Programme Challenge, Roadmaps, Government Strategies

Quality assurance of evidence to support environmental monitoring and enables collection of climate quality data to inform Government strategies. GEO task DA-09-01a requires QA4EO implementation throughout GEOSS. Government policy is to rely on evidence based knowledge and at present the key weakness of EO data and climate impact stems from lack of rigorous QA. This is recognised by UKSA as a key priority and one which is being pushed into ESA.

Synergies with other projects / programmes

This project supports previous and on-going activity both within the Programme to develop and implement the Quality Assurance Framework for Earth Observation. It also supports the internal effort to realise the GEO vision of a Global Earth Observation System of Systems (GEOSS).

Risks

Whilst delivery of the tasks associated with the QA4EO Secretariat role is considered low risk, implementation of QA4EO throughout GEOSS is a significant challenge and relies on detailed practical support, particularly in terms of infrastructure, from the GEO technical communities and Societal Benefit Areas.

Knowledge Transfer and Exploitation

This project will promote and disseminate the outputs of the internal QA4EO implementation activity through the dedicated website (www.qa4eo.org), official QA4EO documentation including guidelines and procedures, and international QA4EO workshops.

Co-funding and Collaborators

The QA4EO Secretariat is co-funded (50%) by the United Kingdom Space Agency (UKSA).

This project will directly collaborate with the QA4EO task group which is composed of representatives from appropriate international bodies representing key GEO technical communities and the nine GEO Societal Benefit Areas. Further collaboration will be undertaken via implementation of QA4EO through the EO community, individual organisations and agencies, and their representative bodies (e.g. CEOS, the World Meteorological Organization (WMO), etc.).

Deliverables

1	**Start: 01/07/2012**	**End: 30/06/2014**	

Deliverable title: Support the implementation of the Quality Assurance Framework for Earth Observation (QA4EO) through provision of the QA4EO Secretariat. Specific activities to include**:**

- Maintain and update the QA4EO web site (www.qa4eo.org) as a central information and resource point for the user community.
- Act as primary contact point for QA4EO and process request for information
- Coordinate QA4EO guidelines and procedure peer reviews
- Draft and edit official QA4EO documentation
- Coordinate the activities of the QA4EO task group
- Provide organisation and logistics planning for international QA4EO workshop(s)

Project No.	EFM12011	**Price to NMO**	£152k
Project Title	High temperature fixed points (HTFPs) for the new high temperature scale – TH9 Part B	**Co-funding target**	£72k
Lead Scientist	Graham Machin	**Stage Start Date**	1 October 2012
Scientist Team	Dave Lowe, Victoria Montag, Helen McEvoy	**Stage End Date**	30 September 2015
		Est Final Stage End Date	
Sector	80% Process control: 20% Traceability and uncertainty	**Activity**	70% NMS infrastructure: 30% International obligations

Summary – Deliverable 4 of Project TH9 approved at 2011 Decision Conference but transferred into Contract EFM11 as this new project with a single deliverable. This project will be delivered alongside the InK EMRP project and the combined outputs are described here.

To lead world in establishing, realising and disseminating a new non-contact thermometry high temperature scale based on HTFPs, that is lower in uncertainty and more robust that the current ITS-90 above the silver point

The Need

ITS-90 above the silver point is realised by a defining fixed point (ie Ag, Au or Cu) and an extrapolation of Planck's law in ratio form. The definition is ambiguous and prone to undetectable uncertainties, which increase as T^2. This project removes the ambiguity and will allow the realisation and dissemination of T rather than ITS-90 at high temperatures, with low uncertainties. This will greatly simplify the realisation and dissemination of high temperatures at NPL and through this work at other NMIs worldwide. Finally the CCT led key comparison (KC) of the high temperature part of the scale was very unsatisfactory because there are currently no suitable artefacts able to perform a KC with the uncertainties NMIs are claiming.

The Solution

NPL is leading a 7 year-long multi-national research project, through the CIPM committee CCT-WG5, that is working towards developing robust and reliable high temperature fixed points[8] and a new high temperature scale. By Mar 2010 the project will be just over half way completed. Prototype HTFPs have been constructed in NMIJ, LNE-INM, NPL and other institutes and a selection of these are currently being used to probe the world status of primary radiometry (current pathfinder/link thermal project).

The current ITS-90 at high temperatures was a pragmatic practical means of realising a defined high temperature scale. The CCT-WG5 project when completed will allow direct access to the unit, the kelvin through primary radiometry made accessable through fully characterised HTFPs. In addition these innovations will make possible rapid low uncertainty KC. This is done through the development of modified HTFPs of "unknown" temperature suitable for use as KC artefacts.

Project Description (including summary of technical work)

Metrology Capability to be Delivered:

a) Improved scale realisation and dissemination: NPL will be one of the few NMIs capable of routinely realising and disseminating T above the silver point using HTFPs b) Ability to construct, and characterise world class HTFP cells c) Disseminate the temperature scale through these cells and/or special low uncertainty pyrometers d) Able to perform/lead comparisons/key comparisons with these or modified versions of HTFPs.

Construction of set of “primary” HTFPs of Re-C, Pt-C and Co-C for T assignment, experimental ultra-HTFP/s >2500 C. Pilot assignment of thermodynamic temperature of selected set of “primary” HTFPs by leading NMIs. Implement realisation and dissemination of thermodynamic temperature using HTFPs in NPL ISO17025 calibration facility. Investigate the effect of doping on HTFP temperature transitions and make unknown temperature artefacts for trial scale/KC comparisons. Trial of low cost, low uncertainty high performance pyrometer

Impact and Benefits

The new high temperature scale will have the following advantages over the current realisation; i) ~5x lower uncertainties ii) significantly improved realisation and dissemination – current dissemination relies on calibrated radiation thermometers which can drift the new method is self-validating and driftless; iii) realising the new scale in industrial laboratories should be simple not requiring skilled personnel; iv) first practical implemention of the mise-en-pratique for the definition of the kelvin (MeP-K) via fully assessed novel high temperature fixed points (HTFPs)

[8] High temperature fixed points are based on eutectic transitions of binary alloys of metal and carbon e.g. Co-C (1324 °C), Pt-C (1738 °C), Re-C (2474 °C)

giving direct access to the SI unit, the kelvin; v) lower realisation costs than the current HT scale; vi) NPL is leading this work and this will grow NPL's reputation as a world leading temperature NMI.
The benefits to industry are: a) Access to a robust, low uncertainty scale, via thermometer calibration or NMI-like uncertainties through supply of validated HTFPs. b) Improved calibration of radiation thermometers at high temperatures lead to better industrial measurements, lower energy use. c) In the longer term - potential for *in-process* calibrants

Support for Programme Challenge, Roadmaps, Government Strategies

Central theme of roadmap for this technical area whose aim is to realise a "step change improvement in high temperature thermometry". Addresses challenges in: Advanced manufacturing, Energy.
Support for; High value manufacturing through improved process control; low carbon through optimum utilisation of energy (reduced CO2 emissions/"zero" waste); Underpinning metrology, disruptive change

Synergies with other projects / programmes

This project is strongly linked to the pathfinder project "Implementing the new kelvin definition through ultra-low uncertainty primary radiometric thermometry at >900 K" and acts as the receptor for that projects output. In addition it is linked to the Thermal programme "Next generation thermocouples to 1500 °C" providing definitive temperatures for the HTFPs used in that project to calibrate Pt/Pd thermocouples. It is also linked with the "non-contact standards provision" project – the outputs of this project will ultimately lead to a reduction in the maintenance and realisation costs of the NPL high temperature scale

Risks

This is a highly innovative project involving partners from different disciplines and organisations. The major risks with this project a) international partners do not deliver – this is mitigated by regular contact and appointment of sub-coordinators of workpackages b) the fixed points prove unsuitable as temperature references – this can be overcome by calibrating a "local" reference set of HTFPs and then using derivatives of those to realise the scale.

Knowledge Transfer and Exploitation

At least four refereed publications. Improved scale realisation and dissemination through supply of calibrated HTFPs and development of low uncertainty high temperature pyrometers. Improved high temperature scale realisation and dissemination through improved ISO17025 accredited calibration service. Potential spin-off applications through development of in-situ validation sources for industrial processes

Co-funding and Collaborators

NMI collaborators of the CCT-WG5 HTFP research plan are putting in equal or more effort than NPL, estimated total equivalent ~8-10 FTE/year. PhD students supervised by NPL at Imperial (Case award), UVa (Spain), PUC-R (Brazil) (both self-funded). Guest worker from Japan envisaged 2011. This project is included in a proposed research topic (PRT) entitled "Novel dissemination routes for temperature" submitted to the EMRP SI Broader Scope 2011 call. External collaborators of the CCT-WG5 HTFP research plan are the following national measurement institutes (NMIs): NIST, PTB, INM, NIM, NMIJ, NMIA, KRISS, VNIIOFI. Within the UK Land Instruments a major UK manufacturer and exporter of IR thermometry equipment is interested in trialing scale dissemination by HTFPs. Potential EMRP partners for deliverbale 4 are PTB, CNAM, CEM, UME, INRIM.

Deliverables

1	**Start: 01/10/2012**	**End: 30/09/2015**	

Description: International prototype comparison of high temperature scales using HTFPs in support of CMCs. The claimed cmcs for radiation thermometry at high temperatures are currently unsubstantiated by measurements. The previous KC led by CCT was unsatisfactory in its outcome, both the range was insufficient and uncertainties too large. Here we propose a completely novel means of performing scale comparisons using a set of at least four HTFPs as comparison artefacts. These have the ability to a) achieve the range required b) form a very stable comparison reference value (artefacts are driftless) c) perform the comparison with uncertainties <0.05% of temperature. This comparison, coordinated by NPL, will be performed by circulating HTFPs between the participants. The timescale is very ambitious, given that the last KC took 10 years, but we believe this is possible given the artefacts in use and the smaller number of participants. CCT-WG5 are very interested in this work and if successful it is intended that a world KC following this method, led from CCT-WG5, will be launched. One secondary benefit of this comparison will be the assessment of the feasibility of dissemination of high temperature scales using these artefacts to industry.
Evidence: NPL claimed cmcs at high temperatures substantiated. Report to CCT and paper describing results submitted

Project No.	EFM12012	**Price to NMO**	£360k
Project Title	Co-funding for EMRP "InK"	**Co-funding target**	This project co-funds an EMRP project of total value at £650k
Lead Scientist	Graham Machin	**Stage Start Date**	1 October 2012
Scientist Team	Michael de Podesta, Emma Woolliams, Martin Dury, Dave Lowe	**Stage End Date**	30 September 2015
		Est Final Stage End Date	
Sector	50% traceability & uncertainty, 50% extension of SI	**Activity**	20% standards & maintenance 80% methodology for new capabilities

Summary

InK aims to make a step change improvement in primary thermometry over six orders of magnitude; 0.0009 K to 3000+ K. NPL will focus on providing a platform for direct dissemination of the anticipated new kelvin at high temperature (> 1000 °C) by primary radiometric methods, rigorously investigating independent methods for realisation and dissemination of high thermodynamic temperatures and by providing ultra-reliable $T - T_{90}$ data from 84 K to 933 K using primary acoustic thermometry.

(The temperature range below 84 K will be investigated in this project but by external project partners including Aalto University, PTB and Royal Holloway University of London)

The Need

Currently almost all temperature measurement around the world is based on traceability to a defined scale, either the ITS-90 or PLTS-2000 (below 1K). Defined scales are used because primary methods, based on equations of state (e.g. the gas law or Planck's law) have been intrinsically less reliable. However recent technical advances at the highest level of temperature metrology, the development of the *mise en pratique* (*MeP*-K) for the definition of the kelvin and the forthcoming redefinition of the kelvin (targeted for around 2015) provide a unique opportunity to fundamentally change the practice of temperature measurement. This project will undertake the necessary background research needed to ready the temperature community (and NPL) for the forthcoming changes to the kelvin, to provide high quality data for the (*MeP*-K) (and to resolve the discrepancies in the current low temperature scale). This project supports NMO strategic aims for exercising international leadership.

The Solution

Develop and demonstrate primary thermometry methods that will challenge and supplant the defined scales at very high (>1000 °C) [led by NPL] and ultra-low (<1 K) temperatures [led by PTB].

Determining new values of $T - T_{90}$ with the world's lowest uncertainties (≤ 1mK) between 1K to 933 K which will provide a low uncertainty data set for the *MeP*-K in the short term and in the long term develop the background primary thermometry techniques to supplant defined scales and to form the backbone of any successor scale to ITS-90.

Determining new values for $T - T_{2000}$ which will address the discrepancy in existing background data of the PLTS-2000.

Project Description (including summary of technical work)

Low uncertainty thermodynamic temperatures will be assigned to a set of high temperature fixed points; Cu (1357.77 K), Co-C (1597 K), Pt-C (2011 K) and Re-C (2784 K) through combining measurements form five European NMI/Dis and five international NMIs. NPL lead

Evaluate two methods to realise and disseminate high thermodynamic temperatures. These dissemination routes will be evaluated with the involvement of all European NMIs capable of such measurements. The two methods are:

absolutely calibrated radiometers, directly traceable to the electrical watt, the metre and the second.

known temperature references, namely high temperature fixed points (NPL participates)

Using various primary thermometry methods (acoustic, dielectric, noise, refractive index and spectral radiometry for >1 K to 933K [NPL participates with acoustic thermometry] and current sensing noise thermometry, magnetic field fluctuation and Coulomb blockade thermometry for <1 K), to determine *T* with low uncertainty. The comparison of results obtained from individual techniques will significantly reduce systematic uncertainties that affect each particular measurement type leading to an ultra-reliable low uncertainty thermodynamic temperature data set.

Impact and Benefits

From a metrology perspective this work will have a very significant impact on the world temperature community. It directly supports the realisation and dissemination of the kelvin; in particular focussing on the proposed redefined kelvin in terms of the Boltzmann constant. The benefits will be realised through the *MeP*-K, where the appropriate thermodynamic methods for a direct realisation of the new kelvin, at low and high temperatures, will be detailed. In addition, low uncertainty differences in $T - T_{90}$ will be accessed through the *MeP*-K, the actual values of which will be significantly influenced by the results of this project. The user (industry) community will welcome the fact that this work will extend the life of the ITS-90, through the mechanism of the *MeP*-K, and negate need for a change to the temperature scale at least until the 2020's.

Support for Programme Challenge, Roadmaps, Government Strategies

This project will ensure that NPL retains and grows its world leading role in the field of thermometry through directly addressing stated programme challenges. For example the pathfinder roadmap has primary acoustic thermometry in the time frame of InK (2012 and 2015). The Engineering and Flow roadmap has dissemination of thermodynamic temperature at high temperatures.

NPL, as chair of the Euramet Technical Committee for Thermometry (TC-T) led the development of a new roadmap for the thermometry area in April 2011. This, with accompanying text can be found at http://www.euramet.org/index.php?id=1652. One of the key features of the roadmap is "deployment of the *MeP*-K" as a high level objective for the second half of this decade. The research in InK and its outcomes are essential to facilitate that important goal.
Recently NPL hosted an international workshop to discuss the implications and realise the benefits of the kelvin redefinition. The research in this project was identified as high priority by the participants of that workshop to ensure to proper functioning and future development of the kelvin for the forthcoming decade.

Synergies with other projects / programmes

This project builds on and relies upon the work of current and previous NMS projects; in particular the Engineering and Flow project "High temperature fixed points" will provide a series of HTFPs for assignment of thermodynamic temperature and, through CCT provide the background international framework to gain acceptance for the novel HTFP temperatures in 2015. The Pathfinder "Boltzmann and acoustic thermometry" project provides the essential background technology to perform world leading low uncertainty $T - T_{90}$ measurements. Within the Physical programme a new primary filter radiometer is being constructed and new lower uncertainty means of calibrating the radiometer is being implemented to facilitate leadership of the thermodynamic temperature assignment of the series of HTFPs.
Objectives beyond this project are to realise and disseminate thermodynamic temperature more reliably and with lower uncertainties than the current ITS-90 above 1300 K. To prepare the radiometry group to undertake lower temperature and longer wavelength primary radiometry, to achieve world leading status of acoustic thermometry and prepare the team to implement the redefined kelvin.

Risks

This is a multi-partner project working at the cutting edge in all the temperature areas it covers; as such there are significant risk examples are:
International partners do not deliver. Mitigated by regular contact and appointment of suitable workpackage leaders.
Not all technical areas may result in reliable temperature values. Mitigated by agreeing consensus temperature values eg based on variance weighting.
Breakage of measurement artefacts during measurement campaign – multiple approaches minimises the impact

Assumptions: related NMS activities are funded, notably in the optical radiometry area.

Knowledge Transfer and Exploitation

This project is high-level metrology and as such the stakeholders are the international temperature community. Outputs from this project will be disseminated in the following ways:
Conferences: for example, Tempmeko 2013, Metrologie 2013, LT27 2014 and QFS 2015
Peer-review publications
Interaction with and technical reports to relevant committees of the CCT,
Presentations to and interactions with Euramet TC-T, annual written reports to other RMO TC-Ts
International discussion workshop at the Royal Society Kavli Centre

Co-funding and Collaborators

Co-funding has been achieved through the EMRP 2011 call. Project consortium members (those who will accede to the JRP contract) include the following national measurement institutes (NMIs), Designated institutes and universities: CEM, CNAM, CSIC, INRIM, LNE, MIKES, PTB, UME. In addition unfunded partners DIISR(NIMA), NIM, UVa and VNIIOFI and collaborators NIST, NRC and Aalto university are all contributing significant MM effort to this project. Additionally there is an integral Researcher of Excellence Grant recipient from RHUL participating.

Deliverables

1	**Start: 01/10/12**	**End: 30/09/15**	

Deliverable title: Primary thermometry from 84 K to 3300 K

NPL will

- Prepare acoustic gas thermometer (AGT) for thermodynamic temperature measurements from 83 K to at least 500 K.
- Develop and demonstrate a proof of concept AGT system operable up to 1000 K
- Provide low uncertainty estimates of T-T_{90} using AGT from 83 K to 500 K
- Write a protocol for thermodynamic temperature assignment of HTFPs
- Measure 4xRe-C, 4xPt-C, 4xCo-C and 4xCu HTFPs at start and end of thermodynamic temperature assignment campaign
- Write measurement report with interim and final HTFP temperature values, to be submitted to CCT, peer review paper
- Construct 2 x Ru-C and 1 x Pt-C HTFPs for prototype temperature comparison
- Measure and assign T_{90} values for 1 each of x Co-C, Pt-C, Re-C, Ru-C HTFPs

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Contract ENG&FLOWKB_EFM-13

This section contains a list of the new projects approved at the June 2013 Decision Conference and subsequently included in the NMS contract ENG&FLOWKB_NMS-EFM13.

Summary of Project costs and timescales

NMO Reference	Title	Proposal Value (£k)	Start Date	End Date
EF/2013/21	Novel optical methods for high temperature surface thermometry	475k	Oct 13	Sep 16
EF/2013/22	Driftless thermometers for challenging environments	300k	Oct 13	Sep 16
EF/2013/23	Primary Thermometry for the New Kelvin	579k	Oct 13	Sep 16
EF/2013/25	Temperature and humidity metrology for meteorology (soil, water, air)	400k	Oct 13	Sep 17
EF/2013/28	Upgrade of internal diameter measurement service	98k	Oct 13	Jun 15
EF/2013/29	Advanced Metrology Space (mSPACE)	528k	Oct 13	Sep 16
EF/2013/33	Standards for industrial dynamic pressure measurement	333k	Oct 13	Sep 14
EF/2013/34	Update of Dimensional Good practice Guides	110k	Oct 13	Sep 14
EF/2013/49	QA4ECV	500k	Jan 13	Dec 17
EF/2013/36	Traceable Calibration and Validation measurement infrastructure for Earth Observation and Climate	1500k	Oct 13	Sep 16
EF/2013/37	Metrology for Earth Observation and Climate (METEOC 2) EMRP co funding	915k	Jul 14	Jul 17
EF/2013/35	Upgrade of Optical Radiation Primary Scales Measurement Infrastructure	150k	Oct 13	Mar 15
EF/2013/38	Co funding for EMRP s23 Moisture in materials	339k	Jun 13	May 16
EF/2013/39	Co funding for EMRP CRYSTAL	272k	Oct 13	Sep 16
EF/2013/40	Co funding for EMRP 6 DoF	276k	Jun 13	May 16
EF/2013/41	LUMINAR - Large volume Unified Metrology for Industry, Novel Applications and Research EMRP co-funding	478k	Jun 13	May 16
EF/2013/42	Co funding for EMRP - Multi-sensor metrology for microparts	399k	Jun 13	May 16
EF/2013/43	Traceable in-process dimensional measurement for machine tools (co funding for EMRP i05 TIM)	388k	Jul 13	Jun 16
EF/2013/44	Optical Radiation Metrology Core Capability Maintenance	450k	Oct 13	Sep 14
EF/2013/45	Technical, Consultative and Standards Committee Activity for Optical Radiation Measurement & EO	178k	Oct 13	Sep 14
EF/2013/46	Technical, Consultative and Standards Committee Activity for engineering measurement	428k	Oct 13	Sep 14
EF/2013/47	Contract Management	217k	Oct 13	Sep 14
EF/2013/48	Programme Management and Formulation	176k	Oct 13	Sep 14

Project No.	EF/2013/21	**Price to NMO**	£475k
Project Title	**Novel optical methods for high temperature surface thermometry**	**Co-funding target**	£150k TSB project to be secured
Lead Scientist	Gavin Sutton	**Stage Start Date**	1 Oct 13
Scientist Team	Robin Underwood, Leigh Stanger, Gordon Edwards, Graham Machin	**Stage End Date**	30 Sep 16
		Est Final Stage End Date	30 Sep 18
Sector	80% High Value Manufacturing; 20% Underpinning	**Activity**	70% Challenge driven R&D; 30% NMS infrastructure

Summary
Many high temperature industrial processes rely on infrared temperature measurement for process control to maintain quality and reduce waste. However, there is a general consensus that the benefit of non-contact measurement is often outweighed by poor accuracy and the inherent technical challenges – i.e. surface emissivity, reflected thermal radiation, variable path transmission and surface condition (composition gradients, wave motion). This situation is unacceptable in the longer term in the face of increasing energy costs and intense drive for improved competitiveness. There are a number of new novel non-contact thermometry techniques that could address surface temperature measurement facing these challenging problems. This project will first perform a study into these novel methods and then select the most relevant to identified needs and develop a working prototype.

