Welcome to the second edition of DireK-T newsletter

Dear colleagues and partners,

Over the past ten months, our team has taken important steps toward building a solid foundation for the dissemination of thermodynamic temperature across the 4 K to approximately 300 K range.

In this issue, we provide an overview of the progress made during the second phase of the project, spanning between June 2024 and February 2025. During this time, I would like to spotlight two key events held in Glasgow: our second consortium project meeting, and an accompanying high-level workshop, organized under the auspices of the Royal Society, both of which played a pivotal role in shaping our collaborative efforts. Discussions on the development of thermodynamic temperature measurements and other state-of-the-art thermometry topics provided valuable technical insights and reinforced future collaborations.

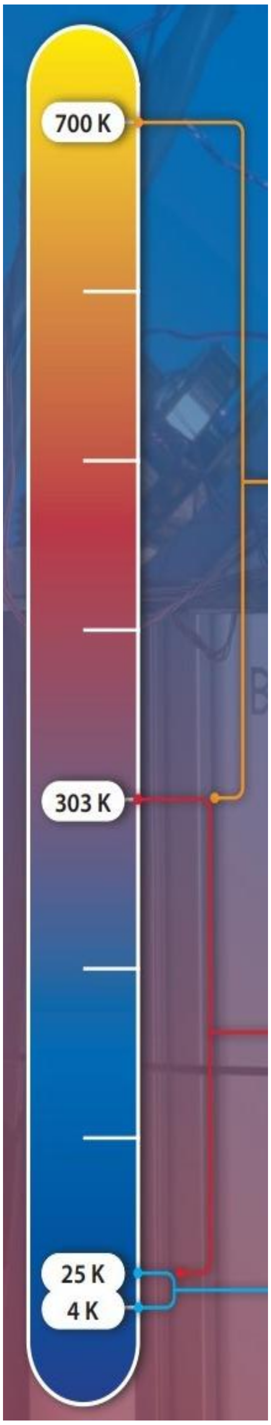
DireK-T project partners and collaborators gathered near the University of Glasgow

Thank you for your continued dedication and support. I hope you may find the content of this newsletter interesting and inspiring, as we continue our journey towards the advancement and innovation of primary thermometry.

Roberto Maria Gavioso,

DireK-T Project Coordinator

Introduction



The European Metrology Partnership research project 'Dissemination of the redefined kelvin' (DireK-T), started in September 2023 with a duration of three years, brings together a critical mass of several leading primary thermometry experts worldwide. The main aim of the project is to take advantage of the kelvin redefinition to demonstrate the validity of primary thermometry approaches for the direct dissemination of thermodynamic temperature.

The kelvin redefinition in May 2019 initiated a comprehensive research phase for the realisation and dissemination of thermodynamic temperature to replace the ITS-90/PLTS-2000 scales currently in use. This research work utilises the experience gained over the past EMPIR project 'Realising the redefined kelvin' (Real-K) https://real-k.aalto.fi, which began the transition away from defined scales by establishing the capabilities to disseminate thermodynamic temperature at high temperatures >1235 K and low temperatures, particularly <5 K.

DireK – T (direk-t.org) addresses the high-level metrology needs stated by CCT recommendation T1 (2021) that NMIs establish capability to determine the difference (T-T_{90}) between the thermodynamic temperature T and its approximation, the defined scale ITS-90 (T90), above 400 K and, in so doing, establish the background capacity for dissemination of thermodynamic temperatures approaching 700 K, ensuring that thermodynamic temperature can be realised and disseminated to room temperature and beyond.

This project will demonstrate dissemination of the kelvin from 4 K to 300 K with defined scale level uncertainties, will develop a robust framework for establishing traceability by primary thermometry and will work towards the next generation primary thermometry to 700 K.

The realisation and dissemination of thermodynamic temperature, as opposed to defined scales, is a long-term objective. The project's outcomes will mark a significant advance towards that objective by using multiple practical primary thermometry approaches to disseminate thermodynamic temperatures. The ultimate goal is to establish an integrated European temperature metrology infrastructure and facilitate the take up of the developed technology and measurement infrastructure by the measurement supply chain (accredited laboratories, instrument manufacturers), CIPM Consultative Committee for Thermometry (CCT), EURAMET and other RMO TC-Ts and relevant end users (industry and academia such as CERN, quantum computing, fundamental materials science communities, etc.).

