

CCT member and observer Activity Report

Period: January 2022 to May 2026

Institute: Laboratoire commun de métrologie LNE-Cnam (Temperature and thermophysical quantities) and LNE-CETIAT (Humidity and Moisture)

State economy: FRANCE

Number of persons involved in thermometry of the institute: about 40 (25 in thermometry)

Short summary of research and development

Mise-en-pratique of the new definition of the kelvin:

We have well-established and operational facilities and methods for thermodynamic temperature measurement and dissemination over a large temperature range, from the lowest temperatures with noise thermometry below 2 K, acoustic gas thermometry (AGT) and refractive index gas thermometry (RIGT) up to 300 K, to the highest temperatures above 1300 K using radiance-based thermodynamic temperature measurement technique and high-temperature fixed points up-to the WC-C point (3022 K).

We implement these techniques in absolute primary thermometry mode for the realization of the kelvin definition, as well as in relative primary thermometry mode (e.g. *fast*-AGT) for dissemination purposes, both without any significant difference in the level of uncertainty reached. We have full and operational realizations of the temperature scales in almost all the defining ranges, namely PLTS-2000 between 0.01 K and 1 K, ITS-90 between 0.65 K and 5 K, then above 13 K up to 3200 K. We determine large datasets of $T-T_{90}$, $T-T_{2000}$ and $T_{90}-T_{2000}$ values, to contribute to the enhancement of the *mise en pratique* of the definition of the kelvin. We perform preliminary tests merging calibration data from thermodynamic temperature and temperature scale calibration (e.g. *hybrid calibration*) to reduce propagation of uncertainties in ITS-90.

In the high temperature range, high-temperature fixed point (HTFP) related-research is ongoing with the improvement of the techniques of realization and operation of HTFPs and the *mise-en-pratique* of the kelvin at high temperature using relative radiometric methods.

Opto-mechanical and photonic temperature sensors:

In collaboration with two major French laboratories in this field: Laboratoire Kastler Brossel (LKB) and Centre de Nanosciences et Nanotechnologies (C2N), LNE-Cnam is developing and characterising quantum optomechanical and photonic temperature sensors for the low temperature range. One Ph-D thesis is currently devoted to this subject.

The research activities are running in the framework of several European projects (JRP PhoQuS-T, European Horizon-2020 project QUANTIFY, National and regional research projects (ANR)..) showing a very dynamic research field.

Moreover, in the recent years, LNE-Cnam has participated in research activities in relation with fiber-optic thermometry in the frame of the JRP project INFOTherm. In this project we have aged and calibrated a series of 14 FO thermometers produced by CEA.

Development of new temperature references for contact and radiation thermometry:

LNE-Cnam has a long experience in filling and producing gas and metal fixed point cells for the calibration of SPRTs and radiation thermometers. We are currently developing new designs of open cells with improved characteristics for contact thermometry. We have recently developed and characterized cells for the triple points of SF₆ and CO₂, we have filled and successfully tested novel cells for the fixed points of indium and zinc, and we'll soon extend the design to tin and aluminum.

Below 1 K, we are developing new melting pressure thermometers for the realization of PLTS-2000.

In the high temperature range, the ITS-90 reference cells are constructed in the lab using the filling technique developed for HTFPs. A series of cells have been constructed and are regularly compared to maintain a batch of reference cells. LNE-Cnam produces all the cells used in radiation thermometry from the Tin point to the WC-C point.

Characterization of reference materials in enthalpy of fusion:

LNE-Cnam improved an absolute method for the measurement of enthalpy of fusion ΔH_f in the temperature range from 23 °C to 1000 °C. It is based on performing during the same low-rate heating run: ① two in-situ calibrations of the calorimeter by electrical substitution before and after the temperature of fusion of the sample, and ② the measurement of ΔH_f with an electrical compensation of the peak of fusion. This method has been applied to the determination of the enthalpy of fusion of indium, tin and zinc with an expanded uncertainty (k=2) between 0.2 % and 0.3 %.

Development of a facility for directional spectral emissivity measurements:

LNE-Cnam is developing a facility for the measurement of directional spectral emissivity from 150 °C to 750 °C, in the spectral range from 1.5 μm to 20 μm and for incidence angles with respect to the normal between 0° and 70 °C. The expanded uncertainty target associated with these measurements is from 0.015 to 0.035.

Thermal diffusivity measurements at ultra-high temperature:

LNE-Cnam used its reference laser flash apparatus for measuring thermal diffusivity of carbon-phenolic ablative materials, graphite materials (dense and macro-porous) as well as refractive metallic alloys up to 2800 °C. In collaboration with three European NMIs, LNE-Cnam wrote the technical guide "High temperature thermal diffusivity measurements by the laser flash method" which is available online on the EURAMET Website since July 2025.

Local probe thermal microscopy:

LNE-Cnam worked on the establishment of SI traceability of thermal conductivity measurements at nanoscale. Protocols for thermal conductivity measurements at nanoscale and calibration of Scanning Thermal Microscope (SThM) probes have been developed. The uncertainty associated to thermal conductivity measurements has been evaluated to 10 % (k=2) for $\kappa < 10 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$. This method has been applied to the study of graphene oxide flakes.