The Need - There is a pressing industrial need for improved accuracy non-contact surface temperature measurement. The high temperatures, harsh environments and liquid (e.g. metal) surfaces found in high value manufacturing/materials processing are not easily amenable to contact thermometry solutions, leaving non-contact as the preferred option. Classical radiation thermometry is widely used but traceability is usually lost, due to unknown/hard to quantify measurement challenges and hence bespoke solutions are very often required. The measurement challenges are significant: high levels of background radiation, unknown/changing emissivity of the surface under interrogation and transmission changes of viewports. Even using current state-of-the-art, thermometry errors in excess of 10% of the process temperature can occur, clearly demonstrating a need for improvement.

The Solution - Identify a generic measurement situation, develop and demonstrate an optical thermometry system that will address the challenges posed by the measurement situation. Namely a novel thermometry technique and clean window system that will mitigate errors due to unknown emissivity and path transmission that can be applied in a number of challenging situations. Possible solutions that may be considered are a) passive radiometric multi-wavelength techniques (completely different approach from classical multi-wavelength pyrometry) and b) active compensation for window degradation. Issues relating to high levels of background radiation and changes in surface morphology will be addressed in future projects.

Project Description (including summary of technical work)
At the end of this project, there will be a demonstrator non-contact thermometer capable of mitigating errors due to unknown emissivity and path transmission and a full evaluation report on measurements made in two processes: 1) laboratory validation target and 2) quasi-industrial trial with the NPL electron beam melter.
The project will be divided into a number of stages:

1. Study of novel non-contact thermometry methods with emissivity mitigation and a detailed sensitivity analysis of selected approach.
2. Detailed design study, lab based optical table mock-up and internal tests on laboratory validation source.
3. At the end of 2. a technical review will be performed. If promising results are obtained the project proceed as planned to develop a transportable demonstrator.
4. Field trials in quasi-industrial environment using NPL electron beam melter.
5. Exploitation plan and papers in refereed journal / trade journal (subject to IP protection strategy).

Impact and Benefits - Improved non-contact surface temperature measurement accuracy will be accomplished in industrial environments, resulting in improvements in process control and associated energy efficiency and product quality. Specifically, improvements in accuracy are envisaged in the refining of metal alloys, steel production, titanium production and potentially the petrochemical industry, in which previously, poor knowledge of the emissivity has seriously increased the uncertainty of optical temperature measurements.

Support for Programme Challenge, Roadmaps, Government Strategies
The proposed work is aligned with the NMS Engineering and Flow Programme Applied Thermometry road map – 'new non-contact techniques' as an enabling science, leading to novel sensors to deliver reliable surface temperature measurements. This was presented to and supported by the Engineering & Flow Working Group in December 12 under the "surface and novel" theme. Few if any NMIs are seriously working on these practical thermometry challenges and this activity (combined with other proposed projects such as contact surface

temperature measurement) will enable us to become leaders in novel/applied thermometry within Euramet region.

Synergies with other projects / programmes

This work aims to make use of facilities in the Materials Division, specifically expertise and use of the electron-beam button melt furnace facility to validate the instrumentation developed within the project. It is also envisaged that there will be strong links with the NPL project 'contact surface temperature measurement' which will aim to both improve and validate each other through joint cooperation.

Risks

This project is technically challenging since it aims to develop at least one novel technique to solve an outstanding measurement problem. The risk of failure will be minimised by building on NPL's previous track record of active and passive non-contact thermometry techniques such as LART and IOFT, only exploiting novel approaches to surface temperature measurement via well-established physical principles. The risk will also be managed by step-wise development, from optical bench implementation to prototype device and quasi-industrial trials. In a follow on project, final tests in a full industrial environment (see for e.g. collaborators CPI) are envisaged.

Knowledge Transfer and Exploitation - Knowledge transfer will be accomplished by a) the publication of a peer review journal article b) presentation at relevant industrial conference c) article in appropriate trade journals will provide good visibility of the novel thermometry technique(s) and their applications d) the route to commercial exploitation will be explored through technology licencing and protection of IP undertaken.

Co-funding and Collaborators

Collaboration with the NPL materials group is envisaged, in particular use of their electron beam melt furnace, access already agreed. Externally, collaboration with the Inter-disciplinary research centre (IRC), at the University of Birmingham, has already been agreed. The partner can provide, in the follow-on project, access to industrial scale materials processing furnaces to perform field evaluation trials of the demonstrator non-contact thermometer.
The Centre for Process Innovation (CPI), Redcar (the process industry part of the High Value Manufacturing Catapult) has given its support for this activity. It is envisaged that from the lessons learnt in the quasi-industrial tests at NPL the novel thermometer will need to be adapted. After that, trials in the more challenging environments as at the IRC and/or CPI can offer would form a good basis for TSB (or other funding channels) to co-support for this activity.

Deliverables

1	Start: 01/10/13	End: 30/06/14	

Description: **Study of novel non-contact thermometry methods with emissivity mitigation, window contamination amelioration, detailed sensitivity analysis of selected approach, outline design study and exploitation plan**
Report describing novel techniques that address the issues of unknown emissivity, variable path transmission and background radiation. The impact in industry of the methods will be considered and the one most likely to have a large impact will be selected for a sensitivity analysis and optical bench design. During the design phase consideration of transferability will be considered – i.e. understanding how the selected method can be adapted for industrial use.

2	Start: 01/07/14	End: 30/09/15	

Description: Final design, construction and evaluation of prototype thermometer with laboratory based trials
Experimental implementation of the chosen thermometry system capable of mitigating errors due to unknown emissivity and variable path transmission: 1) Laboratory validation target 2) Optical table based instrument. 3) Measurements with the validation target. 4) Interim report with recommendations (either continue or change direction) [by Apr 15] 5) Final report or technical paper detailing findings.

Following deliverables will only progress assuming positive results from first two deliverables

3	Start: 01/10/15	End:30/09/16	

Description: Construction of field-trials thermometer, with testing in quasi-industrial environment
1) Design of field-trials thermometer 2) Construction of field-trials thermometer 3) Field trial in NPL's electron beam button furnace. 4) Report or technical paper detailing findings.

Project No.	EF/2013/22	**Price to NMO**	£300k
Project Title	**Driftless thermometers for challenging environments**	**Co-funding target**	£200k (EMRP)
Lead Scientist	Michael de Podesta (PAT) / Jonathan Pearce (PJNT)	**Stage Start Date**	1 Oct 2013
Scientist Team	Michael de Podesta, Gavin Sutton, Robin Underwood, Jonathan Pearce, Claire Elliott, Graham Machin	**Stage End Date**	30 Sep 2016
		Est Final Stage End Date	
Sector	80% Advanced Manufacturing, 20% Energy and environment	**Activity**	50% Challenge R&D 50% NMS Infrastructure

Summary This project will exploit two different primary thermometry methods to develop practical sensing tools for monitoring temperature in hostile environments. Both are potentially driftless temperature sensing systems. The first, practical acoustic (PAT) is at a later stage of development whilst the second, practical electrical noise thermometry (i.e. practical *Johnson* noise thermometry, PJNT), is a new approach for NPL that offers distinct advantages and is currently only research tool in a limit number of institutes. Target sectors include energy generation (nuclear, gas/coal) and advanced materials processing. The overall objective is to develop prototype practical thermometry sensors capable of providing driftless temperature sensing with a target uncertainty of better than a factor 10 on current state of the art.

The Need: Temperature is the single most measured control parameter in industry. There is an on-going need to improved temperature sensing because of poorly understood and uncertain sensor drifts (e.g. thermocouple) in challenging/hostile environments. Due to this problem, that cannot be resolved with conventional sensors because of their reliance on calibration and hence loss of traceability to ITS-90 in use. More radical solutions i.e. use of practical primary sensors, are required to solve this issue.

The Solution: Develop two practical primary thermometry approaches for driftless hostile environment thermometry: namely practical acoustic and Johnson noise thermometry. Two approaches are required because of the wide variety of challenging environments encountered and because of differing requirements depending upon the measurement required – for e.g. PJNT is essentially a point sensor, and is able to cover a much wider temperature range (-273 °C to >2500 °C) whereas PAT is not.

Project Description (including summary of technical work)

Primary acoustic thermometry is the most accurate technique of primary thermometry ever devised (from -266 °C to 250 °C) and has been implemented in a number of NMIs. NPL has taken this technique and developed a practical approach to acoustic thermometry with preliminary tests (as part NMS E&F Programme project TH1 and the EMRP project Metrofission) that have confirmed that practical acoustic thermometer sensors is feasible, and a suitable development candidate for tackling temperature measurement in extreme environments has been realised. However, the acoustic thermometry technique is not yet completely ready for widespread use in industrial environment.

To date the best practical acoustic thermometer sensors we have tested – using a silica tube – a calibration at 20 °C were sufficient to yield the temperature at ~ 1000 °C within 2 °C. This level of agreement means that we can convincingly state that we understand all of the physics taking place in the device. However a silica device is not practical for use in a harsh environment. Three developments are required which will be tackled by this project: regarding the size and shape of the sensor, the durability and drift, and the temperature range. These issues will be addressed in this final phase of the research activity leading to exploitation of the technique.

Johnson noise thermometry is a means of measuring thermodynamic temperature through the measurement of electrical noise generated by random thermal agitation of charge carriers in conductors. Noise thermometers are currently developmental artefacts at a few NMIs for metrology applications concerned with sub-mK accuracy. As a thermodynamic temperature sensor, it is driftless, and does not require calibration; it is insensitive to the material condition of the sensor and therefore immune to the effects of high temperature and ionising radiation. As such, noise thermometry has the potential to implement a step change in temperature measurement in harsh environments.

Noise thermometry is a suitable candidate for tackling the problem of temperature measurement at extreme temperatures (>2500 °C) and in extreme environments, such as that of molten corium, as well as routine temperature measurement at moderate temperatures in a wide range of challenging environments (300-1500 °C). We plan to develop an initial practical Johnson noise thermometer prototype with a target uncertainty of 1 °C. Two key challenges are construction of a robust sensing probe and development of compact electronics capable of amplifying the small noise voltage that can operate in electrically noisy environments.

Impact and Benefits:

Wide range of industrial applications will benefit from this work from sensor manufacturers (such as high end thermocouple manufacturers CCPI) and users (such as Rolls Royce, aerospace).

One big benefit to users will be that the sensing methods are driftless and thermodynamic not requiring recalibration and are hence ideal for long term monitoring and control – particularly in safety critical situations.

NPL will gain a lead in practical primary thermometry for benefit of UK and NPL as a leading NMI.

Better temperature sensing is important to reduce energy use (and hence CO_2 emissions), improve product quality and aid "zero waste" manufacture – all improving industrial competitiveness.

Support for Programme Challenge, Roadmaps, Government Strategies

Practical acoustic and Johnson noise thermometry are both identified challenges on the E&F Applied thermometry roadmaps. They feed into underpinning, advanced manufacturing and energy and environment drivers.

Support for "in-situ traceability", "improved thermometric devices" and "practical primary thermometry" are identified as research priorities on the Euramet TCT roadmap.

Lessons learned from this project, in the latter half of this decade, will feed into development of our own JNT primary thermometry activities as outlined in the primary thermometry roadmap.

Synergies with other projects / programmes

The practical acoustic thermometry builds on the extensive primary thermometry work that was undertaken to determine the Boltzmann constant. Practical acoustic thermometry has had preliminary development in E&F project TH1 and also in EMRP project Metrofisson.

Primary electrical (Johnson) noise thermometry capability is now established in some NMIs around the world and we will take benefit from that through the InK project and also ongoing collaborations with NIM, China. *Practical* Johnson noise thermometry has had little sustained attention though there is some limited activity within the HiTeMS project.

Risks

PAT risks are associated with keeping the gas clean and preventing dimensional changes of the tube due to aging/or slow oxidation. For PAT these risks increase with the temperature.

PJNT cannot be made to work at the 1 °C uncertainty level. Risk is moderate; the chief risk is susceptibility of the device to external electrical noise; there are a range of mitigation strategies. Risk after mitigation: low.

PJNT part of this project requires us successfully securing EMRP MetroSAFE project funding and associated Research Excellence Grant (REG).

Knowledge Transfer and Exploitation

For PAT: case study in trade press. TSB & direct industrial funding to be sought for further industrial trials. At least one paper on PJNT. For PJNT, licensing arrangement to be agreed between Isothermal Technology and Metrosol Ltd. This also represents the route to market.

Co-funding and Collaborators

Development of both PJNT and PAT has been proposed for the EMRP PRT "MetroSAFE". Collaborators for JNT are Isothermal Technology and Metrosol Ltd. In addition PAT has been proposed as a thermometry method for medium and long term nuclear waste stores EMRP PRT "MetroDecom"

Deliverables (only active deliverables shown)

1	Start: 01/10/13	End: 31/04/15	

Description: Modified PAT device with technology demonstrating tests in at least one industrial environment.
This will provided a robust case study to facilitate exploitation on a wider scale through TSB and/or license technology.

2	Start: 01/05/14 (EMRP start date)	End: 30/09/16	

Description: Initial prototype of a practical electrical noise thermometer demonstrated to 500 °C.
PJNT electronics and sensor system developed and integrated (Y1+Y2). Capability tests in laboratory in simulated industrial conditions initially to 500°C (Y3). Refereed paper and recommendations on next steps.

Project No.	EF/2013/23	**Price to NMO**	£579k
Project Title	**Primary Thermometry for the New Kelvin**	**Co-funding target**	
Lead Scientist	Michael dePodesta (AGT)/Helen McEvoy (LTPRT)	**Stage Start Date**	1 Oct 13
Scientist Team	MdP, Robin Underwood, Gavin Sutton HMcE, Aaron Whittam, Graham Machin	**Stage End Date**	30 Sep 16
		Est Final Stage End Date	30 Sep 19 (LTPRT)
Sector	100% Underpinning metrology	**Activity**	100% Long term SI

Summary

This project supports primary thermometry by acoustic methods and begins activity to perform ultra-low uncertainty low temperature primary radiation thermometry (LTPRT). The objective is to determine the difference between thermodynamic temperature (*T*) and the international temperature scale of 1990 (ITS-90) (T_{90}), T-T_{90}, up to the silver point (1235 K). Measurements will be performed in the overlap between acoustic and primary radiation thermometry and *T* measurements of a set of high performance fixed point blackbody cavities. NPL's leadership will be enhanced in the international temperature community, supporting the new kelvin, the emerging *mise en pratique* for the definition of the kelvin (*MeP*-K) and provide vital new data for the future new temperature scale (in 2020's).

The Need

The ITS-90 is more than 20 years old, and was based on a heterogeneous set of temperature values. In the long term the ITS-90 be replaced with a lower uncertainty, more thermodynamically accurate scale. This project will also support our leadership in implementing the new kelvin and the emerging *MeP*-K.

Current state of the art (NPL and elsewhere)

NPL is one of the world leading acoustic gas thermometry (AGT) groups and will shortly publish a Boltzmann constant determination with the lowest ever uncertainty. Precision measurements, by AGT, of $T - T_{90}$ are underway at NPL in the range from 125 K to 400 K using existing facilities. This project will provide support to ensure delivery of InK commitments in at higher temperatures extending towards 1000 K. A new activity in lower temperature primary radiation thermometry (LTPRT) is proposed from 500 K to 1300K. This is a region of the temperature scale that has little data and would *strongly* benefit from further investigation. The current T-T_{90} data by radiometric means has large uncertainties. We will partner NIST (agreed in principle) to develop a project at NPL to determine T-T_{90} with the lowest radiometric uncertainties and determine *T* of the Sn, Zn, Al and Ag points with unprecedented precision.

The Solution

The objective would be to develop a coherent set of NPL data of T-T_{90} from 125 K to 1300 K with substantial overlap by the two methods to minimise the temperature uncertainty.

In AGT the aim would be to progress from 125 K to first the Sn (505 K) and then Zn (693 K) point. Background work will be performed to attempt temperatures up to the Al point (933 K) by 2016.

In LTPRT the objective would be to develop low uncertainty data T-T_{90} for 500 K to 1300 K both at fixed points and through calibrated thermometers by a variable temperature pressure controlled heatpipe blackbody (to Sep 2019).

Metrology Capability to be Delivered

In AGT: measurements up to the In point temperature (430 K) with the current apparatus then modifications attaining the Zn point. A novel resonator will be designed and constructed to approach 1000 K.

In LTPRT: The following world leading metrology capability will be delivered: i) a pressure controlled heat pipe blackbody comparator for determining T-T_{90} from 500 K to 1300 K. ii) primary fixed points blackbodies of Sn, Zn, Al, Ag. iii) Partner with NIST to provide the primary radiation thermometer, calibrated for *T*, with ultra-low uncertainties.

Project Description (including summary of technical work)

In AGT: Modify current equipment to perform measurements to the Zn point. A novel resonator design based on a cylinder will be elaborated to take AGT to higher temperatures (1000 K). Calculations indicate that this design allows microwave assessment of resonator dimensions at all temperatures. Preliminary experiments show that sound can be coupled through acoustic waveguides; however it must be recognised this activity is extremely challenging. Values of T-T_{90} will be available over the range by acoustic methods by the end of this project.

In LTPRT: By the end of Sep 2016 capability for T-T_{90} measurements will have been established. A pressure controlled heat pipe blackbody comparator will be designed and acquired. A set of primary fixed point blackbodies will be constructed. Formal cooperation with NIST will be established and high performance LTPRT acquired.

Impact and Benefits

NPL & NMS: NPL is one of the world leading thermometry laboratories. This project will significantly enhance our reputation in world thermometry at an important juncture of the field (the new kelvin, preparation for implementing the *MeP*-K and the pressing need for essential T-T_{90} measurements for the future temperature scale in the 2020's.)

Euramet: NPL is one of the leading contributors to the Euramet Technical Committee for Thermometry, leading two

EMRP thermometry projects including the important InK project. This work facilitates a successful contribution to AGT in InK and positions NPL to undertake leading LTPRT and so continue its leading position post InK.
International: NPL, through leading the EMRP project InK, is having a strong influence on the direction of nearly all world thermometry research. In addition NPL plays a leading role in CCT chairing WG5 (radiation thermometry) and contributing strongly to its other working groups including, in particular, future strategy. These high level projects will cement collaborations with key NMI partners and strengthen our influence further within CCT.

Support for Programme Challenge, Roadmaps, Government Strategies

This project is central to the programme challenge of being internationally leading. The proposed work is clearly enunciated on the Engineering and Flow Programme: primary thermometry roadmap. This project directly supports: a) the NMS strategy for the DBIS National Laboratory to "maintain NPL's leading international status" "shaping (and leading) European priorities for metrology research" and "exercising international leadership".

Synergies with other projects / programmes - The AGT part of this project builds on the Boltzmann constant & primary acoustic thermometry project (TS004030106). There as reported to the working party through NMS reporting resource was used to complete our world's lowest uncertainty determination of the Boltzmann constant. We now need additional resource to catch up our contribution to the InK project and to complete that activity successfully. There are strong synergies with the EMRP InK project which this work supports and prepares the team (and the international thermometry community) for the kelvin redefinition. Additional strong links with the NMO Engineering and Flow Metrology Knowledge Base Programme project 115486 - NMS/EFM1103232: Radiation thermometry – provision of standards

Risks

There are significant technical challenges associated with both aspects of this project.
As AGT rises to higher temperatures the materials, transducer and thermometry challenges all increase, risk of damage to resonator artefacts is a real possibility and we will need to use all technical resources available to address these issues. The risk is somewhat ameliorated by working in partnership with other InK partners in the same fields eg NIST and INRIM.
In LTPRT we will use our leading expertise in design and construction of isothermal environments to make world class variable temperature and fixed point blackbodies. We will lower risk of delivery by partnering with other key NMIs, already in principle agreed with NIST, so that together a world class experiment will be delivered by NPL.

Knowledge Transfer and Exploitation

Strong linkages to CCT and the international temperature community will ensure that the results of this work will benefit the world temperature community by providing more reliable values for $T - T_{90}$ over the entire temperature range from 125 K to 1300 K. KT will be through refereed papers, presentations at conferences and working papers to the CCT. Exploitation will be through the results making a strong contribution to the consensus values for T- T_{90}, initially for the *MeP*-K, in the latter half of this decade and ultimately for the future ITS-xx.

