NPL activity report to CCT 2024 to 2026

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Introduction

Here we give a brief overview of some of the research activities we have been undertaking in thermometry in the NPL Temperature and Humidity Group in the last two years.

We have been active in seeking to bring the traceability of the measurement closer to the user, through self-validation and practical primary thermometry, such as Johnson Noise and Doppler Broadening. We have also worked on primary thermometry both by acoustic gas thermometry and relative radiometry via high temperature fixed points.

We have maintained our wide range of low-uncertainty CMCs, for calibrating c-SPRTs, SPRTs, HT-PRTs, noble metal thermocouples, ITS-90 fixed-points, and non-contact thermometers, accredited in the UK by UKAS. In particular our high temperature CMCs have been substantiated through the recently completed K10 comparison. We have also expanded our capability for performing calibrations at low temperatures to meet growing customer demand.

We have used our temperature metrology expertise to help solve temperature measurement challenges in fields as diverse as satellite testing, nuclear decommissioning and medical.

We have continued our work on novel primary thermometry techniques including phosphor thermometry and NV nanodiamonds.

We have continued our activity in humidity and moisture particularly in climate monitoring and standardisation activities.

Finally we have published nearly 50 technical papers reporting our research in a wide variety of journals and presented our work at a number of conferences.

Below gives a more detailed summary of our activities in different areas of thermometry.

Contact thermometry

A new capability for comparison calibration of capsule thermometers from 2.5 K to 300 K has been developed using a closed-cycle helium cryostat. This is in response to demand from end-users, mainly in the liquid hydrogen supply chain.

Improved realisation methods for the CO_2 fixed point have been developed and tested, and the system is being prepared for possible introduction as a measurement service (pending an intercomparison).

Substantial improvements in characterisation of the uncertainty associated with SPRT interpolation have been made, which have been presented to CCT-WG-CTh for inclusion in an updated Guide on SPRTs.

NPL has led the updating of the list of secondary fixed points within CCT-WG-CTh by performing a comprehensive survey of the literature.

A bilateral comparison with NRC (CCT-K9.4) for the zinc freezing point has been successfully completed, substantiating our CMCs and marking the final step in closure of the corrective actions following NPL's anomalous result in CCT-K9. https://doi.org/10.59161/KAXC2980

A novel approach to addressing thermocouple calibration drift has been made using sensor network metrology techniques; a multi-wire thermocouple comprises of several different thermocouples, all at the same temperature (because they are connected at the tip). A report has been accepted for publication by the Johnson Matthey Technology Review. https://doi.org/10.1595/205651327X17784910022882

NPL's self-validating thermometry has progressed significantly, with industry trials of the self-validating thermocouple (trade name INSEVA) underway, together with the development of machine-learning/Bayesian automation of melting plateau detection. Furthermore, miniature water, gallium-indium, and gallium phase-change cells have been further developed in collaboration with a spacecraft instrumentation manufacturer, yielding new insights into supercooling and how to minimise it.

Significant progress has been made in the field of air temperature measurement for meteorology and climate with the development and validation of a coupled CFD turbulent flow and thermal model which models all key physics associated with meteorological instrument shelters. In collaboration with the UK's Met Office the model has been used to improve our understanding of temperature measurement errors in this setting.

Digitalisation activities

Over the past several years, the contact thermometry team within the Temperature group has advanced the digitalisation of its measurement services a critical step towards the delivery of DCCs. We now deliver machine-readable certificates for a number of the thermometry group services. We have, in collaboration with NPL's Data Products team, developed an online portal through which machine-actionable digital calibration certificates can be accessed. This service acts as a demonstrator for the future operation of digitally delivered measurement services and is therefore a cornerstone of NPL's digital NMI approach. The portal also enables users to track the calibration history of their equipment.

Non-contact thermometry

The final report of the Consultative Committee of Thermometry (CCT) Key Comparison CCT-K10, of radiance temperature scales from 962 °C up to 3000 °C, was published in the Metrologia Technical Supplement – reference https://iopscience.iop.org/article/10.1088/0026-1394/61/1A/03003

The comparison included the calibration of two transfer high temperature radiation thermometers and the measurement of the melting temperature of a set of high temperature fixed-point blackbody cells. The demonstrated stability of the fixed-point cells meant that radiance temperature scale uncertainties could be probed more precisely.

The results of the comparison confirmed the equivalence of the participants' temperature scales, with, in general, very good agreement in the results, within the claimed uncertainties. NPL has used the results to underpin CMCs for the 962 °C to 3000 °C range and these have been published on the BIPM KCDB.