Development in humidity and moisture measurement:

Development of calibration and measurement capabilities for trace water:

- Development of an industrial dilution facility for generating trace water concentrations
- Acquisition of a transfer standard for low humidity levels

Development of measurement capabilities for water content in solids:

- Moisture analyser, loss on drying (LoD), coulometric Karl Fischer titration, evolved-vapour moisture analyser equipped with a phosphorus pentoxide sensing cell, and water activity facility

- Development, as part of a PhD thesis, of a transfer instrument based on microwave propagation in a cylindrical resonant cavity

Short summary of recent comparison activity:

- CCT-K10 and EURAMET.T-K10: LNE-Cnam has participated in CCT-K10 key comparison and is leading the EURAMET.T-K10 comparison which is currently running.
- CCT-K9 and EURAMET.T-K9: LNE-Cnam has participated to the CCT-K9 comparison and has led EURAMET.T-K9. Both are approved for equivalence since 2024.
- CCT-K7.2001: LNE-Cnam has participated to this key comparison at the triple point of water, and is expected to be one of the loop pilots in the forthcoming associated EURAMET key comparison.
- CCT-K11: LNE-Cnam is participating in this key comparison. Measurements were completed and the comparison is still running.

Short summary of other activities:

- JRP Project DireK-T “Dissemination of the redefined kelvin”. The objective of this European-funded joint research project is to realize two preliminary comparisons in the field of contact thermometry, demonstrating that the redefined kelvin can be disseminated to NMIs devoid of primary thermometers, through a series of thermodynamic temperature calibrations. Should these comparisons prove the feasibility of such dissemination with an uncertainty close to that of national temperature standards, their protocol may be used to implement key comparisons in thermodynamic temperature for supporting CMCs.
- JRP Project Real-K “Realising the redefined kelvin”. This project was completed in 2023. The results obtained in the high-temperature part of the project were very important for the use of HTFPs in the Mise-en-Pratique of the kelvin. Indeed 4 HTFPs have been assigned low-uncertainty thermodynamic temperatures. LNE-Cnam led this work and the publication of the results.
- JRP Project PhoQuS-T “Photonic and quantum sensors for practical integrated primary thermometry” The objective of this European-funded joint research project coordinated by LNE- Cnam is to provide a quantum temperature standard for self-calibrated embedded optomechanical sensor applications. This project aims at developing novel small-scale optical based primary thermometry approaches for the dissemination of thermodynamic temperature to industries such as semiconductor, micro- and nanotechnology, aerospace and naval, green energy and quantum technologies.
- Standardization: LNE-Cnam piloted the revision of the “ISO 19628 standard - Fine Ceramics (advanced ceramics, advanced technical ceramics) - Thermophysical properties of ceramic composites - Determination of specific heat capacity” which was published in November 2024, and currently leads the revision of the “ISO CD 19629 - Fine ceramics (advanced ceramics, advanced technical ceramics) - Thermophysical properties of ceramic composites – Determination of unidimensional thermal diffusivity by flash method.
- JRP INFOTherm “Integrated European research, calibration and testing infrastructure for fibre-optic thermometry”: LNE-Cnam developed accurate methods for quantifying the sources of measurement uncertainty and cross-sensitivities of Raman and Brillouin distributed temperature sensors up to 500 °C.

We have also contributed to the calibration and characterization of FO thermometers supplied by CEA up to 1000 °C.

- JRP PaRaMetriC “Metrological framework for passive radiative cooling technologies”: LNE-Cnam improved a facility for total hemispherical emissivity measurements by designing a new specimen heating system. The uncertainty associated to total hemispherical emissivity measurements has been assessed from ± 0.02 to ± 0.03 ($k=2$) for $T \leq 200$ °C and high emissive materials. The new configuration has been applied to the characterization of passive cooling foils.
- JRP HyMetBat “Hybrid metrology for sustainable and low-carbon footprint battery materials”: LNE-Cnam modifies an existing calorimeter for the measurement of total thermal energy dissipated during charge/discharge cycles of new batteries with a relative uncertainty better than 5%, simultaneously with electrochemical impedance spectroscopy (EIS) measurements in order to study energy dissipation and degradation mechanisms in rechargeable batteries.
- JRP Project PROMETH2O: LNE-Cnam and LNE-CETIAT were involved in this project dedicated to trace water in ultra-pure process gases. Their involvement is mainly focused on provision of robust traceability to trace water measurements in real humid gas mixtures, and namely the measurement of the enhancement factor in selected humid gas mixtures by using quasispherical resonator. LNE-CETIAT leads the work package impact of this project
- JRP Project BiofMET: This project will research more accurate metrological methods and establish advanced traceable measurement standards for the determination of the calorific value, new methods for determining impurities and ash content, new moisture transfer standards and calibration facilities. LNE-CETIAT leads the work package related to the development of online traceability. More specifically LNE-CETIAT is currently developing a transfer standard based on RF/MW technique enabling on-site measurement.
- JRP Project GrainMET: This project advances metrological methods and establishes traceable standards for moisture determination in agri-food products. It focuses on developing and validating reliable methods for water content in plant-origin bulk materials, with emphasis on volumetric Karl Fischer (vKF) titration as a potential primary method. The work includes interlaboratory comparisons and uncertainty evaluations to improve SI traceability and method consistency. LNE-CETIAT leads WP2 and coordinates the interlaboratory comparison between methods.
- Organisation of TEMPMEKO-ISHM 2025 in October 2025 in Reims, France. 40 countries, 400 participants and about 360 scientific presentations (half oral and half posters). French thermal metrology was present in about 10 % of these presentations.

Link to bibliography or list of bibliography (last 5 years):

In the list :

T : Temperatures

TQ : Thermophysical Quantities

H : Humidity and Moisture

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