Research highlights

Demonstrating dissemination of thermodynamic temperature from 4 K to 25 K

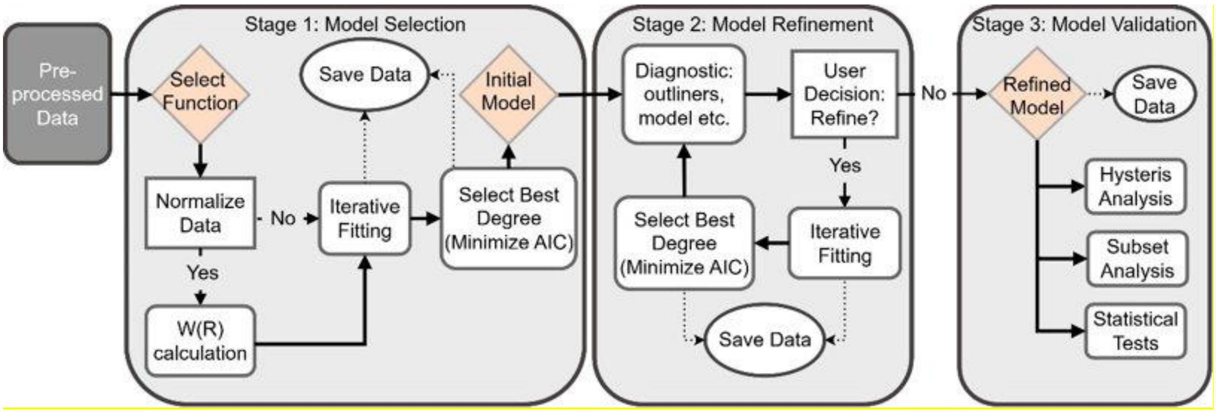


Figure 1. Procedure developed at INTIBS for the determination of the best performing fitting function in the data analysis of capsule thermometers calibration data.

Currently, the ITS-90 temperature scale is not routinely realized anywhere in the world below 25 K. Dissemination relies on sensors calibrated years or even decades ago, which still act as “carriers of the scale.” The most stable and reliable types of these sensors are no longer manufactured, making them unavailable commercially.

Building on previous projects (InK1, InK2, Real-K), the research addressed by the DireK-T project aims at demonstrating that low-uncertainty realization and dissemination of thermodynamic temperature is achievable without relying on a defined scale. Using three primary thermometry methods AGT, DCGT, and RIGT, thermodynamic temperature will be disseminated to two NMIs that lack primary thermometry but maintain ITS-90 calibration facilities and wire scales between 4 K and 25 K.

By directly comparing thermometers calibrated to thermodynamic temperature, these NMIs will, for the first time, confirm the consistency of different primary methods described in MeP-K and assess whether the target uncertainty of 0.3 mK for dissemination in this range can be met.

INTiBS has now completed the ITS-90 calibration of the full set of 16 capsule-type thermometers of various kinds (Pt, RhFe, PtCo), previously selected and delivered by partners, in the range 4 K to 25 K. Calibration was obtained by comparison with other reference thermometers previously calibrated on ITS-90 and/or a wire scale maintained at INTiBS using two different cryostats. INTiBS has also established the sensitivity of the thermometers over the same range and has investigated the best performing algorithms for the analysis of calibration data (see Fig. 1).

The calibration results have been confidentially reported to CEM, the pilot of the comparison of thermodynamic temperature, but remained otherwise undisclosed to the participants.

Delivery of the thermometers was organized so that at least one sensor and two Rh-Fe or Pt-Co have been made available to each participant.

Experimental apparatus and setup for the direct calibration on the thermodynamic temperature scale by the participants have been completed or are close to completion.

Particularly, at TIPC-CAS: the preparation for the *T* calibration with SPRIGT was finished. Repeatability checks of the SPRIGT setup (see Fig. 2) was confirmed over the last 2.5 years at a level below ±0.1 mK.

The thermometers calibrated at INTiBs are now at TIPC-CAS and the *T* calibration with SPRIGT has started.

In addition, TIPC-CAS established a new setup for high quality low-temperature comparison apparatus for the range from 5 K to 25 K (instability lower than 0.01 mK) and they proofed that their scale carriers (two Rh-Fe sensors) remained stable (instability lower than 0.1 mK).