Co-funding and Collaborators

Co-funding will come from InK. In-kind will come from NIST who through long investment is able to provide world class LTPRT at very modest cost. Additionally we will collaborate with INRIM, who has the leading capability on the design of variable temperature heat pipes. Collaboration with NIM and PTB on LTPRT is also envisaged.

Deliverables (only active deliverables shown)

1	Start: 01/10/13	End: 30/09/15	

Description: ***T*-T_{90} values, by acoustic thermometry, at least to the Zn point formally reported to CCT-WG4**

Measurements according to the InK schedule of T-T_{90} to the In point, modification of apparatus and then subsequent measurements to Zn point and if possible to ~1000 K. Refereed paper reporting results and/or report to CCT-WG4.

2	Start: 01/10/13	End: 30/09/14	

Description: Full design of lower temperature primary radiation thermometry facility

A full design of the facility, including variable temperature pressure controlled heatpipe blackbodies, fixed point blackbody cavities – including a transportable device to confirm the stability of the radiation thermometer during transportation from the institute providing the primary radiometry to NPL), agree specification of LTPRT.

3	Start: 01/10/14	End: 30/09/16	

Description: Construct and commission lower temperature primary radiation thermometry facility

Facility will be constructed and commissioned at NPL, including the four fixed point radiators, the pressure controlled heatpipe apparatus and primary radiation thermometer (including calibration+stability) confirmation at partner NMI.

Project No.	EF/2013/25	Price to NMO	£400k
Project Title	Temperature and humidity metrology for meteorology (soil, water, air)	Co-funding target	£300k
Lead Scientist	S Bell/J Pearce/M de Podesta	Stage Start Date	1 Oct 2013
Scientist Team	S Bell, P Carroll, P Miao, M de Podesta, J Pearce, T Gardiner, R Underwood	Stage End Date	30 Sep 2017
		Est Final Stage End Date	
Sector	100% Environment	Activity	100% NMS Infrastructure

Summary

Metrology support for meteorology and climate studies, providing improved uncertainty analysis of meteorology temperature and humidity data; [and future EMRP project: improved airborne reference temperature and humidity measurements; improved reference seawater temperature measurement; and improved reference soil moisture measurements.]

The Need

- Surface and atmospheric measurements of air temperature and humidity are vital to estimates of regional and global climate, and trends in these. Demand is growing for climate assessment with greater reliability, on a variety of timescales, and over both global and smaller localised regions
- Interpretation of temperature and humidity data record is highly complex to achieve the required robustness and credibility. Attempts to predict climate trend still carry large uncertainties.
- Metrological robustness is beginning to be addressed for routine observations of air temperature, pressure, humidity, but this needs to extend to variables of sea temperature and soil moisture which are important to understanding atmospheric humidity and temperature interchange (heat and mass transfer) with sea and land.
- Sea temperature measurements at the required uncertainty of around 1 mK are not credibly supported by available measurement traceability and uncertainty analysis.
- Soil moisture instruments have limited discrimination of surface water and depth profile (calibrations even less so). Methodologies generally give average water content indirectly, using techniques such as microwave capacitance and time-domain reflectometry. Soil moisture calibration approaches typically use excavated soil, not reflecting real soil conditions - surface layer moisture, and stratified sub-surface structure of soil.
- Satellite EO requires estimation of land surface emissivity, which depends on surface water content.

The Solution

- Data for thermometers and hygrometers in meteorological use will be gathered and analysed to identify error characteristics and produce uncertainty models specific to instrument types, using Monte Carlo or other approaches. Uncertainty models relevant to meteorological measurements will then be applicable to historic and future weather observations, and in climate analyses.
- Calibration test beds for soil moisture will be developed using simulated or actual soil, representing real soil structures and moisture profiles. Moisture measurement approaches using point measurement, integrating measurement and surface measurement, will be combined to develop test bed characterisation, and potential calibration methods for commercially-available soil moisture instruments.
- A specialised calibration methodology for deep-sea thermistors will be developed. Contributions to uncertainty would be studied and reduced, by characterisation of self-heating, non-linearity, stability, localisation of the sensing element, stem conduction, lead wire resistance, insulation resistance, and a new interpolation scheme. Characterisation will include tests of deep sea (pressurised) operation, and dynamic response.
- Free-space combined atmospheric temperature and humidity sensing will be developed from proof-of-concept to a working airborne instrument, combining rapid non-contact measurements of temperature (acoustic) with water vapour (TDLAS), and pressure. Potential interferences will be considered and addressed where possible for robustness against ambient acoustic noise, cloud, precipitation, surface wetting, wind, and solar radiation.

Project Description (including summary of technical work)

- Study of uncertainties characteristic of meteorological measurements of humidity and air temperature, resulting in input of these to improve meteorological climate data analysis and data homogenisation, working with several collaborators, published in several peer-reviewed papers in support of validated meteorological “data products” covering a variety of humidity quantities used in climate analysis.
- Proposed EMRP follow-on project MeteoMet2, expected to include:
  - Improved measurement methods and calibration for soil moisture content, especially aiming to give traceability for surface-level and depth information. Improved methodologies for in-situ calibration of soil

moisture sensors, avoiding disruption to soil structure.
  - Development of methodology for traceable calibration of deep-sea thermistors in fixed points in order to obtain lower uncertainties by characterising self-heating, non-linearity, stability, and other aspects of performance, with characterization of thermometers under real operating conditions (sea campaigns).
- Implementation of free-space acoustic thermometer along with free-space water vapour measurement, in airborne form, using NPL balloon launch, or other airborne platform.

Impact and Benefits

- Work will support robust analyses of climate, with elucidation of contribution of temperature and humidity measurement uncertainty
- More accurate and specialised measurement of soil moisture and sea temperature will impact on understanding, analysis, and modelling of meteorology and climate observations
- Improved calibrations for soil measurements will impact on satellite earth observation, and on hydrology including measurement and prediction of drought soil conditions - with potential impact also on agriculture and water management strategies.
- Brings to fruition proof-of-concept of novel free-space thermometer developed in [first] MeteoMet.
- Will provide traceability to ITS-90 European Oceanic and Polar Research centers the in the course of the work.

Support for Programme Challenge, Roadmaps, Government Strategies

Addresses strategic priority area of climate change, which also features on NMO roadmaps for temperature, and for humidity and moisture.

Synergies with other projects / programmes

- Synergy with ongoing provision of diverse humidity/temperature instrument calibrations. Synergy with proposed NMO project (Mathematics and Modelling Group) on *analysis of noise trends /uncertainty evaluation in geophysical time series data*; and with *SENNET* (Sensor networks) EMRP topic proposal, and other cross-team within NPL (EarthObs, Atmospheric measurements)
- EMRP Metefnet2 envisaged work will :
  - Build on and extend benefits of MeteoMet/TH2 work on free-space air temperature measurement.
  - Build on on-going thermometry capability in NMO programme
  - Synergy with (but not duplicating) NMO project starting 2013 on moisture metrology (co-funding METefnet), and builds on existing capability in moisture work.

Risks - Technical risks (various). Risk that EMRP bid is unsuccessful

Knowledge Transfer and Exploitation

- Collaboration with Met Office will supports widely exploitable data products used for analysis of climate
- Proposed EMRP MeteoMet2 (and MeteoMet legacy) provides strong KT channel, and collaboration links. Resulting deliverables will result in new capabilities to provide measurement services and consultancies
- Each deliverable will lead to one or more peer reviewed journal publications.

Co-funding and Collaborators

Collaborators will include: UK Met Office Hadley Centre, International Surface Temperature Initiative Steering Committee, and others such as NOAA, UEA, instrument suppliers and meteorology calibration labs.
EMRP proposal MeteoMet2 (if successful) will include collaboration from National Oceanography Centre Southampton, WMO, many national meteorology organisations, universities, and at least 10 NMIs.

Deliverables

1	Start: 01/10/13	End: 30/05/14	

Description: Initial review of uncertainties characteristic of meteorological measurements of humidity and air temperature in collaboration with Met Office. Findings to feed into future projects (e.g. MeteoMet 2).

2	Start: 01/10/14	End: 30/09/17	

Description: EMRP MeteoMet2 project content unconfirmed, possible NPL actions envisaged include:

- Comprehensive study of uncertainties characteristic of meteorological measurements of humidity and air temperature, resulting in input of these to improve meteorological climate data analysis and data homogenisation.
- New calibration technique for soil moisture measurement.
- Free-space atmospheric temperature-humidity instrument extended from proof of concept to airborne version.
- Seawater temperature measurements evaluated, providing uncertainty analysis for application.

Project No.	EF/2013/28	**Price to NMO**	£98k
Project Title	**Upgrade of internal diameter measurement service**	**Co-funding target**	£60k pa
Lead Scientist	Bruce Duncan	**Stage Start Date**	October 2013
Scientist Team	Mass and Dimensional Group, Engineering Measurement Services Group	**Stage End Date**	June 2015
		Est Final Stage End Date	
Sector	100% High value manufacturing	**Activity**	100% NMS infrastructure

Summary An essential service, delivering ca. 120 calibrations (with considerable fan out) per year, relies on outdated sub-systems that could fail at any time causing disruption to industrial users of the services. This project aims to ensure that proactive action is taken to prevent failure and ensure the long-term future of these well used services.

The Need: This NPL built facility supplies key measurement services to industry but is reliant on sub-systems that are no longer supported and are over 30 years old. Failure of these sub-systems would cause disruption to services and would seriously inconvenience UK industry. Maintenance costs and disruptions to services caused by breakdowns are increasing. Funding for significant upgrades is not included in the normal maintenance project.

The Solution To modernise and make efficiency improvements to the equipment that provides this service to ensure the availability of this service for the foreseeable future.

Project Description (including summary of technical work)

The facility that is in need of update is the NPL Internal Diameter Measuring Machine:

Internal diameter measuring machine (ring gauges, bore diameter)
Replace IT hardware and laser interferometer system. Potentially change motor driver hardware and temperature measurement system. Recode software to NPL level 3. Fully test and take part in any relevant international comparisons. Update technical procedures. Staff training with new system.

Impact and Benefits

This service provides regular calibration services to industry: supporting UK instrument manufacturers, major advanced manufacturers in automotive, aerospace, defence and medical devices sectors, pharmaceutical and health and safety laboratories. The internal diameter facility is also used to disseminate traceability within NPL (e.g. to CMM services, XCT, Freeform, API thread gauges). The project will remove the risk of equipment failures that shut down these services for considerable periods (potentially permanently if funding for replacement is not available). The new instruments will enable delivery of enhanced measurement services for industry and reduced maintenance cost to the NMO. The upgrades of this facility would ensure continuation of this calibration service in the medium to long term.

Support for Programme Challenge, Roadmaps, Government Strategies

Measurement Priorities for Design Engineering and Advanced Manufacturing Roadmap -Quality assurance for advanced manufacturing – quality control and process capability. The fan out of traceability from calibrations delivered through these facilities enables continuation of high value manufacturing activities in critical sectors such as aerospace and defence.

This proposal supports the NMO's aspiration for the knowledge and skills within the NMS to be shared in order to achieve maximum economic and social impact.

Synergies with other projects / programmes

NMS/EFM11029 Dimensional Facilities: Essential support
NMS/EFM11004 Towards verification and calibration of Industrial XCT systems
Proposed Advanced CMM technologies project
Enhanced NPL facilities have the potential to support multiple NMS projects across the whole of NPL.

Will support Product Verification Network activities.

Risks

Low risk – usual technical risk associated with software development but experienced NPL staff available to advise. Risk that parts of the systems (e.g. motor drives) not intended to be replaced may not be compatible with new IT systems and equipment procurement budget may be higher than anticipated.

Knowledge Transfer and Exploitation

The main method of knowledge transfer will be through provision of measurement services. Presentations and trade press articles about the new facilities will be produced to publicise the capabilities. Knowledge gained through upgrading these facilities will be used to train and develop staff in the Engineering Measurement Services group, enabling newer staff to take a greater role in maintaining NPL built facilities, reducing reliance on senior staff.

Co-funding and Collaborators

Co-funding will result for on-going measurement services income streams (approximately 120 calibrations per year). Regular customers include Pyser, Taylor-Hobson, Trescal, Rolls-Royce and AWE.

Deliverables (only active deliverables shown)

1	Start: 01/10/13	End: 30/06/15	Cost: £98,000

Description: Enhanced NPL internal diameter measuring machine

Replace IT hardware and laser interferometer system. This may result in a change the motor driver hardware and temperature measurement system depending on compatibility. Recode software to NPL level 3. Fully test and take part in any relevant international comparisons. Update technical procedures. Revise uncertainty budgets. Staff training with new system. UKAS accreditation.

Project No.	EF/2013/29	**Price to NMO**	£528k
Project Title	**Advanced Metrology Space (mSPACE)**	**Co-funding target**	£100k grant/3rd party, 1 licensee
Lead Scientist	Ben Hughes	**Stage Start Date**	1 October 2013
Scientist Team	Dan Veal, Andrew Lewis, Ben Hughes, Alistair Forbes	**Stage End Date**	30 September 2016
		Est Final Stage End Date	
Sector	100% High value manufacturing	**Activity**	100% Challenge R&D

Summary

Finalisation of the Metrology Space concept prototype from the previous NMO project into a fully working, robust, large volume metrology system, suitable for on-site work and industrial dissemination, together with a method for performance verification of the *mSPACE* system which can also be used to verify similar, lower accuracy, commercial systems. In a previous NMO project we demonstrated the ability of the Metrology Space camera concept to operate at short range in prototype form using 3 cameras. The system achieves its uncertainty reduction through the use of targets which do not have the limitations of conventional photogrammetry targets (*e.g.* distortion at oblique angles, limited visibility arcs).

The Need

Large Volume Metrology (LVM) users who cannot afford laser trackers tend to use photogrammetry systems as a cheaper alternative. However, conventional photogrammetry systems are accuracy limited to around 1 part in 10^4, with the very best systems (operated in controlled environments) achieving 1 in 10^5. For many users in aerospace, automotive and high value manufacturing, this accuracy is insufficient. Laser trackers are also single point 3DoF measurement devices unless equipped with either lower accuracy 6DoF probes or scanners. A higher-accuracy, real-time, relatively cheap, scalable, multi-user, frameless coordinate measurement system capability is the 'holy grail' for advanced high-value manufacturing. The nearest to achieving this is 'indoor GPS' (iGPS) which uses fanned infrared beams, but it is fundamentally limited to around 200 µm to 250 µm accuracy and is not selling well. Aerospace users have stated that accuracies of 100 µm or better, over ranges up to 5 m to 10 m, are required to enable automated inspection and control of automated robotic systems. No system exists that will fulfil these requirements. Furthermore, R&D into future advanced manufacturing, as exemplified by the EPSRC Light Controlled Factory project, will require instruments with better accuracy and traceable verification of such devices, including robust uncertainty reporting. Whilst there are some commercial systems available of lower accuracy there are no NMIs offering performance verification for such systems. The FSI system developed in the LUMINAR project is higher accuracy and much more expensive.

The Solution

A novel combination of 'dumb' omni-directional targets, high resolution real-time cameras, novel illumination (of workspace) and innovative data processing algorithms, could provide the required functionality at reasonable cost. This follow-on project will extend the work undertaken in the earlier Metrology Space project to produce a longer range multi target, multi camera system with integrated software, operating in real-time, with output of measurement coordinates (3D and 6D) as well as covariance matrix representation of the uncertainties, compatible with other metrology tools and software. Key to exploitation of this '*mSPACE*' system will be demonstration in a typical end user environment as well as proof of full accuracy in NMI-based testing. Additionally, to verify the performance of *mSPACE*, a performance verification technique will be developed. This could also be used on commercial equipment.

Project Description (including summary of technical work)

The project builds on the initial work performed under the previous Metrology Space project. The project takes the prototype systems and software to a stage where they are suitable for use in a real-world measuring task, as well as developing a performance verification technique to test the achieved accuracy. R&D tasks include:

- Improve robustness of existing hardware and increase number of sensors and targets.
- Develop algorithms for 3D and 6D target tracking with multi-sensors.
- Improve robustness of target identification and location algorithms.
- Incorporate dynamic models to deal with target motion, station drift.
- Detailed error modelling and error propagation to output target location uncertainties in *e.g.* covariance matrix representation.
- Develop a performance verification technique for *mSPACE*, which is also suitable for commercial systems.
- Make measurements in an NMI and non-ideal environments, *e.g.* at N-AMRC or AMRC as well as NPL.
- Peer-reviewed papers and conference presentations *e.g.* LVMC, CMSC.

Impact and Benefits

Time taken for LVM in industry using *e.g.* photogrammetry costs £10k per day of depreciation on large items. Existing

systems such as laser trackers are too expensive, too inflexible, too slow or too inaccurate, or a combination of these. An *mSPACE* system with real-time live coordinate output will reduce the time taken for photogrammetry setup, be more flexible than photogrammetry and increase the available accuracy, making significant savings for end users. *mSPACE*, which is deliberately designed to be cheaper than the FSI concept in project LUMINAR, is ideally suited for 6DoF tracking of medium accuracy robots, to improve their positioning accuracy, and for stability/deflection monitoring of tooling jigs and for medium accuracy tracking items moving in a 3D factory environment.

Support for Programme Challenge, Roadmaps, Government Strategies

Direct fit to NMS Road Map for dimensional large volume metrology and also the corresponding EURAMET TC-Length roadmap. Supports the recently-announced BIS £45 million package of investment in manufacturing. Supports the Clean Skies initiative. Supports BIS Strategy 'Overarching challenge' directly in growing the high value manufacturing sector; indirect support for sustainability (improved efficiency in aerospace) and energy (use in fusion reactor or laser fusion vessel metrology).

Synergies with other projects / programmes

Fits well with the NPL 2020 Vision, encompassing: measurement in harsh environments, ubiquitous metrology, metrology at the shop-floor, SI traceability at the shop-floor. Outline fit with EU 'Future Factories' programme.. Complementary measurement technique to the FSI system to be developed in LUMINAR (and EMRP), and a backstop alternative if long-range FSI is unachievable. There is a long term possibility of combining the FSI and *mSPACE* concepts into a single measurement device, but this is outside the current timeframe. Outputs (both early stage and end stage) from LUMINAR are useable in conjunction with this technology (*e.g.* use of 3D refractive index to improve the accuracy of *mSPACE* over longer ranges). Feeds in to EPSRC Light Controlled Factory project.

Risks

Target tracking could become complicated for many targets and few cameras, possibly to the point of being insoluble for pathological cases – mitigation by increasing the number of cameras and implementing target tracking with unique identification across multiple cameras. Risk of reaching eye-safety level for longer beam operation – mitigation is back-to-back operation of multiple cameras.

Knowledge Transfer and Exploitation

Initial KT will be via publication of R&D in papers and at conferences, both for academic audiences and end users (*e.g.* LVMC, CMSC). Initial exploitation will be the use of the system by NPL to offer on-site measurements for customers. Next exploitation route is via a new measurement service for performance verification of commercial systems. Final KT/Exploitation route is by licensing of the IP (already patented) to third parties. One equipment manufacturer already interested.

Co-funding and Collaborators

UCL knowledge in photogrammetry will benefit the project via links in LUMINAR. The UCL 3D refractive index determination is a camera-based concept, ideal for integration with the cameras of *mSPACE*.

Deliverables (only active deliverables shown)

1	Start: 1 October 2013	End: 30 September 2016	

Description: **Fully working longer range multi camera multi-target 3D/6D mSPACE system**

A fully operating system, robust enough for use in real-world scenarios, operating with multiple cameras, tracking multiple targets and outputting real-time position and uncertainty information.

2	Start: 1 October 2013	End: 30 September 2016	

Description: Error modelling and error propagation

An error model of the mSPACE measurement system incorporating camera- and target-based errors, with propagation of input error parameters and measurement results to output uncertainties.

3	Start: 1 October 2013	End: 30 September 2016	

Description: Demonstration against precision CMM and in site tests, and development of verification technique.

A measurement process which can be used to give a performance verification of an mSPACE system or other commercial system (operating using similar camera-based techniques) with SI traceability. Process to be suitable for later development to a measurement service. Test of mSPACE system against other metrology system at NPL and at another facility.

Project No.	EF/2013/33	**Price to NMO**	£333k
Project Title	**Standards for industrial dynamic pressure measurement**	**Co-funding target**	£50k pa service income
Lead Scientist	Andy Knott	**Stage Start Date**	1 Oct 2013
Scientist Team	Stephen Downes, Ian Robinson	**Stage End Date**	30 Sep 2014
		Est Final Stage End Date	
Sector	80% High value manufacturing; 20% Energy	**Activity**	100% NMS infrastructure

Summary
This is a follow-on project to extend NPL's dynamic pressure standards to provide improved support to the automotive and energy sectors. NPL's existing unique facility is providing customers with pressure steps of up to 1 MPa, but an increase in amplitude of up to 5 MPa would be highly beneficial to industrial users.

The Need
Measurement and control of combustion dynamics is key to reducing fuel consumption and NOx emissions in gas turbines for both electricity generation and powering aircraft, and also within automotive engine research. Pressure measurements are an integral part of this process, but no suitable dynamic calibration facilities currently exist. A system capable of generating known dynamic pressures with amplitudes of up to 5 MPa, frequencies of up to 100 kHz, and expanded uncertainties of no greater than 2 % would be of great benefit.