NPL is preparing the framework for realising and potentially disseminating thermodynamic temperature above the Ag point using the internationally agreed values for high temperature fixed point phase transitions given in the *MeP*-K annex – the details of this is given in Lowe, D., Machin, G., "Low uncertainty thermodynamic temperature above the silver point using relative primary radiometry", *Proceedings of the 10th International Temperature Symposium, AIP Conf. Proc.* **3230**

100002 (2024) https://doi.org/10.1063/5.0234817. We have been performing measurements of $T - T_{90}$ above the silver fixed point but further work is needed to reduce the uncertainties.

Primary thermometry

Acoustic Gas Thermometry

NPL is continuing research into acoustic gas thermometry (AGT), both for measurements of T-T_{90} and for direct dissemination of the redefined kelvin. As part of these activities, we are developing a new AGT system for the calibration of long-stem SPRTs over the temperature range 100 K to 300 K. The system will use a closed-cycle cryocooler for ease of operation and reliability. The system will accommodate two SPRTs and several capsule-type SPRTs, and is carefully designed to minimise temperature differences between the SPRTs and argon gas in the resonator cavity.

In addition, we are continuing our collaboration with CMS/ITRI (Taiwan) on high temperature AGT from 300 K to 573 K. Preliminary T-T_{90} results have been obtained using the NPL-built cylindrical resonator system at CMS/ITRI.

Johnson Noise Thermometry

We have been proactively supporting a UK instrumentation electronics design and manufacturing company with the development of a practical Johnson noise thermometer. Key developments in the last two years include further improvement and testing of EMC compatibility, probe development (including conventional wire-wound probes and also a ceramic-encapsulated graphene sensor), and further development of resistance measurement. Support from NPL covers a wide range of activities including electrical, electromagnetic and temperature metrology, data science / mathematics, publicising to potential industrial users, and obtaining joint funding.

Novel thermometry

Phosphor thermometry

Our research has focused on extending robust surface temperature measurement by phosphor thermometry (emissivity free, invariant to background radiation) to higher temperatures. This has extended the upper temperature limit from 700 °C to about 1200 °C, using a new phosphor YAG:Dy. The work, funded by the EMP project ThermoSI, involved assessment and optimisation of a high temperature phosphor and binder recipe, development of a new spectral intensity ratio (IR) based phosphor thermometer instrument, and industrial testing. Additionally, work is on-going to place phosphor coatings on inline-processes allowing active adjustment of thermal imager's emissivity through known temperature determinations from the coating – this has included assessment of a typical phosphor coating's emissivity versus both wavelength and temperature, essential to understanding how the coating may perturb the surface temperature.

We have produced the first world's first practical (hand-held and mountable) phosphor thermometer based on the ubiquitous phosphor MFG and utilising the intensity ratio technique. The instrument, designed and built in-house by NPL's Engineering Team, has been shown to be capable of measuring temperatures from -195 °C to 650 °C and has been tested in several industrial environments (AFRC and BAE Systems).

Finally NPL is hosting the 5th International Conference on Phosphor Thermometry (ICPT2026) in June 2026, highlighting the leading position we now have in phosphor thermometry.

Luminescence-based nanothermometry

In 2024 we began work developing a metrological framework for luminescence-based nanothermometry, with a particular focus on biological applications. This approach exploits the temperature-dependent light emission of luminescent nanomaterials to enable accurate temperature measurements with sub-micrometre spatial resolution in biological environments.

Initial work focused on phosphor particles (MFG, $Mg_4GeO_{5\cdot5}F:Mn$). A dedicated widefield microscopy platform, instrumented with multiple thermocouples for precise temperature field characterisation, was developed to investigate their temperature-dependent spectral red shift. This enabled evaluation of temperature sensitivity and signal stability over the range 20 to 60 °C.

More recently we are investigating quantum-based sensing using nitrogen-vacancy (NV) nanodiamonds as a possible primary nano-thermometry platform. These yielded relative sensitivities of up to 6% $°C^{-1}$—approximately an order of magnitude improvement compared to MFG phosphors—over the same temperature range. Current efforts are focused on the installation and calibration of an optically detected magnetic resonance (ODMR) system targeting colour centres ion NV diamonds, to enable direct benchmarking between all-optical sensing methods and ODMR-based thermometry. Future work will include validation of these techniques in biologically relevant media, planned for the coming year.