Preparative steps for thermodynamic calibration at LNE-CNAM have also been completed, with four capsule-type thermometers previously calibrated at INTiBS checked at the triple point of water, with no discrepancies resulting greater than 0.5 mK. Following an initial verification of its required performance, the AGT experiment set up at LNE-CNAM, has been used to recorded five helium AGT isotherms in the range 24.5 K to 11 K.

At PTB, cryostats have been successfully relocated to a new building, and the DCGT setup—previously used for measurements from 2.5 K to 273 K—has passed testing at the triple point of water.

Thermometers calibrated at INTiBS are installed, and DCGT measurements are scheduled to begin in April 2025.

At INRIM, thermometers calibrated at INTiBS were delivered and confirmed stable at the triple point of water. Completion of the AGT cryostat was delayed by two months due to leak issues. Analysis of previous AGT results obtained for various types of capsule thermometers in the WP1 range is complete and will be submitted for publication by April 2025.

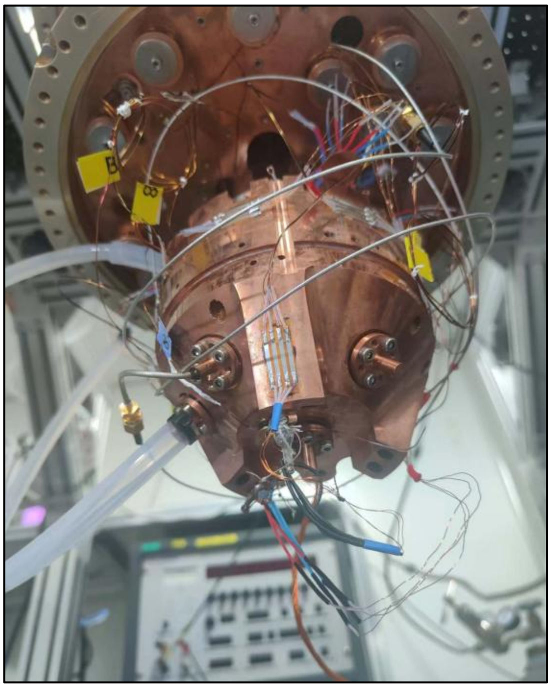


Figure 2. Detail of a copper quasi-spherical resonator used in the RIGT apparatus developed at TIPC-CAS.

Demonstrating dissemination of thermodynamic temperature from 25 K to 300 K

Above 25 K (near Neon's triple point), ITS-90 is easier to realize but has two major drawbacks: deviations from true thermodynamic temperature around 100 K (~10 mK) and non-uniqueness due to cSPRT calibration at different fixed points. Calibrating thermometers directly to thermodynamic temperature removes these problems. The project uses Refractive Index Gas Thermometry (RIGT) and Acoustic Gas Thermometry (AGT) to calibrate practical thermometers, then employs them as transfer standards to disseminate thermodynamic temperature to other institutes. This approach enables routine, practical dissemination later this decade and supports consistent thermometry for fields like climate science and materials research.

ITS-90 Calibrations Completed

Ten out of twelve cSPRTs have been successfully calibrated to ITS-90 by INTiBS, CEM, INRIM, SMD, and UL. These thermometers have been delivered to partners for thermodynamic calibration under WP2. Stability checks at the triple point of water confirmed no anomalies. Calibration results have been reported to CEM, the pilot for the WP3 thermodynamic temperature comparison.

Thermodynamic Calibration Underway

Apparatus for calibrations across 25 K–303 K are now complete or near, and measurements have begun. Particularly,

- at **LNE-CNAM** (see Figs. 3 and 4): four cSPRTs (received from CEM, UL, SMD) were installed in the AGT system. Measurements at –20 °C, –10 °C, 0 °C, and +10 °C were completed by measuring the speed of sound in He along four isotherms, up to 675 kPa, with 11 pressure points per isotherm.