Similarly, there are no SI-traceable dynamic pressure calibration facilities over lower frequency and amplitude ranges, despite strong industrial demand, and pressure shocks of magnitudes of hundreds of megapascals are also being measured in certain applications, with no absolute traceability.

The Solution
- A 1.4 MPa capacity PVC shock tube has been successfully developed within the 2010-2013 NMS Engineering and Flow Programme, together with a secondary system for calibrating working sensors against primary transducers characterised within the shock tube. Experience in the design of, use of, and analysis of data from shock tubes has been gained. A steel shock tube with a nominal pressure rating of 7 MPa, capable of generating pressure steps of at least 5 MPa, will be developed, taking into account the lessons learnt during commissioning of the 1.4 MPa system. The existing secondary system will also require modification to generate these higher pressures.
- To meet the industrial demand for lower frequency standards, work towards the development of a periodic pressure generator will be carried out. This instrument will have traceability to static pressure standards via an innovative technique, so this preparation work will include IP protection registration as well as the development of a performance specification for consultation with potential end users. Recommendations covering dynamic pressure work to be initiated in October 2014 will be drawn up.
- The needs of users measuring higher amplitude shocks, within the explosives and ballistics areas, will be surveyed to assess demand for further development of primary shock tubes, possibly up to 20 MPa.

Project Description (including summary of technical work)
A 7 MPa dynamic pressure standard will be developed – a primary, shock-tube based system for the dynamic characterisation of pressure transducers. In addition, the existing secondary comparator-type system for the calibration of industrial transducers will be modified to increase the magnitude of pressures generated.

The performance specification for a periodic pressure generator will be developed, taking into account the demands of industrial end users – this will lead to recommendations for a future project in the dynamic pressure area. A survey to assess user demand for higher pressure traceability during shock events will also be carried out.

Impact and Benefits
The project will enable developers to improve automotive and gas turbine engine design by giving an accurate real-time understanding of their performance, allowing the fuel injection and combustion timing process to be optimised to reduce emissions and increase efficiency. Reasons for the significant existing discrepancies between sensors from different suppliers will be determined, enabling better measurements to be made.

Support for Programme Challenge, Roadmaps, Government Strategies

NMS Strategy - National Challenges

Energy

"Support the achievement of carbon reduction targets . . . by providing the underpinning measurement infrastructure needed to verify reductions in energy consumption and improvements in energy efficiency"

"Develop . . . monitoring techniques to improve the efficiency . . . of fossil fuel plant"

Science excellence

"Deliver next-generation metrology and its application (including the SI units and their extension)"

TSB Focus Areas

Energy

"Reducing greenhouse gas emissions at point of use"

High value manufacturing

"Maintaining or enhancing the international competitiveness of UK-based manufacturing industries, including aerospace, automotive . . . through the development and application of innovative technologies"

Transport - Aerospace

"Developing vehicles and systems for an integrated, sustainable and economically efficient transport system"

Synergies with other projects / programmes

NPL is leading the dynamic pressure workpackage of EMRP project IND09 – development of the 7 MPa shock tube will extend the available range of high-frequency dynamic pressure standards within Europe and the EMRP project is an ideal vehicle through which to demonstrate its performance. The shock tube will be designed as a versatile instrument, making it suitable for applicability within other NPL technical areas dealing with fast-acting events, such as combustion and gas studies, acoustics, and shock/impact loads.

Risks

Fidelity of generated waveforms makes achievement of desired uncertainty levels challenging – mitigation includes collaboration with NPL and other experts in signal processing, materials modelling, and vibration effects.

Knowledge Transfer and Exploitation

The project will be exploited via NPL-based calibration services and associated KT activities, including technical advice, good practice recommendations, and conference presentations. Possible spin-offs include combustion studies and licensed sales of secondary dynamic pressure generation systems.

Co-funding and Collaborators

Partners include Kistler, the Institute of Shock Physics at Imperial College London, and other European NMIs. Collaborators have agreed to provide in-kind support, such as loan of sensors and instrumentation, access to facilities, and engineering design and manufacture.

Deliverables (only active deliverables shown)

1	Start: 01/10/13	End: 30/09/14	
Description: Development of 7 MPa shock tube, associated secondary system, and service for investigation and calibration of dynamic pressure sensor systems			
2	Start: 01/10/13	End: 30/09/14	
Description: Development of performance specification for a periodic pressure generator, together with survey to assess demand for a high amplitude shock tube standard			

Project No.	EF/2013/34	**Price to NMO**	£110k
Project Title	**Update of Dimensional Good Practice Guides**	**Co-funding target**	
Lead Scientist	Bruce Duncan	**Stage Start Date**	1/10/2013
Scientist Team	David Flack, Richard Leach, Michael McCarthy	**Stage End Date**	30/9/2014
		Est Final Stage End Date	
Sector	100% High value manufacturing	**Activity**	100% Knowledge transfer

Summary
Update of five dimensional Good practice Guides. Investigate methods of electronic dissemination.

The Need

Over the last ten years NPL has produced numerous good practice guides relating to dimensional metrology. Many of these guides are still used but are in desperate need of updating. These guides are used extensively by industry and whilst some of the information is still current they are beginning to show their age. Updated guides will give UK industry access to the latest information and good practice. There is also demand for the guides to be available in other electronic formats such as those compatible with e-readers.

The Solution

The following guides will be updated; GPG 37, GPG 39, GPG 40; GPG 41 and GPG 43. These guides will be updated into the more modern looking GPG format; images will be updated along with references to out-of-date material. Where technology has advanced this will be reflected in the updated guides, particularly in GPG 43 on CMM probing.

The option will also be taken to investigate the use of e-publication of these documents to enable them to be viewed on tablets and e-readers etc.

Project Description (including summary of technical work)

The following guides will be updated to the A5 format in current use and extensively reviewed and updated

The measurement of surface texture using stylus instruments GPG 037
Dimensional measurement using vision systems GPG 039
Callipers and micrometers GPG 040
CMM measurement strategies GPG 041
CMM probing GPG 043

Impact and Benefits

The dimensional good practice guides are some of the most popular downloads from the NPL website and are only exceeded by the generic good practice guides on measurement uncertainty. For 2012 alone the guides between them were downloaded 1617 times. The number of individual downloads varied from 241 (Guide 43) to 456 (Guide 40). Updating these guides will ensure that UK industry has access to the latest good practice in dimensional metrology and that UK industry is aware of the latest technologies and standards. The guides will also raise NPL's profile both nationally and internationally and provide UK engineering students with up-to-date course material.

Support for Programme Challenge, Roadmaps, Government Strategies

This proposal supports the NMO's aspiration for the knowledge and skills within the NMS to be shared in order to achieve maximum economic and social impact. The use of Good Practice Guides is a proven method of providing access to the expertise and knowhow within NPL. This is fully compliant with the Governments growth and skills agenda.

Synergies with other projects / programmes

NMS/EFM11007 Structured surface metrology
NMS/EFM11009 Unified micro co-ordinate measurements
NMS/EFM11029 Dimensional Facilities: Essential support

Risks

This project is low risk. Many of the original authors of these guides are still at NPL and will be conversant with the changes that are needed to update these guides.

Knowledge Transfer and Exploitation

Knowledge transfer will be through the guides themselves which will be extensively publicised by e-mail, websites and trade journals. The guides are used as part of the training framework thus providing an additional dissemination route.

Co-funding and Collaborators

Equipment manufacturers will be encouraged to provide material, e.g. photographs, diagrams as they have in the past. Collaborators will be sought to aid distribution and promote awareness such as universities and equipment manufacturers.

Deliverables (only active deliverables shown)

1	Start: 01/10/13	End: 01/07/14	
Description: Five updated good practice guides.			
2	Start: 01/07/14	End:30/09/14	
Description: Publicise guides through trade journals and electronic media.			

Project No.	EF/2013/49	**Price to NMO**	£500k
Project Title	**QA4ECV**	**Co-funding target**	£325k(FP7) £600k (Climate KIC)
Lead Scientist	Joanne Nightingale	**Stage Start Date**	Jan 2014
Scientist Team	Fox, Origo, Woolliams, Bialek, Mittaz	**Stage End Date**	Dec 2017
		Est Final Stage End Date	Dec 2017
Sector	100% Environmental Sustainability	**Activity**	100% NMS infrastructure

Summary: This project co-funds a successful bid for an FP 7 project led by KNMI with 16 international EO/Climate expert partners, to develop a top level QA framework, expressly based on metrological best practices, as a potential prototype for a future EU climate service. In part to test the prototype, six new example climate services (3 land and 3 atmosphere products) will be developed using up to ~ 30 yrs of satellite EO data.

Policy makers are increasingly reliant on Earth Observation (EO) data to make decisions on mitigating and adapting to climate change. These decisions need to be 'evidence-based' and this requires complete confidence in information from EO-derived products. Although EO data is plentiful, it is rare to have reliable, traceable and understandable quality information which is consistent from both similar and different observation platforms e.g. between different satellites sensors and in-situ measurements. The situation is often further confused because various versions of the same product exist from data providers using different retrieval algorithms. This is further complicated when different conclusions on the state of the planet can be drawn from different climate products/services. This project seeks to develop best practice guidance, procedures and tools to ensure that understandable quality metrics can and are applied to climate information in a harmonized trustable manner

The Need: Currently a wide range of Essential Climate Variable (ECV) products/services are available and under development for several user communities with European governments/agencies playing an internationally lead role through its copernicus (GMES) program. Different data providers offer similar versions of the same data product, which can lead to final ECV products based on a combination of different input datasets and retrieval methods. Many developers attempt to validate their products using what validation data is available, but these efforts are generally sparse, poorly documented and lack robust independent evidence of traceability and reproducibility. This makes it difficult for stakeholders to reliably assess the adequacy of the data or derived information for their application, including the associated uncertainty, and its suitability to support critical judgements at an understood level of confidence.

The Solution

- Traceable methods, ideally based on existing best practices and training to underpin assessment of uncertainties in EO product generation from raw data through to processed ECV products and climate data records.
- Generic uncertainty methods and tools for data fusion, including the linkage of multiple disparate satellites and in-situ data to enable interoperability and continuous decadal measurements required for climate assessment.
- Definition of user friendly 'fit for purpose' quality metrics and provision of metadata via the QA4EO framework
- Establishment of a prototype QA and validation service for multiple ECV products including the potential of 'certification' framework for both input data and delivered services

Project Description (including summary of technical work) The project will build on current community best practices working closely with a wide range of domain experts seeking to build a forum for information exchange on QA. Its technical work will focus on meeting the immediate priorities of its projects' case studies: atmospheric and land ECVs (such as NO_2, HCHO, CO LAI, fPAR and Albedo). These will be analysed to extract specifications for generic procedures, methods and standards to support the implementation, assessment and reporting of QA. To facilitate this process, and maximize applicability, a survey will be conducted to better understand the longer-term needs of the data user and supplier community's requirements for QA in ECV records. Commonalities in the data stream uncertainty propagation process for all ECVs will be identified to enable harmonized retrievals for past, current and future sensors. This will include approaches to evaluate and visualize traceability chains and their associated uncertainties. Methods to validate the ECV records generated in the QA4ECV project will be explored in relation to ground-based field and instrument measurements, sampling schemes and scaling of biophysical parameters for independent verification. A draft outline of a pre-operational QA4ECV service will be developed in accordance with community and best-practice standards and methodologies.

Impact and Benefits

- Space agencies/international organisations are adopting traceability as requirement for EO & climate information. NPL is sought out as a key partner in QA related ESA projects; increasingly larger scale and focused on services. Maximum benefit from NMO investment at NPL in this area is obtained from detailed involvement through all stages of the information product development as 'users' only see the delivered products.
- The UK, through; UKSA, NERC, Met office and the Satellite Applications Catapult is positioning to become internationally recognised as the nation of excellence for EO (particularly climate) applications and services to facilitating the growth ambitions from this sector. Metrologically robust QA is seen as a key enabler and market differentiator and one which the UK seeks to exploit through NPL and its CCM.
- Horizon 2020 will establish an integrated climate service, complementing the ESA (Harwell) CCI program. The UK has ambition to lead this service with QA, and NPL seen as having a key enabling role. This project was explicitly established by the EU as a prototype for this. NPL leads the development of the QA element.

Support for Programme Challenge, Roadmaps, Government Strategies:

- NMS, CCM and UKSA strategy for climate services. Underpins principles outlined in E&F and Euramet roadmaps
- 2010 BIPM/WMO workshop on climate, CEOS WGCV and member agencies, GEO
- EU Horizon 2020 program and in particular Copernicus climate services and ESA CCI program

Synergies with other projects / programmes: some synergies with Maths and modelling programme looking at data fusion and climate data. The externally funded Climate-KIC FOREST. Follow-on TSB projects to TRUDAT, other associated NMS projects in EO including EMRP projects. Also links with various NERC programs and CEOS/GEO.

Risks: Challenges proposed here are ambitious but necessary to meet the communities long term needs. Most activities require close collaboration with & input from numerous science teams throughout the EU. Some work may stall/slow down whilst waiting for user and supplier survey feedback or responses from collaborating partners.

Knowledge Transfer and Exploitation: The FP 7 has a detailed KT and exploitation plan in which NPL plays a lead role. This includes development of climate user forum, a specialised uncertainty training course, an uncertainty QA 'helpline' and a variety of best practise guidance documents and templates for QA assessment. The aim is to provide a pre-operational QA service which can be subsequently adopted/evolved by a future EU climate service.

Co-funding and Collaborators: This project is the co-funding component of an FP 7 project with 16 EU partners led by KNMI of Holland including organisations such as Eumetsat and JRC and from the UK, UCL and CGI. An opportunity for significant cofunding exists from the Climate KIC initiative and is currently being explored.

Deliverables:

1	Start: Jan 2014	End: Dec 2014	

Description: Conduct survey to better understand the longer-term needs of the data user and supplier communities requirements for QA in ECV records. Analyse and publish results, establish climate users forum and outline traceability status maps of project ECVs.

2	Start: Mar 2014	End: Jan 2017	

Description: Work with ECV development experts (Climate community) on methods and tools to provide reliable, traceable and understandable quality information on their products via a full detailed end to end to assessment of traceability with propagated uncertainty generalised for multiple ECV in a generic manner include in detail at least SST, Ocean Colour and one non-optical ECV, with others from ESA CCI program at least in outline.

3	Start: Jul 2014	End: Oct 2017	

Description: In collaboration with ECV development experts (project collaborators), produce and publish best practise guidance documents related to analysing uncertainty propagation through algorithm processing, ground measurement and validation chains for project specific ECV products.

4	Start: Jan 2014	End: Oct 2015	

Description: Make initial field measurements over a subset of Landnet, Forest test sites, in collaboration with ECV community, to define the nature of parameter measured e.g .spatial representativeness as a basis to develop models & mathematics to improve means to scale spatially and extraction from noise (environment and natural variability).

5	Start: Jan 2015	Dec 2017End:	

Description: Define an outline prototype QA framework (including tools and guidance documents) to facilitate assignment and interpretation of metrologically robust quality metrics with bio-geo physical parameters typical of ECVs and deliver a tailored e-based uncertainty training programme

Project No.	EF/2013/36	**Price to NMO**	£1.5M
Project Title	**Traceable Calibration and Validation measurement infrastructure for Earth Observation and Climate**	**Co-funding target**	£500k
Lead Scientist	Nigel Fox	**Stage Start Date**	1/10/13
Scientist Team	Woolliams, Green, Theocharous, Winkler, Bialek, Levick, Greenwell, Gorrono	**Stage End Date**	30/9/16
		Est Final Stage End Date	
Sector	100% Environmental Sustainability	**Activity**	100% NMS Infrastructure

Summary: Establishes the underpinning SI traceable infrastructure needed to support global measurements of the Earth & climate: pre-flight/post-launch. Provides the international metrology focus for the EO/climate community.

The Need: The Earth's climate is changing, resulting in unprecedented economic and social consequences. Monitoring and interpretation of the current health or state of the planet, and forecast of likely changes, is heavily reliant on optical radiation based measurements**.** Of the 50 Essential Climate Variables (ECV) in the UN Global Climate Observing System ~2/3 involves the measurement of optical radiation. The challenge of detecting small signals from a background of noise is the classical metrology problem. However, since these signals require measurement across global scales in timescales of decades, this becomes the most demanding metrology challenge of our era. Observations from satellites are critical to our understanding but the satellite's size, complexity, non-return-ability and high susceptibility to degradation, means that the traditional methods and standards evolved over the last century for terrestrial applications are far from adequate. Instruments need to be calibrated pre- and post-launch in operationally representative conditions to enable them to make measurements of incoming and out-going radiation of Land, Ocean & Atmosphere at uncertainties close to primary realisations- often 10X more demanding than terrestrial applications. Consideration also needs to be given to the traceability and uncertainty, between the primary measurand (e.g. reflectance/radiance) and the bio-geophysical parameter typical of an ECV.

The Solution

- Adaptation of existing, and development of new, radiometric standards and methods to meet the operational and physical characteristics of Earth Observation (EO) e.g. vacuum/field/size etc
- Development of strategies & associated standards to enable on-board SI traceable satellite sensor calibration
- Establishment of Calibration test sites capable of providing SI traceable in-situ 'truth' values representative of satellite observations (Land, Ocean, Atmosphere) propagated to Top of the Atmosphere (TOA) – ideally autonomous, temporally continuous, globally distributed but coordinated as an operational network.
- Metrologically robust methods and uncertainty analysis to facilitate post launch calibration and inter-satellite data harmonisation for global observations derived from localised often sub-sampled in-situ data sets for both primary Level 1 measurands (e.g. radiance/reflectance) and higher level retrieved products typical of ECVs.
- Development of SI traceable methods to replace current 'community based' standards where possible.
- Promote best practice and benefits of SI traceability to EO stakeholder community – instrument builders, users and the customers of their data

Project Description (including summary of technical work): Provides a national based project to underpin and extend NPL's role and activities in related co-funding projects. Allows NPL and the UK to maintain and expand its international leadership role in EO & Climate ensuring it can maximize opportunities to interact with key stakeholders and capitalize on other (co-)funding sources. Much of the work outlined will be fine-tuned over the 3 yrs to align with the priorities of the UK and international community facilitating the UK NMS to be seen as the first port of call for EO traceability. This project provides the core EO infrastructure which builds upon the generic measurement capabilities of the Optical program and may stimulate the need for additional related projects as it progresses.

- **Develop, with international EO science teams a QA framework to provide post-launch SI-traceability for satellite derived EO data: Formal comparisons, Sampling and characterization methods for test sites**
  - Reference standards, methods and analysis techniques to support international comparisons of field deployed (Cal/Val) instrumentation and in-orbit satellite to satellite sensors used for, e.g. Ocean colour, Sea & Land surface 'brightness temperature measurements (includes lab and field based activities)'
  - Best practice methods in characterisation techniques to establish and assign SI traceable values to specific test sites enabling them to be recognized as 'international standards'. Provide international coordinating role for a prototype in-flight calibration service for satellite sensors initially L1 with target of L2 (subject to co-funding)
- **Developing methods & instruments for pre-launch and in-flight calibration activities, for use in operationally representative conditions e.g. Thermal/Vacuum. Selected activities could change with co-funding opportunities.**
  - Extension of portable tuneable extended size vacuum radiance source to Near IR spectral region
    - Spectral radiance source for <1% calibration of atmospheric sensors in UV.
    - Facility to provide Climate quality calibration uncertainties for sensors and sub-systems under thermal

vacuum conditions including potential for multi parameter testing. Will include capacity to evaluate thermal gradients on instruments and standards, alignment and optical stimulus coupling techniques
    - Upgrade AMBER facility to improve accuracy of IR radiance calibrations of black bodies for space instruments
- **Methods to facilitate assignment of SI traceable uncertainty to Biophysical parameters as is typical of ECVs**
    - Analyse representative retrieval algorithms e.g. Atmospheric correction, for methods to allow assignment of metrological uncertainty including input parameters and establish where possible generic test methods
    - Establish user friendly metrics to describe 'quality' / uncertainty of high level products.
- **Provide international NMI leadership on promoting the uptake and benefits of SI traceability for EO and climate**
    - Active participation in international standardization and coordination bodies

Impact and Benefits

- Space agencies & international coordinating bodies are now adopting traceability as a requirement. NPL is sought out as a key partner in QA related ESA funded projects ensuring maximum benefit from NMO investment.
- Improve capabilities of instrument builders and EO/Climate service producers. Success will lead to improved forecasting of climate change impact and monitoring of mitigation strategies.

Support for Programme Challenge, Roadmaps, Government Strategies:

- NMS, CCM and UKSA strategy for climate services. Underpins principles outlined in E&F and Euramet roadmaps
- The UKSA has established a strategy for the UK to be global leader in Climate services with EO data quality and Cal/Val as the key enabler with NPL and the NMS identified as key provider.
- 2010 BIPM/WMO workshop on climate, CEOS WGCV and member agencies, GEO

Synergies with other projects / programmes This project and its sister on EO applications are both dependent on many of the facilities maintained in the Optical capability programme and is of course linked with other EO projects.

Risks: The challenges here are highly ambitious but necessary to meet the communities long term needs and so by their very nature may not be fully achieved in the timescales, with the planned resources. However, the gap between need and state of the art is so large that any advance is seen as progress and this is low risk.