Photonic thermometry

NPL has established strong cooperations in photonic thermometry with the University of Glasgow (active ring resonator thermometry, aRRT) and University of Strathclyde (practical Doppler Broadening Thermometry, pDBT). Good progress has been made in demonstrating pDBT at room temperature and in making the first aRRT structures in InP. Papers giving the first results have been published in the open access journal https://royalsocietypublishing.org/rsta/issue/384/2312 and others in the bibliography.

Applied thermometry

We have applied our temperature metrology skills to a wide variety of applied temperature measurement settings. Three illustrations are given below as examples of the sort of activity we have been working on.

Space: A software tool was developed, in cooperation with the European Space Agency (ESA), for 3D thermal and dimensional measurement data with solution finding for true surface temperature; integrated with thermos-elastic deformation outputs and export to compare to modelled data. This used a new physically based ray tracing and solution finding approach for surface thermometry. The thermometry aspect has been validated by comparing corrected thermal imaging results with surface mounted temperature sensors, type T thermocouples and PT100s. A range of temperatures from 60 °C to 140 °C were used and long-wave and mid-wave infrared thermal imager and photogrammetric data sets were captured. For these ambient conditions, with the surfaces and temperature set points used the imager apparent temperatures (uncorrected values) deviated from reference temperatures by between 5 °C and 20 °C. After processing within the software tool, the corrected surface temperatures agreed with the reference temperatures to < 5 °C, within the combined measurement uncertainties.

Nuclear decommissioning: We have worked with the UK Nuclear Decommissioning Authority, UK National Nuclear Laboratory and Sellafield on a number of thermometry and humidity measuring challenges. These have included measuring, for the first time, traceable temperatures inside spent nuclear fuel pins, qualifying thermal imaging for use inside intermediate level nuclear waste stores, developing thermal measurement strategies and approaches both inside nuclear waste containers, on their surfaces and also inside waste stores as well. Some of this work has been published – see the bibliography.

Medical: We have worked with a range of clinical partners to a) help improve the outcomes for diabetic foot ulceration patients (see bibliography papers) b) to improve clinical thermometry in general – this arose from work we did during the COVID-19 pandemic, and also requests from the NHS to help improve triaging of patients with suspected sepsis c) we have a PhD student starting in Autumn 2026 who will examine if there is a reliable correlation of core body temperature to inner-canthi temperatures derived from thermal imaging.

Humidity and moisture

2nd half 2024 – Collaboration with EPM ProMetH2O, contributing NPL experimental data on water vapour enhancement in hydrogen. Air temperature research for meteorology, focusing on uncertainty due to radiative influence on thermometers. Novel approach to assessing thermometer response-time testing using solar simulation facility. Project on modelling of metrological Stevenson Screens. Input to analysis of CCT-K8 and by EURAMET.T-K8.

2025 – Presentation of WMO training videos in collaboration with Slovenian Environment Agency. TEMPMEKO – ISHM main steering committee and invited roundtable plenary. Work on development of noise analysis techniques to identify changes in humidity datasets for climate (NPL with Met Office).

2026 – Led revision of Chapter 4 (Humidity) of WMO Guide to Instruments and Methods of Observation (GIMO) in collaboration with WMO Expert Team (ET-QTC). Collaboration with KRISS visiting researcher on water vapour enhancement factor.

International meetings/conferences/ knowledge transfer

NPL led a Royal Society Theo Murphy discussion meeting "The redefined kelvin: Progress and prospects" to mark the bicentenary of the birth of Lord Kelvin. This was held in Glasgow 25-26 Feb 2025 and temperature measurement experts from around the world presented both the cutting edge of thermometry research and also presented their views as to the future development of the SI unit. There was also a poster session. Subsequently a volume of Phil Trans Roy Soc A with the same name was published – which is open access and can be found at: https://royalsocietypublishing.org/rsta/issue/384/2312

NPL was also well represented, giving oral and poster presentations at the Tempmeko & ISHM 2025 conference held in Reims, France, October 2025.

We have been active in promoting our digitalisation activities by a poster being presented at the Royal Society "The redefined Kelvin: progress and prospects" (Glasgow, February 2025) on "Digitalisation of the measurement services at temperature area was presented" and at the "DCC workshop for UK calibration laboratories" in October 2025.

NPL organised and hosted an online industrial stakeholder workshop in April 2026 which attracted 80 attendees from around the world, and covered topics including phosphor thermometry, thermocouple drift mitigation, quantitative thermal imaging, Johnson noise thermometry, and sensor network metrology.

We also ran the popular NPL Temperature measurement & calibration training course in June 2024 and Nov 2025, which attracts delegates from around the world.

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