Knowledge Transfer and Exploitation: The EO projects are presented to most VIP visitors to NPL. In addition to presenting outputs at conferences and through publications the project is structured to be delivered through partnerships with the international EO community. The project leader chairs the international body coordinating Cal/Val activities of space agencies and is also the interface for BIPM CCPR with WMO. Many of the activities are collaborative and co-funding will be sought which will lead to commercially delivered calibration services.

Co-funding and Collaborators: NPL, through its leadership role in CEOS and GEO, has collaborations with many public funded organisations (inc. ESA, UKSA, NASA, NERC, CNES, WMO, JRC) universities, and commercial organisations (inc. Astrium and SSTL). Many are providing co-funding. Two case studentships & two NPL staff Phds.

Deliverables (only active deliverables shown)

1	Start: 01/10/13	End: 30/9/16	
Description: Support uptake of SI traceability through organisation of international comparisons (satellite & ground), provision of transfer standards. Establish NPL as the global focal point for metrology for EO/climate issues.			
2	Start 01/10/13	End: 30/04/14	
Description: Development of roadmap and exploitation plan to support NMS/NPL/UK strategy to achieve fit for purpose quality metrics on EO/climate data.			
3	Start: 01/10/13	End: 30/4/15	
Description: Develop generic best practice methods to assess, report and establish traceability at necessary uncertainty levels for retrieval algorithms linking satellite derived data with climate 'ECV' parameters. Initial example will be atmospheric correction for Deliverable 5. Others dependent on establishing partnerships with key teams.			
4	Start: 01/10/13	End: 30/9/16	
Description: Establish infrastructure to enable the delivery by NPL of climate quality SI traceable pre-flight calibration of optical sensors under simulated operational conditions, vacuum/thermal etc for key parameters.			
5	Start: 01/10/13	End: 30/9/16	
Description: Establish prototype operational post-launch satellite calibration/bias harmonisation service (radiometric) through the creation, in partnership, of an SI traceable autonomous network of test sites (LandNET). Includes development of best practice for site characterisation. Will utilise outputs of MetEOC 1 and 2. Support the creation of similar test sites/networks for the Ocean/Land/atmosphere with appropriate partnerships.			

Project No.	EF/2013/37	**Price to NMO**	£915K
Project Title	**Metrology for Earth Observation and Climate (MetEOC 2) EMRP co-funding**	**Co-funding target**	£735k
Lead Scientist	Nigel Fox	**Stage Start Date**	1/07/14
Scientist Team	Origo, Woolliams, Bialek, Mittaz, Nightingale, Green, Greenwell, Theocharous, Gorrono	**Stage End Date**	31/7/17
		Est Final Stage End Date	30/6/17
Sector	100% Environmental Sustainability	**Activity**	100% NMS infrastructure

Summary: This project co-fund and EMRP project which ultimately seeks to develop the framework for an NPL Led European virtual centre of excellence in metrology for Earth observation and climate. Developing and adapting bespoke calibration and validation methods and instruments to support the Climate community utilising optical related remote sensed data. The project performs work in the form of case studies in collaboration with sector practitioners on end to end solutions for Essential Climate Variables (ECV) and resultant climate data records (CDR) including: Pre-flight, post-launch and associated retrieval algorithms and statistics to allow trustable quantitative confidence in the information derived from the combination of data from multiple observation platforms. .

The Need: There is an urgent societal need to improve climate models to make more reliable predictions of future climate change. Such models rely on accurate data on the state of the Earth's systems and much of that data is based on optical Earth Observation (EO) instruments on satellites. Around 2/3 of the 50 ECVs have an optical related measurement. Satellites have been observing the Earth for several decades, but none with sufficient accuracy for climate requirements, where small decadal trends need to be detected from noisy data (natural variability & instrument performance). SI traceability both pre-flight calibration and post-launch must be established under operationally representative conditions to achieve this goal. This EMRP co-funded project seeks to build European NMI capacity (and ultimately a virtual center of excellence) under the leadership of NPL. It will address the demands not only on the measurements made by the sensor but also the validation and retrieval processes needed to meet the uncertainty requirements for bio/geo physical parameters, ECVs and Climate Data Records.

The Solution Requires a step change in NMI practices, moving away from the precisely controlled lab based measurements towards delivering state of the art uncertainties at a customer, in the field and in space. In most cases this requires adaptation of existing methods used to establish primary scales, but in some cases more radical rethinking of methods is required. It also requires new work (and expertise) on retrievals validation and mathematical methods for large multivariate complex data sets.

- Radiometric standards and methods for cal/val under operational conditions.
- Development/characterisation of on board calibration standards e.g. diffusers stable to UV radiation.
- Establishment of calibration test sites – land surface areas (deserts, ocean sites, forest sites) with SI-traceable radiance and reflectance values, and ocean sites for sea surface temperature, for the validation of satellite products, including developing instrumentation and data analysis techniques
- Prototyping the TRUTHS satellite, "an NMI in space", with primary radiometric traceability from orbit
- Working with domain experts e.g. forest and sea surface temperature to review and address traceability requirements throughout a processing chain

Project Description (including summary of technical work)

- **Developing, with international EO science teams and European NMI partners, approaches to provide full end-to-end SI-traceability for ground-based instruments used to validate EO data, specifically**:
  - Aerosol optical depth traceability (new lab based SI methods for sun photometers)
  - Instruments for Brightness temperatures for sea and land surface temperatures validation
  - Spectral Albedo (instruments for measuring goniometrically resolved downwelling & upwelling radiation)
  - CEOS Radiometric gain autonomous test site network instrumentation and analysis methods to support: characterization, traceabiity and interoperability of existing and new 'Landnet' reference sites as part of a contribution to an international community project to establish an operational cal service for sensors.
  - Forest test sites instrumentation and methods to validate both radiometric reflectance and higher level products such as leaf area index
- **Developing methods and instruments for key pre-launch and in-flight calibration activities, specifically:**
  - Pre-flight SI-traceable calibration of the CLARA total solar irradiance satellite instrument
  - Developing a solar diffuser for in-flight calibration resistant to UV degradation
  - Prototyping the calibration chain for the TRUTHS satellite (NMI in space) using laser diodes
- **Developing mathematical tools for uncertainty assessment of climate data records, specifically:**

- End-to-end uncertainty propagation from top-of-atmosphere reflectance to ECV products including "type classification" steps
- Optimal sampling approaches for efficient validation of vegetation and sea surface temperature ECVs and techniques for data fusion, representativeness, natural variability

- **As project coordinator, NPL will lead the development of formal links to promote traceability with the international EO community & establish virtual center of excellence**

Impact and Benefits Space Agencies & international bodies such as CEOS, GEO and EU have climate as a key focus and are now adopting traceability as a requirement for EO data products. NPL is sought out as a key partner in ESA funded projects where traceability, Quality assurance are essential, although it is recognized in the longer-term that it would be preferable if this were done under a non-national badge. The UK, through the UKSA & NERC has an agenda for the UK to become the Centre of Excellence for EO data quality and cal/val, as implemented through CEMS and the new NPL partnership with RAL, with the aim for this to underpin significant economic growth in climate services.

Support for Programme Challenge, Roadmaps, Government Strategies

- NMS, CCM and UKSA strategy for climate services underpins principles outlined in E&F and Euramet roadmaps
- 2010 BIPM/WMO workshop on climate, work plans of CEOS WGCV and member agencies, GEO

Synergies with other projects / programmes: This work is co-funded by the EMRP project MetEOC-2, a follow on from the original EMRP MetEOC project. The mathematical aspects are complementary to projects in the maths program. It is dependent on many facilities maintained in optical Capability project.

Risks: Very ambitious & relies on strong collaborations with partners, (other NMIs & EO scientists in public and commercial organisations. NPL already has strong partnerships with these organisations, but most will be doing work on a best efforts basis. It is possible that some of the outcomes may not fully achieve the ideal goal but intermediate s steps in progress will provide immediate value to users.

Knowledge Transfer and Exploitation: Projects is dependent on close collaboration with partner organisations and will deliver regular outputs as part of collaborative case studies. The project leader chairs the international body coordinating optical cal/val activities for space agencies (CEOS WGCV-IVOS), and thus the closest possible interface to the EO community. The new RAL/NPL calibration center & Reading/Surrey university link are key interfaces.

Co-funding and Collaborators: The project explicitly co-funds an NPL led EMRP project with ~8 partners but also has indirect co-funding from a variety of collaborators ranging from NASA, CNES, ESA, DLR, Astrium, RAL, China …

Deliverables

1	Start: July 2014	End: Dec 16	
Description: Develop metrologically traceable autonomous field instruments (including methods, procedures, statistics & tools) to derive comparable Top and Bottom of Atmosphere measured digital signals to support the establishment of a prototype CEOS Satellite L1 (reflectance/radiance) calibration service			
2	Start: July 2014	End: July 16	
Description: Establish fully validated field measurement instrumentation, based on best practice methods, to assess and report status of traceability and uncertainty through the ECV and CDR data processing chain. Sources of uncertainty in observation data will be assessed, and will include both historical and future data			
3	Start: Jul 2014	End: July 17	
Description: Construct and operationally demonstrate new primary SI traceable reference radiometers for field measurements of Surface brightness temperatures (oceans and Land) at uncertainties suitable for a climate record.			
4	Start: July 2014	End July 2017	
Description: Development of UV damage resistant lambertian diffuser for both pre-flight and on-board calibration of satellite sensors at uncertainty levels of <1% with a target of <0.2%.			

Project No.	EF/2013/35	**Price to NMO**	£150k
Project Title	**Upgrade of Optical Radiation Primary Scales Measurement Infrastructure**	**Co-funding target**	NIL
Lead Scientist	Teresa Goodman	**Stage Start Date**	01 October 2013
Scientist Team	Rainer Winkler, John Mountford, Faye Lai, Andrew Deadman	**Stage End Date**	31 March 2015
		Est Final Stage End Date	
Sector	100% Traceability & Uncertainty	**Activity**	100% NMS Infrastructure

Summary

This project will provide essential upgrade of the UK primary standard cryogenic radiometer facilities to ensure continued provision of SI traceability for radiometric scales. The primary standard has now reached the end of its operational lifetime and must be replaced to ensure continued support for ongoing research and measurement service activity in the optical radiation and Earth Observation & climate science areas.

The Need

The UK primary standard cryogenic radiometer underpins all radiometric measurements scales within the NMS and is required in order to provide SI traceability for a wide range of measurements services and research activity. Whilst the current cryogenic radiometer continues to operate successfully, it has reached the end of its operational lifetime and a number of the sub-systems utilise obsolete components that are no-longer cost effective to maintain. Failure of these sub-systems would cause disruption to services and would seriously inconvenience UK industry and research activity under the NMS.

The Solution

Construct and commission a new mechanically cooled primary standard cryogenic radiometer and upgrade selected instrumentation of the radiant power calibration facility to ensure continued provision of SI traceability for UK radiometric scales. Modification of the exiting design is required to replace obsolete components and instrumentation with up to date alternatives.

Project Description (including summary of technical work)

Modify the design of the current NPL mechanically cooled primary standard cryogenic radiometer to replace obsolete sub-systems with modern technology. Manufacture and assemble the new instrument in collaboration with NPL Engineering Services. Modify the trap detector translation stage to improve the efficiency of the calibration process. Construct a light tight enclosure around the primary standard facility to enable efficient shared use of the laboratory space. Upgrade control software to take account of new instrumentation. Fully test new primary standard to ensure consistency of primary scale realisation and dissemination. Update technical procedure and supporting documentation. Construct and calibrate a new set of reference trap detectors and incorporate into the dissemination chain for spectral responsivity.

Impact and Benefits

The immediate benefit realised at the end of this project is reduced risk to provision of SI traceability for UK radiometric and photometric scales. Longer term benefits include reduced maintenance costs associated with the realisation and dissemination of primary optical measurement scales including radiant power responsivity and spectral responsivity.

Support for Programme Challenge, Roadmaps, Government Strategies

The outputs from this project will directly support research activity under the Earth Observation & Climate, Applied Temperature Measurement, and Primary Thermometry roadmaps of the NMS Engineering and Flow Programme. The measurement services underpinned by the primary radiometric scales also support the Climate Data and Low Carbon Technologies themes of the Centre for Carbon Measurement, and Government Strategies for improved quality assurance of Earth Observation data, validation of low carbon lighting and solar energy technologies.

Synergies with other projects / programmes

Engineering & Flow Programme

Quality Assurance for Earth Observation and Climate

TS003408 Cofunding for EMRP 17e Traceable Radiometry for Remote Measurement of Climate Parameters project

(optical element)
EFM12012 Co-funding for EMRP “InK”
EFM12002 Filter Radiometry
Innovation R&D
IRD\2012\11 Novel photovoltaic characterisation techniques

Risks

Technical risk is low and is mitigated via the use of established and proven knowledge, measurement procedures and instrumentation. The unexpected loss of availability of key staff would have an impact on the efficiency of delivery. Upgrade of primary standard cryogenic radiometer requires minimal disruption to continuity of service delivery.

Knowledge Transfer and Exploitation

The main method of knowledge transfer from this project will be through dissemination of primary radiometric scales via calibrated reference standards. The mechanically cooled cryogenic radiometer was developed at NPL and is still considered to be a state of the art instrument. The unique design of the radiometer has been exploited commercially through contracts to supply primary standard instruments to a number of NMI laboratories across the World. The upgraded design of this instrument will provide the opportunity for further commercial exploitation and collaboration with other NMI laboratories to maintain the NPL position as a world leading NMI in this field.

Co-funding and Collaborators

No direct co-funding or collaboration is envisaged in relation to the delivery of this project.

Deliverables (only active deliverables shown)

1	Start: 01/10/13	End: 31/03/15	

Description: Upgrade the primary standard cryogenic radiometer and selected sub-systems of the radiant power calibration facility to ensure continued provision of SI traceability for radiometric scales.

Project No.	EF/2013/38	**Price to NMO**	£339k
Project Title	**Co funding for EMRP s23 Moisture in materials**	**Co-funding target**	Co-funding by EMRP project, plus additional in-kind funding from several collaborators.
Lead Scientist	S Bell	**Stage Start Date**	1 June 2013
Scientist Team	S Bell, P Carroll,	**Stage End Date**	30 June 2016
		Est Final Stage End Date	
Sector	100% high value manufacturing	**Activity**	100% NMS infrastructure

Summary

The Need

Moisture content of materials is important for a vast range of processes and products. Some 70 % of all industries use drying; yet direct measurements of "dryness" are under-used, due to measurement and traceability challenges. Optimal moisture control saves on energy costs, process time, waste and environmental impact. But moisture measurement and calibration techniques are inconsistent in several ways. New developments are needed to address these discrepancies through relevant and effective traceability to the SI.

Moisture measurement uses many "non-absolute" methods: RF/microwave absorption or transmission, IR reflectance, electrical conductance, and others. Calibration is essential, but applicability of calibration methods varies - some with no easy route to SI traceability. Discrepancies can be several percent.

Water (or moisture) fraction is a derived quantity, traceable to mass (kg) or amount (mol), but this traceability alone is not robust - it does not address ambiguities of measurand, method-dependence, and applicability of calibrations in terms of the actual quantity to be measured. Certified reference materials (CRMs) exist, but key difficulties are: their narrow applicability, ambiguous measurand (water *versus* moisture including all volatiles); distinguishing free and bound water; method-specific results; and lack of other traceability routes. A survey (in previous E&F Project TH6) of 66 UK industrial and research users found existing CRMs are: unsuitable for instrument type (50 % of respondents), and/or material type (43 %); and/or too unstable (25 %).

Existing reference methods have drawbacks. The "benchmark" for moisture is mass-loss-on-drying, but is method-dependent - with a different temperature/time protocol for every application. Karl-Fischer titration is an established water-specific reference method at NMI level, but not fully exploited as a focal point for traceability chain. The science spans physical and chemical metrology, and treatment in CIPM CCs, RMOs and standardisation bodies is currently fragmented. Numerous published standards perpetuate a method-driven culture, rather than traceable measurements for outcome-based verification.

The Solution

A number of these problems can be addressed through developing improved dissemination routes of SI traceability to moisture measurements in industry, aiming to eliminate ambiguities and inconsistencies in moisture measurement and calibration techniques. This will be achieved through development of new more relevant and effective methods of realising and disseminating SI-traceable moisture quantities, and provision of metrology infrastructure for moisture measurements. This requires:

- Provision of traceability in terms of water fraction (by mass or amount).
- Traceability which addresses measurand ambiguity - distinction between water and moisture (other volatiles).
- Development of improved moisture reference materials that address some of the user concerns about applicability, stability, and method-specific results.
- Integrated working across disciplines of physical and chemical metrology (and their technical committees) and dissemination of best practice to users of measurements.

Project Description (including summary of technical work)

NPL proposes to:

- Adapt and refine an existing measurement method (evolved vapour analysis) validating it as a first-principles primary measurement of water content with full uncertainty analysis
- Study and develop one or more new reference materials to certification, improving on existing CRMs for water content (better applicability, specificity, stability and/or other benefit)
- Measurement comparisons with EMRP partners to test realisations, and ensure consistency of outcomes
- Interaction with moisture standards-developing committees to disseminate best practice.
- Interaction with technical working groups in physical and chemical SI metrology (CIPM-CCs, EURAMET TCs, others …) to develop coherent working at all levels across metrology disciplines concerned with moisture

Impact and Benefits

- Key sectors include pharmaceuticals, plastics, foods, (and also, solid and liquid fuels and biofuels, paper, wood agriculture, conservation ….).
- More reliable moisture measurements affect: product quality and lifespan; process speed/throughput; market price by weight; re-work and wastage. Example: in a single milk-drying plant, 0.1 % in moisture content is worth 0.5 M€ pa in throughput alone [source: GEA Niro].
- Significant energy savings and carbon reduction if drying and other moisture control processes are optimised through reliable measurement.
- Improvements to national and international metrology infrastructure – NMI standards, and steps towards NMI CMCs, key comparisons, commercial lab accreditations, traceable calibrations.
- Work by the NPL humidity team, and equivalent teams at other NMIs, uniquely draws on application of humidity expertise to problems of moisture in materials.
- Benefits of wider EMRP project deliverables and collaboration.

Support for Programme Challenge, Roadmaps, Government Strategies

Contributes to advanced manufacturing, energy saving and carbon reduction.

Synergies with other projects / programmes

Builds on TH6 Moisture in materials project (2010-13) which developed capability for moisture measurement at NPL using several techniques. Synergy with on-going maintained capability for moisture measurement.

Risks

Technical risk. Risk that outreach to make new contacts with standards committees will be rejected. Risk that coherent working between chemistry and physical metrology groups gains only limited success.

Knowledge Transfer and Exploitation

NPL leads the EMRP Impact WP and so will oversee the KT and exploitation of work from all partners. NPL will conduct a campaign of outreach to standards committees to generate engagement in the project, and to offer input on best practice, measurement traceability, and measurement uncertainty. This is a key channel of action because of the importance and vast number of moisture-related standard (some 1300), and because this reaches influential measurement users. The one or more specimen CRM(s) developed in the project will be provided with an exploitation plan for manufacture, routine certification, and distribution. Refinement of NPL-owned instruments as potential primary standards offers a new capability which may provide new customer services.

Co-funding and Collaborators

Co-funding EMRP project METefnet starts June 2013 with 9 NMI partners. Sector and instrumentation collaborators working directly with NPL in the EMRP project include: LGC, Intertek Pharmaceutical Services, UCL School of Pharmacy, Sartorius (UK/Germany), BERGHOF Products + Instruments GmbH - plus at least 13 other collaborators more generally.

Deliverables

1	Start: 01/6/13	End: 31/5/16	

Description: Validation of primary moisture measurement with new certified reference material

- Validation of primary moisture measurement, and comparison measurements.
- One or more new certified reference materials for water content, improving on existing CRMs (better applicability, specificity, stability and/or other benefit).

2	Start: 01/6/13	End: 31/5/16	

Description: Delivery of Impact work package

The key NPL outputs are:

- Impact activities, including outreach to standards committees, metrology committees, leadership of EMRP Impact work package.

Project No.	EF/2013/39	**Price to NMO**	272k
Project Title	**Co funding for EMRP CRYSTAL**	**Co-funding target**	
Lead Scientist	Andrew Yacoot	**Stage Start Date**	Oct 2013
Scientist Team	Mattia Lazzerini, Matthew Tedaldi, Jason O'Neill	**Stage End Date**	Sept 2016
		Est Final Stage End Date	
Sector	100% Underpinning	**Activity**	100% NMS infrastrucure

Summary

This project provides matching funding for NPL's participation in the EMRP project SIB61 CRYSTAL Crystalline surfaces, self assembled structures, and nano-origami as length standards in (nano)metrology. This project aims to develop new types of standards in the nanometre and sub-nanometre range to trace back instruments to the SI unit of length with a small uncertainty of u(h) = 10 pm (for step height prototypes) and to reveal characteristics of the instruments (flatness). New techniques will be developed by using the nature of crystalline materials as well as by using a promising lithographic technique based on block co-polymers. Another goal to be investigated is the use of the nano-origami technique as a production technique to fabricate structures of nanoscale size. Whereas the first will go beyond today's limit of available standards below 6 nm for step height and below 100 nm for pitch standards. The latter technique will be useful to create geometrically well-defined nano-objects that are necessary for near future validation of such instruments like AFM for the dimensional measurements of 3D-nano-objects.

The Need

To promote the sustainable development of the nanotechnology market and to foster the implementation of traceable measurement capabilities in fundamental research, e.g. in surface and material science or biophysics, the introduction of new types of samples for length metrology at the nanoscale need to be initiated. To meet this need a simple improvement of existing technology is not sufficient: existing technology relies on a top down approach using conventional fabrication techniques that are unlikely to achieve the required repeatability and accuracy. The proposed method in this project are based on fundamental constants of nature. A new paradigm for the production of nanoscale standards is required, e.g. utilising invariants of nature (lattice parameter) and self-organisation principles at the nanoscale. These approaches have been highlighted by the Consultative Committee on Length's (CCL) sub working group on nanometrology.

The Solution

Prototypes of next generation of step height standards will be produced (by PTB) based on the lattice parameter of crystalline material, mainly silicon. This will result in step height standards with sub-nanometre step heights and with a target expected expanded uncertainty of 10 pm. The latter will be achieved by improved laser-interferometry and by the use of the discrete nature of crystalline materials by using multiple steps. Hence, the dimension and the uncertainty will be reduced by more than a factor of 10, compared to the currently available step height standards.

Lateral standards will be produced by other partners (PTB and INRIM) based on the lattice parameter of silicon and on self-organisation principles will be used, to produce lateral structures with a pitch of 5 nm. Another self-organisation principle using diblock copolymers will be used for the formation of laterally structured patterns by self-assembly with a tuneable pitch value in the region of 5 – 50 nm.

Project Description (including summary of technical work)

NPL will participate in several work packages with other partners to specify the requirements of the calibration standards, compare with these commercially available and determine the long term stability of the samples produced. NPL will measure the height of the step height standards using the tip-sample interaction AFM and optical microscopy. In addition the development of a Fabry Perot Fibre interferometer sensing head for an AFM will be explored. Measurements of lateral pitch will be made using the X-ray interferometer AFM system developed within the EMRP project Scatterometry that is currently underway.

Impact and Benefits

Filling the gap in length standards for nano metrology will support the continuous shrinking process in the semiconductor industry and of nanotechnology products. The project will create impact for three different stakeholders: End users in industry (such as the nanotechnology and semiconductor industry) and scientists involved in fundamental research and R&D. The results of this project will enable end users to calibrate their instruments in the nano- and sub-nanometre range with traceability to the SI unit of length and with small uncertainty (u(h) = 10 pm). Step height samples are essential for revealing the vertical resolution power of optical instruments non-ambiguously. Hence, these prototype standards will reduce the effort and costs for the implementation of QM systems or they will enable the use of such a system for the first time.

Support for Programme Challenge, Roadmaps, Government Strategies

The work within this EMRP project fits into our Engineering measurement roadmap for nanometrology and will enhance UK competence in dimensional nanometrology. It meets the needs identified both by the recent EU CO-Nanomet project surveying European requirements for nanometrology and the CCL working group on Nanometrology to address the lack of traceable calibration standards at the nanometre level.

Synergies with other projects / programmes

The work complements our NMS AFM metrology and build on the results of other EMRP projects. It supports the overall strategy of enhancing NPL's capability for dimensional nanometrology. Results from the project will be of benefit to all AFM users and across NPL as well as those optical microscope users who are interested in nanometrology.

Risks

Loss or unavailability of key staff, damage to x-ray interferometer or AFM. Lack of support from partners.

Knowledge Transfer and Exploitation

At the beginning of the JRP an Advisory Committee will be established by the JRP-Coordinator (with assistance from the WP leaders) to ensure two-way communication between the active stakeholders and JRP-Partners. The committee will be open to all the interested stakeholders. A website will be established for the JRP providing information on the project for stakeholder and for exchange of information between JRP-Partners. The results of the JRP will be presented as at least impact international and national conferences and meetings. Papers containing the results will be submitted to international journals. The measurement practices developed in the JRP will be published as a good practice guide for the crystalline step height prototype samples. The project partners have links to international standards committees and will disseminate project results to appropriate committees. In addition training workshops will be organized.
Principal customer include AFM community, AFM manufacturers & users in industry and universities
Outputs include Good practice guides, publications and possible workshops as the need is identified.

Co-funding and Collaborators

EMRP cofounding, collaborators, PTB, CMI, INRIM, MIKES,

Deliverables (only active deliverables shown)

1	Start: 01/10/13	End: 30/9/16	

Description: Develop and test requirements for crystalline step standards
NPL is participating in EMRP project JRP project SIB61 CRYSTAL Crystalline surfaces, self assembled structures, and nano-origami as length standards in (nano)metrology.

- Specification of requirements for crystalline step calibration standards and measurement strategy
- Investigation of Fabry Perot interferometer for AFM cantilever detection
- Measurements of lateral standards on x-ray interferometer

2	Start: 01/10/13	End: 30/9/16	

Description: Produce Good Practice Guide and publications

- Guidelines for good practice of use of crystalline step heights
- Publication of paper in refereed journal.

Project No.	EF/2013/40	**Price to NMO**	276k
Project Title	**Co funding for EMRP 6 DoF**	**Co-funding target**	
Lead Scientist	Andrew Yacoot	**Stage Start Date**	1/6/ 2013
Scientist Team	Matthew Tedaldi, Mattia Lazzerini, Jason O' Neill	**Stage End Date**	31/5/ 2016
		Est Final Stage End Date	
Sector	100% Underpinning	**Activity**	100% NMS infrastructure

Summary

This project provides matching funding for NPL's participation in the EMRP project JRP i07 6DoF Metrology for movement and positioning in six degrees of freedom. It will support traceable 6 Degree of freedom measurement by the complementary development of optimized measurement instruments based on interferometric techniques to establish a direct link to the definition of the length unit. A high performance multi axes Fabry-Perot interferometer system will be developed in the EMRP project.

This JRP aims to improve nano positioning systems for the various future relevant high-tech fields not only by novel hardware technology but also by optimized sensor and actuator components as well as optimized measurement and control strategies. Higher speed scanning will address another limiting factor of industrial use of AFM. This will be achieved by using stiffer scanner units and non-equidistant sampling.

The Need

Current trends in precision engineering demand ever higher accuracies for industrial high-end production and measurement equipment. This requires control of positioning systems over measurement ranges from nanometres to millimetres in all 6 degrees of freedom (DoF). The application of high precision motion systems ranges from nanometrology (AFM, SEM) to industrial production technologies (machine tools, CMM, photo lithography) to large scale applications like telescopes.

The Solution

A high performance multi axes Fabry-Perot interferometer system will be used to provide metrology for stages used in high speed AFMs and in a test bed developed to assess nanopositioning stages. Error mapping of stages is a practical possibility for more accurate positioning metrology at all levels reducing effort and costs. In mechatronics applications this includes dynamic error budgeting, taking into account dynamic and thermal deformations. For nanometrology and in particular AFM metrology, point by point error mapping enables a calculation to be made of local uncertainties for position and other terms that are dependent on position such as surface texture parameters. In recent years there has been a growth in the development of high speed AFMs working at video rate. These can be used for the examination of live processes particularly in the field of biology and medicine and have been imaging things as diverse as the decay of dental enamel. The translation stages used in these AFMs require a high bandwidth and are devoid of any intrinsic metrology. Introducing metrology to High Speed AFM will allow it to be used to obtain quantitative data.

Project Description (including summary of technical work)

A Test Bed for nanopositioning stages will be developed to determine the accuracy of motion and characterize the stage errors such as angular errors and orthogonality, straightness of motion. The metrology for the Test Bed is based on conventional metrology methods using optical interferometry and autocollimation. NPL will develop fibre interferometer that could offer a low cost alternative to the commercial option and perform a rigorous characterization of the NPL designed interferometer against the x-ray interferometer. Its performance will also be assessed over a longer range using the test bed.

Routines will be developed for intelligent AFM scanning for metrological AFMs and for high speed AFMs. In collaboration with CMI and Bristol University, optical interferometry will be introduced to high speed AFMs. In collaboration with CMI there will be further development of routines used for error mapping of stages and comparisons made between conventional optical method and grating based methods

Impact and Benefits

Precision engineering is a competitive and strong industry in Europe across many sectors including: production technologies, process engineering, communication technologies, aerospace, automotive industry, semiconductors, opto-technology, and mechanical engineering. The sector is hugely profitable and a large employer.

However many precision engineering companies are small to medium sized, and may not have the resources or expertise to perform basic research; this JRP will positively impact them allowing their design decisions to be based on verified high quality data. These industries represent growing multi-billion Euro markets and represent key economic sectors in knowledge-based industrialised Europe, with ageing population and high labour costs. Improved

metrology tools are necessary to support innovation and enabling technologies for new cost-effective and reliable production processes and goods. Impact is expected both for larger industrial entities that run their own metrology laboratories and SME without these capabilities. Best practice guides on new methodologies are expected to feed in to industrial standardisation.

Support for Programme Challenge, Roadmaps, Government Strategies

The work within this EMRP project fits into our Engineering measurement roadmap for nanometrology and will enhance UK competence in dimensional nanometrology.

Synergies with other projects / programmes

The project builds on work already done within the NMS projects on optical interferometry and AFM metrology, in particular the error mapping work started by NPL and CMI as an informal collaboration. We have already established links with Bristol University for high speed AFM work.

Risks

Loss or unavailability of key staff, damage to x-ray interferometer or AFM. Lack of support from partners.

Knowledge Transfer and Exploitation

The transfer of knowledge generated during the project into industry will be an essential aspect of this project. A stakeholder committee will be formed at the start of the project from industrial and academic collaborators that will help to steer the project and will also receive results of the project first-hand. The project will be targeted at the entire semi-conductor and MEMs manufacturing supply chain as demonstrated by the project collaborators, which include manufacturing companies, instrument manufacturers and research institutes.
The aim of this work package is to disseminate the project results to the Stakeholders and to create impact for industry, service providers and the scientific community. Key stakeholders are PI, Queensgate and Universirty of Bristol. Outputs include good practice guides which can be publicised and it is intended a workshop will be held in conjunction with IOP and manufacturers
Work will be disseminated via a project web page, publications, conferences and workshops for industry. Where appropriate results will be disseminated to relevant ISO committees such as ISO/TC201/SC9 “Scanning probe microscopy” and ISO/TC229/JWG2 “Nanotechnologies : Measurement and characterisation

Co-funding and Collaborators

This project supports an already won EMRP project and NPL’s work in the project is done in collaboration with CMI, PTB, LNE and University of Bristol.

Deliverables (only active deliverables shown)

1	Start: 01/06/13	End: 31/5/2016	

Description: Demonstrate application of interferometry to multi axis measurement

- Fibre interferometer system for multi axis displacement measurement
- Test bed for error mapping stages

2	Start: 01/06/13	End: 31/5/2016	

Description: Produce Good Practice Guide and operating proceduress

- Good practice guide on error mapping stages
- Methodology for fast scan routines for AFM
- Submission of at least two papers to journals

Project No.	EF/2013/41	**Price to NMO**	£478k
Project Title	**LUMINAR - Large volume Unified Metrology for Industry, Novel Applications and Research EMRP co-funding**	**Co-funding target**	EMRP contribution to JRP: €371500 EPSRC light controlled factory: £2.5M (+£1.25M industry)
Lead Scientist	Andrew Lewis	**Stage Start Date**	1 June 2013
Scientist Team	Ben Hughes, Matt Warden, Dan Veal (Graham Machin, Jonathan Pearce, Gavin Sutton)	**Stage End Date**	
		Est Final Stage End Date	31 May 2016
Sector	100% High value manufacturing	**Activity**	50% Challenge R&D; 50%NMS infrastructure

Summary

Co-funding for EMRP JRP Large Volume Metrology in Industry (JRP IND53) plus funding for similar work to support EPSRC Light Controlled Factory (LCF) *via* University of Bath. Both projects tackle fundamental issues affecting users of Large Volume (dimensional) Metrology equipment in industrial environments. The NPL work in JRP IND53 will be on two novel measuring systems based on Frequency Scanning Interferometry (FSI) and metrological camera systems, with the majority (90 %) of the work being centred on FSI. In addition, this co-funding project will support the EPSRC LCF project which requires NMS-level knowledge of temperature sensing accuracy in industrial applications.

The Need

Particle physics, healthcare, advanced manufacturing, aerospace and 'Future Factories' all require dimensional metrology at 10 µm to 100 µm accuracy in industrial environments, where close-control of the temperature is not achievable or is uneconomic. Aerospace wants to reduce aircraft weight and use natural laminar flow wings. Oncology treatment using beam therapies relies on accurate dimensional metrology for synchrotron construction and beam delivery. Next generation particle accelerators (*e.g.* CLIC superseding the LHC) require positioning accuracy of 20,000 beam steering sub-systems to 10 µm every 200 m. Advanced high-value manufacturing needs faster measurement of expensive products such as aircraft engines, but performed *in situ* in non-controlled environments. All these needs can be summarised: better accuracy, traceable, 'shop-floor' metrology that operates over large volumes. These needs are currently not being addressed either by NMIs or commercially.

Technologically, this requires: line of sight refractive index compensation for any optical based measuring system to achieve the required accuracy; reinstatement of SI traceability routes for Absolute Distance Measuring (ADM) systems; compensation for thermal effects on large structures; compensation for refraction effects across a 3D volume; and development of more flexible/configurable, higher accuracy multi-target measuring systems.

The Solution

The problem is so big that the optimum solution is to tackle simultaneously several key underlying problems associated with LVM in industrial environments. This requires a multi-disciplinary, multi-team approach, hence the need for an EMRP JRP. In the JRP NPL will develop novel metrology systems such as: an FSI-based system operating at > 5 m ranges, with intrinsic traceability, multiple targets, and faster data rate; a camera based novel photogrammetry system using through the lens illumination. JRP Partners develop other parts of the solution matrix: develop 3D refractive index compensation (EMRP partner UCL); develop new SI-traceable ADM systems (EMRP partner CNAM); develop advanced laser trackers (EMRP partner PTB); develop line of sight refractive index compensation (EMRP partners CNAM, PTB); and provide NMI-based long range traceable test environment (EMRP partner GUM).

Project Description (including summary of technical work)

The project at NPL will deliver two fully-operational desktop demonstrator measuring systems and then develop one further to a long range system. The selected system for long range development is FSI, with a fall-back of further developing the camera system as a contingency.

The NPL work will include: take existing FSI and metrology camera hardware and finalise two desktop short-range demonstrator systems. Extend the working range of FSI using optical techniques; optimise the use of $n = 2$ spheres as targets; 3D multi-lateration algorithm development; scale-up to full system; interact with UCL on 3D refractive index solutions and utilise their knowledge for both camera based and FSI systems; test against other techniques *e.g.* PTB advanced laser tracker, other laser trackers; demonstrate operation on site at Airbus and AMRC/N-AMRC, including thermal compensation by University of Bath.

Utilise knowledge of NPL Thermal Metrology team to understand measurement uncertainty of temperatures of large structures in industrial environments (support for LCF EPSRC project).

Impact and Benefits

Staff at CERN are already asking for this capability to be demonstrated to them on site - willing to fund secondments. Recent NPL work with an aerospace manufacturer showed that existing equipment cannot achieve what they want

(accuracy, speed). Airbus already road-mapping the use of FSI for use in its factories. Metrology equipment manufacturers expressed interest in project. The accuracy improvements the project can deliver could be used by aircraft manufacturers to reduce aircraft weight by at least 100 kg, leading to 1600 tonnes less CO_2 emitted *p.a.* per aircraft, hence 1.4 M litres of fuel saved *p.a.* per aircraft.
Anticipated financial benefits include: helping to safeguard €2.3 trillion aerospace orders (to 2030) whilst complying with 2020 regulations; saving money for high value components: €10k per day depreciation per aero engine; inspection time reduced; no expensive thermal control required in factories.
Societal benefits: enabling metrology for LHC successor (protecting science jobs); enabling improved beam therapies for oncology; maintaining European advanced manufacturing advantage; allowing wider uptake of Large Volume Metrology tools, leading to new applications at SMEs.

Support for Programme Challenge, Roadmaps, Government Strategies

Direct fit to NMS Road Map for dimensional large volume metrology and also the corresponding EURAMET TC-Length roadmap. Supports the recently-announced BIS £45 million package of investment in manufacturing. Supports the EU Clean Skies initiative, plus underpins several EU Directives associated with measuring instruments, aviation and underground storage of fuels and waste (2008/101/EC, 2002/30/EC, 2003/55/EC, 2011/92/EU, 2004/22/EC, 2009/31/EC, 2011/70/EURATOM). Supports BIS Strategy 'Overarching challenge' directly in growing the high value manufacturing sector; indirect support for health (beam therapy), sustainability (improved efficiency in aerospace) and energy (wind turbine blade metrology).

Synergies with other projects / programmes

Fits well with the NPL 2020 Vision, encompassing: measurement in harsh environments, ubiquitous metrology, metrology at the shop-floor, SI traceability at the shop-floor. Outline fit with EU 'Future Factories' programme and EPSRC Light Controlled Factory.

Risks - May be difficult to increase the operational range of FSI – will use the camera system as a fall-back option. Risk of running an EMRP project with several NMIs and unfunded partners. Risk of failing to avoiding overlap between JRP IND53 and the EPSRC LCF projects.

Knowledge Transfer and Exploitation

KT and Exploitation are integral parts of any EMRP Industry JRP and the project scored 4.5 out of a maximum 5 in this category. The EMRP project partners anticipate significant IP outputs suitable for licensing by third parties. The JRP will hold a workshop near the end of the project to showcase the new IP and results from using it in live end-user environments. We anticipate around 8 to 10 peer-reviewed publications and at least 6 conference presentations. In addition NPL has already patented the FSI and camera-based techniques and is seeking licensees for these. Additionally the project plans: a stakeholder committee; JRP open website; trade magazine articles; a good Practice Guide; inputs to the NPL Dimensional Training Framework; support for standards committees such as ISO, BS, VDI/VDE, UNI, ASME and metrology committees such as EURAMET, CCL.

Co-funding and Collaborators

EMRP co-funding this project. Similar LCF project has secured EPSRC funding (£2.5M). Unfunded partners taking part in EMRP project. Collaborating with: PTB, INRIM, CNAM, GUM, Airbus, Boeing, SIOS, AMRC, UCL, and University of Bath. Anticipating collaboration with: NIST, additional Stage 3 REG applicant (*e.g*. another European university).

Deliverables (only active deliverables shown)

1	Start: 1 Jun 2013	End: 31 May 2016	

Description: Development and demonstration of long range FSI system.

- Long range FSI system: modified hardware for long rage operational and giving 3D locations at long range.
- Long range FSI system verified using measurements at other partner NMI.
- At least 3 presentations and 3 papers (international/peer reviewed).
- Demonstration of long range FSI system at stakeholder location in typical measuring environment.
- International workshop for outputs from project and looking at ways forwards for Large Volume Metrology.
- Completion of all duties of JRP Coordinator for this €3M project.

2	Start: 1 Jun 2013	End: 31 May 2016	

Description: Thermal metrology support for Light Controlled Factory (EPSRC) project.
Future years will be in-kind contributions such as loan of equipment, access to laboratories, *etc*.

Project No.	EF/2013/42	**Price to NMO**	£399k
Project Title	**Co funding for EMRP - Multi-sensor metrology for microparts**	**Co-funding target**	£349k
Lead Scientist	Richard Leach	**Stage Start Date**	1 June 2013
Scientist Team	Richard Leach, James Claverley, Wenjuan Sun	**Stage End Date**	31 May 2016
		Est Final Stage End Date	
Sector	100% high value manufacturing	**Activity**	100% NMS infrastructure

Summary
The project will develop methods for characterising the form of micro-CMM probes by building on an existing instrument for sphere interferometry, develop techniques to further miniaturise CMM probe tips and will develop an infrastructure to allow the adjustment of optical CMMs for systematic effects.

The Need
Microparts with complex geometry are becoming increasingly important for numerous industrial products found in many industries, e.g. automotive, medical and telecommunications. The need for improved metrological capabilities in this field has been identified by several roadmap studies and has been expressed by instrument manufacturers and standardisation bodies. One of the most important development trends in industrial dimensional metrology, having the potential to fulfil the requirements to measure complex microparts, is multi-sensor coordinate metrology, which combines the speed of optical measurements with the accuracy and 3D capability of tactile measurements (and, more recently, the ability to measure interior features using computed tomography with x-rays – although this does not feature in this project). While tactile and optical techniques are well-established for intermediate workpiece size and accuracy, less progress has been made for 3D measurement of small parts with sub-millimetre features and sub-micrometre tolerances, so called microparts.

The Solution
In previous (and parallel-running) projects, NPL has developed a new micro-CMM probe. It is now time to fully characterise this and other probes and this will be carried out by developing dedicated instrumentation and calibration methods. The natural next-step is also to further miniaturise this probe and this will be carried out (later projects will require a redesign of the flexure mechanism). Also, previous projects have investigated optical micro-CMMs by using exiting theory. This project will develop the new theoretical infrastructure that is required to use such probes as true rivals to contact probes. This project will address the theory and practical development of such optical systems.

Project Description (including summary of technical work)
The tasks in this project relate to the main factors limiting the accuracy and applicability of tactile and optical sensors measuring microparts. The accuracy of tactile micro-sensors and probe styli able to measure more complex geometrical features, such as undercuts and smaller internal features, will be improved, including full 3D probe stylus characterisation and correction at uncertainties in the nanometre range. This will include (for the first time) a full mapping of the stylus form using a modification to the sphere interferometer developed in current NMS project Metrology for Structured Surfaces. New probing styli with very small diameters (<100 µm) will be developed and characterised. For optical sensors, the influence of the workpiece characteristics will be investigated to obtain traceable results in industry. Knowledge of the many influence factors will be used for a correction of the results to increase accuracy, with particular emphasis on rough surface measurement (i.e. measuring surfaces outside the aperture limit).

Impact and Benefits
Key applications of multi-sensor metrology of microparts will be demonstrated in cooperation with the industrial partners. The key applications will be in the fields of medicine, automotive and plastic manufacturing. In addition to the demonstrations, the project and the results will be made public by a webpage, a workshop and publications. The project will support innovative design and accelerated development of new production technologies for small mechanical components due to better measurement capabilities for geometrical specifications of micro-components with improved accuracy and reliability. This will result in a reduction of manufacturing costs, in new products based on miniature components and in an increased market penetration of UK (and other European) manufacturers. The industrial sectors addressed by this project are mechanical engineering, measuring instrument manufacturers, process engineering and production technologies, automotive and medical. Benefits to NPL also include the enhancement of our measurement services for microparts using exiting tactile services and optical instruments.

Support for Programme Challenge, Roadmaps, Government Strategies
The project is in direct response to requirements in the NMS and EMRP Roadmaps for micro-co-ordinate

metrology. The government strategies in High-Value Manufacturing (see TSB reports) are focussed on exploiting the UK's ability to design and manufacture innovative products. Maximising this wealth generation mechanism will depend on successfully realising next generation innovative production systems, including the metrology. The project will also leverage the work conducted under the EPRSC CIM in Ultra Precision from Cranfield/Cambridge and that of the CIM in Advanced Metrology at Huddersfield.

Synergies with other projects / programmes

This project directly relates to a three-year NMS project developing the NPL vibrating micro-probe. The systems developed in this project will be very beneficial to the XCT project and to the Ultra Precision Manufacturing Metrology project, which both need 3D micro-co-ordinate metrology for traceability. On the optical side, there is a strong link with the Metrology for Structured Surfaces project. Many areas of NPL (materials, optics, analytical, electrical and acoustic) make use of NPL's existing micro-co-ordinate metrology services. This project is also closely linked to the FP7 project, MIDEMMA.

Risks

The main risks in this project all stem from its difficult technical nature. 1. The sphere interferometer cannot measure micro-CMM probe tips – during the development of the sphere interferometer, this potential issue was always considered and this is now a low risk. 2. It is not possible to manufacture and assemble smaller probes – this is a medium risk as most of the technology is understood and we just need to put all the pieces in place. 3. It is not possible to develop fast enough algorithms for non-linear optical modelling – we are partnering with the world-expert in this area – Prof Jeremy Coupland from Loughborough University (Loughborough are a REG partner in the EMRP project.

Knowledge Transfer and Exploitation

The project will enhance the capabilities of existing micro-CMMs by integrating the new NPL calibration techniques and small probes onto existing micro-CMMs. Manufacturers and users of existing non-contact systems will be able to exploit the new calibration and adjustment methods developed by this project, which will include a measurement service for the calibration of micro-co-ordinate measuring artefacts. The project will result in an enhanced measurement service to be used by industry. Developments of this project will be reported to suitable conferences and journals and will also be submitted to existing ISO committees to assist in the development of standards aimed directly at micro-co-ordinate metrology.

Co-funding and Collaborators

Co-funding of this project will come from the EMRP project IND59 (same name as this project). Collaborators in that project include: PTB, METAS, VSL, LNE, BAM, Danish Technical Institute, Loughborough University and University of Erlangen-Nuremburg. Note that we are also applying for a member of staff at Loughborough to spend the duration of the project at NPL (50 % of his time) under a Royal Society Industrial Fellowship. Industry partners include: Bosch, IBS (with whom we are commercialising our probe), Lego, Novo Nordisk (medical), Xpress (instruments) and UK STFC (targets for inertial confinement fusion energy research). It is also expected that we will have further PhDs with Loughborough (funded under NPL Strategic Research) and a PhD though the CDT in Ultra Precision with Cranfield and Cambridge. Co-funding in-kind will be through the loan of a focus variation microscope (Alicona) and a coherence scanning interferometer (Bruker). We will work with the NTUT (Taiwan – a long-standing collaboration) to develop the small probe tips. There is also expected to be collaboration (on probe cleaning and repair) with Nottingham, who are applying for REG.

Deliverables

1	Start: 01/10/13	End: 31/5/16	
Description: Development of a probe tip form measurement technique			
2	Start: 01/6/13	End: 31/5/16	
Description: Development of probe tip with diameters less than 50 μm			
3	Start: 01/6/13	End: 31/5/16	
Description: Develop non-linear scattering model for optical micro-CMM measurements			

Project No.	EF/2013/43	**Price to NMO**	£388k
Project Title	**Traceable in-process dimensional measurement for machine tools (co funding for EMRP i05 TIM)**	**Co-funding target**	£297k
Lead Scientist	Michael McCarthy	**Stage Start Date**	01 July 13
Scientist Team	TBA, Recruitment required.	**Stage End Date**	30 Jun 16
		Est Final Stage End Date	
Sector	100% High value manufacturing	**Activity**	100% NMS infrastructure

Summary

To establish traceable in-process metrology. The philosophy of in-process metrology is to obtain the measurement data directly in the manufacturing process and to use them for effective process control and for reliable quality assurance. The goal is to improve the manufacturing quality of complex machined parts directly on the shop floor and consequently to reduce the expensive scrappage and to save cost and energy. One prerequisite to significantly improve the manufacturing processes is the incorporation of traceable dimensional metrology directly on machine tools. Project delivery involves 24 partners; familiarisation with JRPi05 is desirable before reading further.

The Need

Traceable in-process dimensional measurements of machine tools offer high product quality at lower manufacturing cost, high productivity, reduced scrappage, and prompt and real-life assessment of product quality. Unreliable dimensional measurements on metal cutting machine tools (cutting, grinding, milling, and turning), most especially at the manufacturing finishing point (on the shop floor) can have a huge negative economic impact.

The Solution

In order to realize reliable and high accurate measurement results there is a requirement for robust material standards provided by national metrology institutes (NMIs) to support industrial end users to establish traceability.

Project Description

Establish scientific and technical backgrounds for developing standards and procedures for assessing and assuring traceability of in-process measurements. Develop methods for implementing high accuracy dimensional measurements on machine tools by developing high precision and robust material standards that are deployable on industrial machine tools used in the manufacturing industries, and beyond. Development of a portable shop floor chamber suitable for simulating manufacturing floor environmental conditions to enable preventing the adverse influence on the quality of the manufactured parts. Provision of procedures, and good practice guide that ensure reliable measurement on machine tools.

To ensure a smooth uptake of the project results through industrial demonstrations and integrations to the end-users. This will focus on the potential economic and technological impacts in the manufacturing and machine tools industry and beyond.

Impact and Benefits

Ability to measure fabricated parts accurately 'in-process' will significantly improve and facilitate automation in Europe ; Enhancing 'in-process metrology´ will provide market benefit and ensure that European companies remain competitive globally; With the aid of the new environmentally controllable portable test chamber (large enough to house a medium size machine), industry will be able to verify the metrological performance of machine tools on site; The test chamber facilitates and accelerates the verification of the machine performance; Reducing unnecessary scrap and reworking by improving the quality of manufactured parts, so that end-users can make better decisions about part conformance; Improved in-process metrology means cost reduction; Knowledge transfer and dissemination via stakeholder group, paper publications, conferences, workshops, best practice guides and the project web-site

Support for Programme Challenge, Roadmaps, Government Strategies

Aligns with NMO Engineering roadmap. Aligns with EMPR Road map. Aligns well with the challenges identified in the EMRP Outline 2008: Improvement of dimensional metrology for advanced manufacturing in a well- controlled to harsh production environments. Industries to benefit from development of traceable, fast and robust in-process metrology enabling improved process control include: auto, aero & machine tools industries.

Synergies with other projects

Aligns with NPL 3rd party Aero projects and NMO activities at MTC.

Risks:
High. Adventurous technology ambitions and involves large number of partners. NPL deliverables are highly reliant on input from other partners**.**

Knowledge Transfer and Exploitation: Publication, workshops, Trade fairs. Exploitation will be undertaken by training and dissemination of JRP knowledge via standardization bodies, workshops, visits and exchange of staff Exploitation of JRP results on new procedures on in-process parts quality assessments, machine performance evaluations, simulation of machine working environments. The results will be exploited through the large number of collaborators associated with this project (see below). In the UK, we will work with the High Value Manufacturing Catapult who will provide an exploitation route to their extensive membership.

Co-funding and Collaborators : JRP-Partners:
NPL, Airbus (UK), Roll Royce (UK), CD Measurements(UK) +PTB, Germany, CEM Spain, CMI Czech Republic, LNE France, Metrosert Estonia, MIKES Finland, NPL UK, UM Slovenia, Daimler AG Germany, MAG Germany, EMO Slovenia, Gorenje Slovenia, Veplas Finland, TEKN Spain ,UNIZAR Spain, Alwaid Czech Republic, SolidVision Czech Republic, Roll Research Finland, VUOS Czech Republic, Mitutoyo Germany, GEOMNIA France.

Deliverables

1	Start: 01/7/13	End: 30/6/16	Cost: £150k

Description: Determine and evaluate current machine tool measurement uncertainties

- Compilation of end-user survey of existing measurement standards for different applications of in-process metrology.
- Catalogue describing the general requirements of material standards of machine tools.
- Estimation of uncertainties of appropriate state-of-the-art optical measuring systems.
- Document detailing technical attributes, function definition, construction material and manufacturing techniques with uncertainties for all designed standards.
- Report of evaluation of optical properties of different materials suitable for the manufacture of measurement standards.

1	Start: 01/7/13	End: 30/6/16	

Description: Evaluate measurement standards in representative operating envelope

- Report of mathematical modelling of standards at different temperatures using FEA to detect potential problems of non-homogeneous temperature variations, internal stress and form deformation..
- Report specifying the measurement and calibration tasks including procedures and methods to be used for the calibration of manufactured standards.
- Report of comparison of data sets to reverse engineering the CAD model.
- Report of computation of uncertainties for selected measurement standards.
- Feasibility study of dynamically monitoring the position of a tool relative to the area of the surface being machined.

1	Start: 01/7/13	End: 30/6/16	

Description: Best practice guides on machine tool uncertainty

- Procedure to evaluate CNC machine cutting errors associated with software limitations when translating CAD package drawings into CNC machining cutting commands.
- Procedure to evaluate the thermo-mechanical stability of a typical machine tool when manufacturing process has been interrupted and restarted
- Best practice report on dimensional production uncertainty of machine tools.
- Reports of 6 measurement modules of experiment carried out in industry.
- Best practice guides for mapping task-specific measurement errors.
- Peer reviewed papers and conference paper.
- National seminars and workshops.

Project No.	EF/2013/44	**Price to NMO**	£450k
Project Title	**Optical Radiation Metrology Core Capability Maintenance**	**Co-funding target**	£400k p.a.
Lead Scientist	Teresa Goodman	**Stage Start Date**	01 October 2013
Scientist Team	Optical Measurement Group	**Stage End Date**	30 September 2014
		Est Final Stage End Date	
Sector	100% Traceability & Uncertainty	**Activity**	100% NMS Infrastructure

Summary

To maintain existing facilities, capability and expertise used in the realisation and dissemination of optical radiation measurement scales and standards to meet UK industrial requirements and regulations, provide SI traceability for Earth Observation measurements for climate, and maintain NPL status and credibility in the international arena.

The Need

To be competitive in a global market, UK industry need access to suitable traceable radiometric and photometric measurement standards, in which there is universal confidence. Through participation in international comparisons, the UK scales are checked to ensure their quality and consistency with the global community and maintain the status and credibility of NPL. The dissemination of these scales to the Earth Observation and climate community supports efforts to ensure long-term confidence in the accuracy and quality of Earth observation data and products.

Current State of the Art (NMI and elsewhere)

Internationally peer reviewed through the CIPM MRA. A comparison of Calibration Measurement Capabilities (CMCs) can be made by accessing the BIPM CMC database here: http://kcdb.bipm.org/appendixC/default.asp.
Also NPL's performance in intercomparisons can be viewed in the Key Comparison Database here:
http://kcdb.bipm.org/default.asp

The Solution

Continued provision of the UK primary optical radiation measurement scale infrastructure to underpin UK innovation, competitiveness and quality of life. Prioritisation of NMS infrastructure investment to address key national challenges in the sustainability and energy sectors.

Metrology Capability to be Delivered

Radiometry and photometry; providing traceability for Earth Observation measurements and climate, optical radiation safety, and low energy lighting solutions.

Materials Characterisation which encompasses measurements of the optical properties of materials used in many industries including chemical, pharmaceutical, optical components and coatings, textiles, food, aerospace, glazing, energy, construction and water treatment; applications include materials science, thermal control in buildings and spacecraft, Earth observation, infrared tracking and guidance systems, colour standards and for environmental, health and military agencies.

Instrumentation Characterisation and calibration of optical radiation sensors for either spectral responsivity or relative spectral responsivity. Providing support across a range of optical and photonic instrument measurement capabilities, such as traceability for the calibration of fibre optic power meters.

Project Description (including summary of technical work)

This project is concerned with maintaining primary optical radiation measurement scale realisation, maintenance of dissemination facilities, and expertise necessary to provide the underpinning NMS capability and efficient delivery of measurement services.

Summary of Technical Work

- Realisation and dissemination of primary optical radiation measurement scales and standards, including the candela. Maintenance of facilities and infrastructure for the delivery of calibration and testing services to UK stakeholders. Maintain scope of UKAS accreditation for selected calibration and testing services. Comparison of UK measurement scales to ensure quality and consistency with the global community and maintain the status and credibility of NPL.

Impact and Benefits

- The optical radiation measurement scales and capability maintained by this project underpin a broad range of industrial and academic sectors, including Earth Observation & climate, space, health & safety, medical, low-energy lighting, solar, instrumentation, communications and defence. Traceable measurement scales allow industry to meet regulations and industry standards associated with health and safety, quality, and labelling of energy using products. Measurement traceability is provided to UKAS accredited and lower-tier laboratories with significant calibration and metrology fan-out. The outputs from this project also impact other areas of the NMS including underpinning support for radiation thermometry, environmental measurements, photonics, and photovoltaics.

Dissemination and knowledge transfer increases the integration of metrology into new optical technologies and

instrumentation or their wider uptake.

Support for Programme Challenge, Roadmaps, Government Strategies

- This project directly supports the Earth Observation & Climate, Applied Temperature Measurement, and Primary Thermometry roadmaps of the NMS Engineering and Flow Programme.
- The capability maintained under this project support the Climate Data and Low Carbon Technologies themes of the Centre for Carbon Measurement.
- The facilities, expertise and services provided though this project underpin Government Strategies for improved quality assurance of Earth Observation data, validation of low carbon lighting and solar energy technologies.

Synergies with other projects / programmes

This project provides the underpinning infrastructure for all the optical related projects within the Engineering and Flow Physical Programme. It also provides some underpinning capability for the Thermal Imaging and Non-Contact Thermometry projects with the programme. Has some synergies with remote sensing activity under the Chemical and Biological Metrology Programme, materials for solar energy under the Materials and Modelling Programme, and photonics measurement services delivered under the Electromagnetics and Time programme.

Risks

This project has a limited technical risk since the mechanisms involved in the realisation and dissemination of optical scales are well established. The loss of key staff members and the failure of bespoke measurement instruments and/or supporting services infrastructure are key risks. Key risks are mitigated through cross-training of staff during delivery of this project and prioritised investment in new instrumentation and facilities through the linked Optical Radiation Measurement Capability Upgrade project.

Knowledge Transfer and Exploitation

The focus of this project is to maintain the capability and infrastructure that has been built up over many years to provide support to industry through measurement services, consultancies and expert advice and to provide the critical mass of core facilities needed to deliver our research and development projects. In many cases the facilities are available to industry and academia through collaborative arrangements. The key method for knowledge transfer is through the provision of measurement services to industry and the advice provided to end users to ensure the measurements offered meet their needs. In addition, the project will deliver presentations/papers at workshops and conferences (including NEWRAD 2014 conference), reviewing papers for journals, technical information for pages on the NPL website, articles for newsletters, and dissemination of information to user groups through the Measurement Network. Exploitation of the knowledge maintained under this project is achieved through a sustained level of third-party instrumentation supply contracts to other National Measurement Institues and the licensing of Intelectual Property developed under previous projects to industrial partners (for example the 'Optoblok' optical table laser guarding product licensed to Lasermet Ltd.).

Co-funding and Collaborators

Co-funding through measurement services, consultancy and third-party instrumentation facility supply contracts underpinned by this project. The direct revenue generated from industry for measurement service and small consultancy activities is £400k per year. Collaboration with National Measurement Institutes via intercomparison of measurement scales. Collaboration with industrial stakeholders via consultancies and knowledge transfer activities. The comments and feedback from the users of the services help to shape the development of new capabilities.

Deliverables (only active deliverables shown)

1	Start: 01/10/13	End: 30/09/2014	

Description: Maintain core underpinning measurement capability and UK traceability for optical radiation measurements. Provide industry with access to facilities and specialist knowledge October 2013 – September 2014
Evidence: Delivery of calibration certificates and test reports for completed measurement services, and relevant scope of UKAS accreditation successfully maintained.

2	Start: 01/10/13	End: 30/09/2014	

Description: Demonstrate international equivalence of UK optical radiation measurement scales through participation in selected key and supplementary comparisons via CIPM CCPR and Euramet TC-PR.
Evidence: Participation in CCPR-K6 Key Comparison of Spectral Regular Transmittance and peer review of CMCs

3	Start: 01/10/13	End: 30/09/2014	

Description: Disseminate NMS core knowledge in optical radiation metrology to UK and international stakeholders
Evidence: Participation in NEWRAD 2014 conference, submission of 2 peer reviewed papers in partnership with external organisation, review of technical information for Optical Radiation Measurement presented on NPL website.

Project No.	EF/2013/45	**Price to NMO**	£178k
Project Title	**Technical, Consultative and Standards Committee Activity for Optical Radiation Measurement & EO**	**Co-funding target**	£15k
Lead Scientist		**Stage Start Date**	October 2013
Scientist Team	Nigel Fox, Teresa Goodman, Emma Woolliams, Simon Hall, Paul Miller	**Stage End Date**	September 2014
		Est Final Stage End Date	
Sector	100% Standards & Regulation	**Activity**	80% International obligations: 20% NMS infrastructure

Summary The project provides for national and international representation of the NMS and the UK on the most relevant national and international committees for optical radiation metrology and the calibration and validation of data for Earth Observation and climate.

The Need

The CIPM Consultative Committee on Photometry and Radiometry (CCPR) and the EURAMET Technical Committee of Photometry and Radiometry (TC-PR) are the coordinating bodies for international and European co-operation in the field of optical radiation metrology. The CCPR and TC-PR are responsible for planning new Key Comparisons in support of the Mutual Recognition Agreement and is the forum for discussions of future service devolution and cooperation under programmes such as EMRP, which will oversee the re-shaping of NMI metrology research funding across the whole of the EU, with direct consequences for NPL and the NMS. The CCPR and TC-PR are heavily influenced by other National Measurement Institutes and this needs to be balanced by strong UK/NPL/NMS input.

The International Commission on Illumination (CIE) promotes worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, colour and vision, photobiology and image technology. The CIE Technical Committees of the CIE develop basic standards and procedures of metrology and is recognized by ISO as an international standardization body. Board Membership of CIE and CIE-UK allows for direct NMS influence of CIE activities.

The CIE, CEN, ISO and BSI, are responsible for drafting the specification standards that are followed by calibration and testing laboratories, and by industry in the UK. Without membership on these committees, the UK would not be able to vote on new standards or influence their technical content, potentially disfavouring UK industries and users.

The Committee on Earth Observation Satellites (CEOS) is the focal point for international coordination of space-related Earth Observation (EO). The CEOS Working Group on Calibration and Validation (WGCV) aims to ensure long-term confidence in the accuracy and quality of Earth observation data and products. Participation in CEOS WGCV through chairmanship of Infrared and Visible Optical Sensors sub-group allows for direct NMS influence of CEOS activities and is essential for disseminating the NMS research activity on initiatives such as the Quality Assurance Framework for Earth Observation (QA4EO).

The Solution NPL will provide representation on the most critical and highest impact national and international committees for optical radiation measurement and the traceability of data for Earth Observation and climate. This will include chairing the committee or working group where this is of key benefit to the UK NMS.

Project Description The project will fund work by committee members and chairpersons, including travel & subsistence for attending essential meetings, and annual membership fees (where applicable) for the following:

CIPM Consultative Committees for Photometry and Radiometry (CCPR) and Working Groups: CCPR-WG Strategic Planning (Fox, Goodman); CCPR-WG Key Comparisons (Fox, Woolliams)

EURAMET Technical Committee Photometry and Radiometry (Fox, Goodman)

CEOS WGCV IVOS (Fox, Chair); European Space Agency Working Group on Cal Val (Fox)

CIE Board of Administration Vice-President Publications (Goodman); Official UK Member for CIE Division 2 Physical Measurement of Light and Radiation (Goodman); CIE TC 2-65 Photometric Measurements in the Mesopic Range (Goodman, Chair)

CIE-UK Supporting Organisation; CIE-UK Board of Trustees (Goodman)

CEN TC 169 Light & Lighting WG 7 Photometry (Miller)

BSI CPW 172 Optics & Photonics (Hall, Chair); ISO TC 172 Optics & Photonics (Hall)

BSI EPL 76 Optical Radiation Safety & Laser Equipment (Hall); IEC TC76 Optical Radiation Safety & Laser Equipment

Impact and Benefits

This project provides direct representation of UK interests in the international metrology community to ensure that UK industry is not disadvantaged when new international standards are written and EU Directives are implemented. The project funds representation on committees which decide on the portfolio of key comparisons which NPL must undertake on behalf of the NMO, and on the future directions of the SI, including new realisations of units, new

traceability routes and new areas for targeted metrological research. International trade is also dependent on underlying equivalence of measurement standards and mutual acceptance of test and measurement certificates and procedures. Work under the MRA to reduce trade barriers is performed through technical discussions at CCPR and EUROMET TC-PR and their Working Groups.

The project supports representation of UK interests internationally within the EO and climate community through CEOS WGCV. This allows NPL and NMS to provide leadership to the EO community in the development and implementation of Internationally accepted methodologies to enable SI traceability and allow quality assurance metrics to be ascribed to a knowledge information product to meet the needs of all EO stakeholders. Indirectly all of society will benefit from improve traceability and quality assurance for EO data for climate monitoring.

Support for Programme Challenge, Roadmaps, Government Strategies

Through membership of and EURAMET TC-PR and CCPR Strategic Planning and Key Comparisons working groups the Programme benefits from a clear understanding of the long term drivers and future measurement/KC requirements of those communities. These in part shape the content of the technical area roadmaps. In addition, by holding those key positions it is possible, whilst benefiting the wider measurement community, to shape the proposed research agenda of the committees for the benefit of the UK NMS.

This project directly supports the Earth Observation and Climate road map. Quality assurance of evidence to support environmental monitoring and enables collection of climate quality data to inform Government strategies.

Synergies with other projects / programmes

The project has direct synergy with all other optical radiation measurement projects in the Programme as it is both an over-arching and underpinning activity. The UK will continue as a signatory of the Metre Convention, necessitating representation on the CCPR and associated working groups. Also anticipated is on-going membership of EURAMET, particularly in regards of influencing programmes such as the future EMRIP through TC membership.

Risks This project is reliant on a number of key NPL staff who hold positions of influence within committees. The increasing demand for traceable optical radiation measurements in the Earth Observation sector may lead to an increase in the number of national and international committees that demand NMS representation within the limited resources of this project. Prioritisation of committee members is therefore a key requirement.

Knowledge Transfer and Exploitation

Direct knowledge transfer will be via published standards, technical reports, papers and influence of international optical radiation metrology. Input will be provided into documents regarding the *mise en pratique* for the definition of the candela. Take up will be across many sectors using standards and guidance documents: Earth Observation, lighting, aerospace; automotive; industrial and advanced manufacturing; measurement & control (including instrumentation manufacture); science base.

The output from CEOS WGCV IVOS activity is directly reported to the UK Space Agency and publicised through the websites, newsletters, workshops, and other interactions with stakeholders.

Co-funding and Collaborators Co-funding support will be sought from the UK Space Agency and CIE-UK towards the cost for CEOS WGCV and CIE Division 2 meeting attendance. Support for participation in BSI EPL 76 & IEC TC/76 is provided under the NPL Corporate Assurance Health & Safety programme. Collaborators include the other NMIs, CEOS Agencies, standards bodies, industrial experts, and technical experts from around the world.

Deliverables (only active deliverables shown)

1	**Start: 01/10/14**	**End: 30/09/2014**	
Description: UK Representation on CIPM Consultative Committee for Photometry and Radiometry, including attendance at Working Group meetings.			
2	**Start: 01/10/13**	**End: 30/09/2014**	
Description: Representation of NMS and UK on EURAMET Technical Committee on Photometry and Radiometry, including attendance at annual meeting.			
3	**Start: 01/10/13**	**End: 30/09/2014**	
Description: International Commission on Illumination (CIE)			
4	**Start: 01/10/13**	**End: 30/09/2014**	
Description: Work on BSI, CEN, ISO and other standards committees.			
5	**Start: 01/10/13**	**End: 30/09/2014**	
Description: Participation in CEOS Working Group on Calibration & Validation (WGCV) and chairmanship of CEOS WGCV Infrared and Visible Optical Sensors Sub-Group.			

Project No.	EF/2013/46	**Price to NMO**	£428k
Project Title	**Technical, Consultative and Standards Committee Activity for engineering measurement**	**Co-funding target**	NIL
Lead Scientist		**Stage Start Date**	October 2013
Scientist Team	Lewis, Davidson, Knott, Leach, Yacoot, McCarthy, Hughes, Machin, Bell, de Podesta, Pearce, Gunn, Robinson	**Stage End Date**	September 2014
		Est Final Stage End Date	
Sector	100% Standards & Regulation	**Activity**	80% International obligations: 20% NMS infrastructure

Summary

The project provides for national and international representation of the NMS and the UK on the most relevant national and international committees: scientific, technical, standardisation, and metrology.

The Need

The CCL, CCM, CCT, CCEM and EURAMET are responsible for planning new Key Comparisons and are the forum for discussions of future service devolution and cooperation under projects such as EMRP, which will oversee the re-shaping of NMI metrology research funding across the whole of the EU, with direct consequences for NPL and the NMS. EURAMET is heavily influenced by PTB and this needs to be balanced by strong UK/NPL/NMS input. ISO and BSI are responsible for drafting the specification standards that are followed by calibration and testing laboratories, and by industry in the UK. Without membership on these committees, the UK would not be able to vote on new standards or influence their technical content, potentially disfavouring UK industries and users. The Institute of Physics (IOP) journal Measurement Science & Technology (MST) is one of the leading journals (with high impact factor rating) relating to metrology and board membership would allow for direct NMS influence. In addition membership of the IOP Nanoscale Physics and Technology (NPT) committee gives us visibility to the academic nanotechnology community. The International College for precision engineering, manufacture, design and processing (CIRP) is an internationally influential body that performs measurement comparisons, coordinates research, publishes high quality peer reviewed papers and sponsors major conferences. NPL Corporate membership would be beneficial in terms of networking with influential industrial companies from around the world, as well as access as a publication output. All the UK's oil and gas industry use standards that are controlled by the American Petroleum Institute (API) committee. Technical issues which arise need UK input, to prevent US & China dominance. The International Measurement Confederation (IMEKO) supports international co-operation between measurement scientists and is the major forum for technical exchanges within the mechanical metrology area. The Institute of Measurement and Control's (InstMC's) Weighing and Force Measurement Panel's (WFMP's) remit is to promote standards, guides, and codes of practice in all areas of industrial weighing and force measurement to UK industry. NMS inputs to these committees are vital.

The Solution

NPL will provide representation on the most critical and highest impact national and international committees, either by simple membership, or by chairing the committee or working group where this is of key benefit to the UK NMS.

Project Description (including summary of technical work)

The project will fund work by committee members and chairpersons, including travel & subsistence for attending meetings. Annual membership fees (where applicable) will be funded. Representation will be provided on the following:

CIPM Consultative Committees for: Length (CCL); Mass & related quantities (CCM); Thermometry & related quantities (CCT); Electricity and Magnetism (CCEM)

CIPM Consultative Committee Working groups:

CCL-WG Strategy (Lewis); CCL-WG Key Comparisons (Lewis, chair); CCL-WG-MRA (Lewis); CCL-WG CMCs (Lewis); CCL-WG Nano (Yacoot)

CCM-TG1 & TG2 steering committees (Davidson); CCM–WG Density (Davidson); CCM-WG Force (Knott); CCM-WG Hardness (Knott); CCM-WG CMCs (Davidson), CCM-WG Gravimetry (Robinson)

CCEM-WG Kilogram (Robinson, Chair)

CCT-WG5 Radiation thermometry (Machin, chair), CCT-WG6 Humidity (Bell, Chair), CCT-WG1 Primary scale realisation (Machin), CCT-WG Strategy (Machin), CCT-WG2 Secondary thermometry (Pearce), CCT-WG4 Primary thermometry (dePodesta), CCT/WG7 Key comparisons (Bell)

EURAMET Technical Committees:

TC-Length (Lewis)

TC-Mass & related quantities (Davidson, Knott); TC-M Mass WG (Davidson, chair)

TC-Thermometry & related quantities (Machin, nominated chair, if accepted handover begins Apr-14); TC-T Strategy Group (Machin, chair, Bell); TC-T CMC review (Machin); TC-T Humidity subfield (Bell)

IMEKO TC12 – International technical committee on thermometry and related quantities (Machin, UK representative). ISO/IEC - Thermal Imager Specification Standards (Machin, chair). ISO TC213 Wg10-Laser Trackers (Hughes). ISO 213 Geometrical Product Specification WG 10 Coordinate measuring machines (McCarthy); WG 16 Surface Texture (Leach); ISO 229 Nanotechnologies (Leach); ISO committees within TC 164 covering force, extension, torque, hardness, fatigue (Knott). BSI TDW/4 Technical Product Specification (Leach & McCarthy); BSI committees within ISE/101 (testing of metals), covering force, extension, torque,

hardness, fatigue (Knott); BSI CPI/29 Temperature and humidity conditioning requirements (Bell, chair). BSI FME/9 & ISO/TC1/2 CEN/TC 185 – fasteners (Gunn) Institute of Nanotechnology Advisory Board (Leach). SPIE 3D Imaging Metrology - Organising Committee (McCarthy). European Society for Precision Engineering and Nanotechnology Advisory Board (Leach). InstMC WFMP (Knott). Coordinate Measuring Technique PL.–Technical committee (McCarthy). IMEKO TC3 (force, mass, and torque) and TC5 (hardness) (Knott). CIRP Scientific & Technical Committee – Precision Engineering & Metrology (STC-P) (Lewis). Editorial Board MST, IOP Nanoscale Physics Group Committee, Nanoscale Conference organizing Committee (Yacoot). Society of Environmental Engineers - Climatic and Reliability Group (Bell). American Petroleum Institute gauging committee (Gunn).

Impact and Benefits

This project provides direct representation of UK interests in the international metrology community to ensure that UK industry is not disadvantaged when new international standards are written and EU Directives are implemented. The project funds representation on committees which decide on the portfolio of key comparisons which NPL must undertake on behalf of the NMO, and on the future directions of the SI, including new realisations of units, new traceability routes and new areas for targeted metrological research. About 1% of the turnover of UK aerospace, engineering and automotive sectors is measurement and testing based. This fraction represents about £1 bn turnover, 11,000 jobs, and over £500 M of exports. International trade is also dependent on underlying equivalence of measurement standards and mutual acceptance of test and measurement certificates and procedures. Work under the MRA (see below) to reduce trade barriers is performed through technical discussions at EUROMET, CCM, CCL, CCT and their Working Groups. The EU's Market Access Sectoral and Trade Barriers Database lists around 70 trade barriers that are based on standards & other technical requirements.

Support for Programme Challenge, Roadmaps, Government Strategies

Through membership/chairing of CC and Euramet TC Strategy groups the programme benefits from a clear understanding of the long term drivers and future measurement/KC requirements of those communities. These in part shape the content of the technical area roadmaps. In addition, by holding those key positions it is possible, whilst benefiting the wider measurement community, to shape the proposed research agenda for those CCs and Euramet TCs for the benefit of the UK NMS. Strong representation on these highly prestigious committees (particularly the CCs) gives a firm message to the international measurement community that the UK (NMS) is a strong and committed partner in CCL, CCM, CCT and CCEM, as befits the UK's status as a Member State of the Metre Convention.

Synergies with other projects / programmes

The project has direct synergy with all other projects in the Programme as it is both an over-arching and underpinning activity. It is anticipated that the UK will continue as a signatory of the Metre Convention, necessitating representation on the CCL, CCT, CCM and CCEM, and their working groups. Also anticipated is on-going and strengthened membership of EURAMET, particularly in regards of influencing programmes such as the current and future EMRP, through TC membership. Much of the scientific outputs of the Programme are likely to be presented or published at CIRP, IMEKO, Tempmeko or in relevant journals and the R&D work will underpin and influence future specification standards.

Risks An increase in the number of ISO/BS committees that require NMS representation and therefore need prioritisation.

Knowledge Transfer and Exploitation

The output from these committees will publicised through EMAN, newsletters and trade journals. This will ensure UK industry gets full visibility of new standards to allow early uptake. Direct exploitation will be via published standards, papers and influence of international metrology. Key input will be provided into documents regarding the implementation of the new definition of the kelvin (and other defined base units) through preparation of text for the *mise en pratique* for the definition of the kelvin. Take up will be across many sectors using standards: aerospace; civil engineering; industrial process control; automotive; industrial manufacturing; advanced manufacturing; measurement & control (including instrumentation manufacture); science base. Indirectly all of society will be affected through the promulgation of the SI units, and their future realisations.

Co-funding and Collaborators

No direct co-funding is envisaged though some cost savings may be made by influencing the choice of meeting venues, and co-locating committee meetings with scientific conferences. Collaborators will include the other NMIs, particularly within EURAMET, standards bodies and industrial experts, and in the case of the CCs, technical experts from around the world. Through chairmanship of CCT-WG5 NPL is leading a large multi-national research project for new high temperature fixed points and scales; this part directs the research programmes of other NMIs which can be considered as co-funding. The IOP pays T & S expenses for MST and IOP NPT group meetings.

Deliverables (only active deliverables shown)

1	**Start: 01/10/13**	**End: 30/09/2014**	

National and international engineering representation of the NMS, to include

- EURAMET Technical Committee membership (TC-L, TC-M, TC-T), including WGs
- CIPM Consultative Committee membership (CCL, CCM, CCT, CCEM), including WGs
- Work on CEN, EN, BSI, ISO and other standards committees
- CIRP, IMEKO, API, Inst MC, IOP, and other technical committees

Project No.	EF/2013/47	**Price to NMO**	£217k
Project Title	**Contract Management**	**Co-funding target**	N/A
Lead Scientist	Leon Rogers	**Stage Start Date**	October 2013
Scientist Team		**Stage End Date**	September 2014
		Est Final Stage End Date	
Sector	100% Management	**Activity**	!00 % Programme Management & Formulation

Summary

This project will deliver effective contract management for the programme. Work in this project will ensure timely invoicing and reporting to the NMO each month and delivery of an annual progress report to the NMO and programme working group.

The Need

Contract management is essential to ensure seamless delivery of the science projects in the programme while attending to all reporting and invoicing requirements of the NMO. A central point of control is also required for effective operational oversight and governance of the programme.

The Solution

This project will deliver effective contract management through a contract manager dedicated to this programme. They will have oversight of all:

- Project delivery;
- Invoicing;
- Contract status and variations;
- Monthly and annual reporting.

Project Description (including summary of technical work)

1. Attend meetings as necessary to support contract delivery and the needs of the NMO
2. Prepare reports monthly (invoices, progress report and financial forecasts)
3. Liaison with working group, industrial advisory groups & clubs
4. Manage delivery of the contract and submit change requests and contract amendments as necessary
5. Analysis of programme performance and revenue forecasts for the financial year
6. Ensure that the contract is managed to NPL's ISO 9001 accredited quality system
7. Deliver annual report and present programme progress to working group and the NMO as required.

Impact and Benefits

This project will ensure that all operational, financial and reporting requirements for the programme are met. The work in the programme covers the oversight of delivery from all the technical projects and hence is where ultimate responsibility lies for the success of the programme.

Support for Programme Challenge, Roadmaps, Government Strategies

Not applicable.

Synergies with other projects / programmes

Not applicable.

Risks

The main risks are the inability to deliver the monthly reports and invoices to the NMO and the failure to deliver the annual report to the programme working group. Both of these risks are mitigated by the availability of a large pool of senior managers who are available to step in to assist or take over delivery if adverse circumstances are causing problems with the completion of the key tasks of this project.

Knowledge Transfer and Exploitation

Not applicable.

Co-funding and Collaborators

Not applicable.

Deliverables

1	**Start: October 2013**	**End: September 2014**	
Contract management including production of monthly invoices and reports to the NMO			
2	**Start: October 2013**	**End: September 2014**	
Produce annual report and present progress to the NMO and working group			

Project No.	EF/2013/48	**Price to NMO**	£176k
Project Title	**Programme Management and Formulation**	**Co-funding target**	N/A
Lead Scientist	Neil Campbell	**Stage Start Date**	October 2013
Scientist Team		**Stage End Date**	September 2014
		Est Final Stage End Date	
Sector	100% Management	**Activity**	100% Programme Management

Summary

This project will formulate a proposal of work for inclusion in the 2012/13 programme and engage with key stakeholders to ensure maximum impact is achieved from the science delivered by the programme. To achieve these objectives the project will:

- Maintain and develop the programme strategy and roadmaps;
- Consult with key stakeholders in government, industry, academia, regulators and other end users in order to determine future measurement requirements or other related issues that need to be addressed by the programme;
- Develop a series of project proposals for prioritisation by the programme working group;
- Implement and maintain a balanced scorecard for the programme as a measure of the impact of the programme on the UK economy and society.

The Need

New measurement requirements are constantly emerging from all areas of UK life. For example, new technologies require new underpinning metrology and standards, as do new regulations or environmental targets. To underpin areas such as growth in the economy, public health issues or mitigation of environmental impacts these measurement requirements must be successfully addressed as early as possible. In order to achieve these objectives effectively an overview of the research priorities and how to address them is required. Maintaining and developing a programme strategy and roadmaps achieve this objective and allow, in conjunction with knowledge of specific technical requirements obtained through stakeholder consultation, the formulation of a work programme that address UK measurement needs. Both the careful design of any programme of work coupled with the continual review of opportunities for increased impact are essential in order to make sure that the maximum value possible is extracted from the investment made in the technical projects.

The Solution

The views of a wide range of stakeholders from industry, regulators, government and other end users will be sort through a wide ranging consultation process in order to capture current and emerging measurement requirements. This process will include looking at independent evidence of measurement needs as expressed in government reports, foresight activities, industry roadmaps etc. as well as conducting meetings, surveys and interviews as required that focus on specific topics of interest. Collation and assessment of information from all sources will enable the programme strategy and roadmap to be developed which will guide the future direction of the programme. The detailed technical requirements will then formulated into a series of projects for prioritisation by the independent programme working group. Projects that receive the highest ranking will form a programme of work, which will be initiated at the start of the next programme cycle.

In addition to the programme formulation, work will be undertaken to understand and maximise the impact of the research. This will be assisted by the implementation and maintenance of a balanced scorecard for the programme consisting of a number of key metrics. The balanced scorecard will be developed initially as part of the Pan-Programme KT activity.

Project Description (including summary of technical work)

- Horizon scanning, capture and analysis of Industry and Societal needs to feed into current and future programme direction;
- Development and updating of programme roadmaps and strategy;
- Engagement with programme stakeholders to:
    - Realise outputs and maximise benefits to the UK;
    - Ensure alignment of programme with UK Government, Industry and Societal drivers;

- Oversee preparation of project proposals for review and prioritisation by the programme working group;
- Submission of final programme proposal for contracting;
- Liaison with the NMO programme supervisor to deliver maximum impact and efficient delivery;
- Identification of exploitable material for increased impact through channels provided by the Pan-Programme KT programme and other KT avenues;
- Assessment of the impact of the programme through use of a balanced scorecard;

Impact and Benefits

Effective programme management will maximise the outcomes to key stakeholder communities from the outset of the technical work and ensure knowledge transfer activities in the programme are efficient and effective. The programme as a whole addresses many measurement challenges across the broad sweep of the UK economy and society. Therefore, the design of knowledge flows and exploitation plans in technical projects which occurs during the formulation process is essential for delivery of the wide benefits of the programme to the broadest possible audience.

Support for Programme Challenge, Roadmaps, Government Strategies

This project underpins the work of the whole programme through development of an overview of key societal drivers and measurement requirements as captured in the programme strategy and roadmaps. These key programme documents are utilised during development of technical projects to guarantee that all the technical work in the programme is aligned to addressing the metrology needs of the UK.

Synergies with other projects / programmes

This project will interact with the other NMS programmes so that synergies and common goals can be identified to ensure that the maximum value is returned from the investment in the NMS portfolio.

Risks

This project has no technical risks but is dependent on the availability of senior staff to assess and interpret the societal drivers in order to develop the programme strategy and roadmaps and hence determine the future technical work required in the programme.

Knowledge Transfer and Exploitation

The main functions of this project are to ensure the development of a new programme of work and to measure and increase the impact of the programme. Improvement of the programme impact will be achieved through proactive intervention in the technical projects within the programme rather than through direct knowledge transfer activity in this project.

Co-funding and Collaborators

Not applicable.

Deliverables

1	**Start: October 2013**	**End: September 2014**	

Programme Management and Formulation

Change History

Date	Project	Change	Reason
20th November 2013			**Initial issue**

National Measurement System

The National Measurement System delivers world-class measurement for science and technology through these organisations

National Measurement Office

NPL National Physical Laboratory

LGC Setting standards in analytical science

nel technology for life

The National Measurement System is the UK's national infrastructure of measurement Laboratories, which deliver world-class measurement science and technology through four National Measurement Institutes (NMIs): LGC, NPL the National Physical Laboratory, TUV NEL The former National Engineering Laboratory, and the National Measurement Office (NMO).