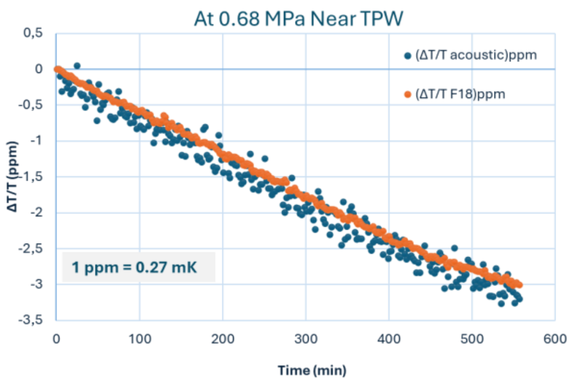


Figure 3. Comparison between relative variations of resistance- and acoustic thermometry at LNE-CNAM.

Future measurements will cover the interval between the TP of Ar and the MP of Ga.

- at **PTB**: the DCGT apparatus complete; with thermometers installed and ready for thermodynamic measurements, expected to start in August 2025.
- at **INRIM**: the completion of the AGT apparatus was delayed by two months due to technical issues mentioned above.
- **at NPL**: the AGT system previously used to determine (T-T_{90}) over the range between 118 K and 323 K was rebuilt and validated at TPW. cSPRTs from INRIM, SMD, and UL were installed. Next steps: measurements near the CO_2 triple point (217 K) and gallium point (30 °C), with temperature control via recirculating chiller. If time allows, a GM cryocooler will extend measurements to lower temperatures.

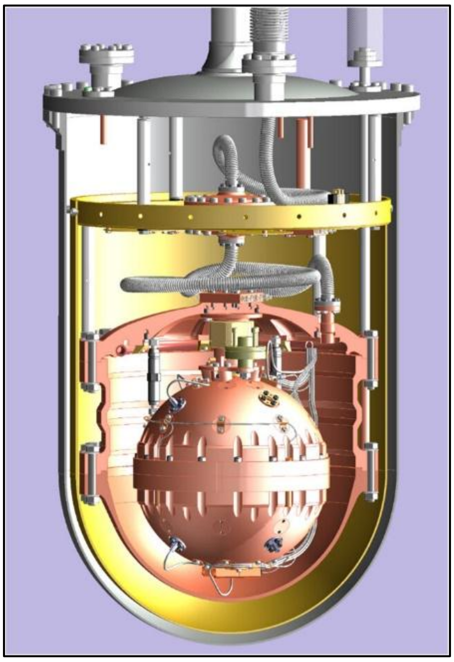


Figure 4. Experimental AGT system at LNE-CNAM based on the 3-L volume copper resonator previously used to achieve the most ever accurate determination of the Boltzmann constant.

- Project collaborators **NRC** and **KRISS** have also successfully completed their AGT apparatus and started thermodynamic measurement runs.

New primary thermometry capabilities

TUBITAK and CMI have reported significant progress about the development of their AGT systems. Particularly, TUBITAK has completed the analysis of previous measurements of speed of sound in Ar at the TPW, demonstrating performance of the experiment at a few ppm level. Measurements at the Ga and Hg fixed points will complete the dataset needed to report their first (T-T90) results. CMI has completed the realization of the pressure vessel and the thermostatting bath for the AGT. Measurements at the TPW started in June 2025

Development of a coherent framework for thermodynamic temperature dissemination

The current absence of a coherent framework for the dissemination of thermodynamic temperature presents a significant limitation. Although the mise en pratique for the definition of the kelvin (MeP-K-19) identifies acceptable thermodynamic methods - such as Acoustic Gas Thermometry (AGT), Dielectric Constant Gas Thermometry (DCGT), and Refractive Index Gas Thermometry (RIGT) - it does not provide practical guidance for implementing these methods to establish traceability. This project addresses that critical gap by developing a structured framework that defines procedures for inter-comparing thermodynamic methods, with the goal of demonstrating their mutual consistency and enabling a robust, reliable dissemination chain. The ultimate objective is to support a formal recommendation to the Consultative Committee for Thermometry (CCT).

As part of this effort, two detailed protocols have been developed and approved by all project partners. These cover the temperature ranges of 4 K to 25 K and 25 K to 303 K, respectively. Drafted by CEM, and refined through consortium-wide consultation, the protocols specify the technical and organizational procedures for the comparison of thermodynamic methods. This includes timelines for measurements, logistics for the delivery and exchange of capsule Standard Platinum Resistance Thermometers (cSPRTs) used as transfer standards, communication protocols between participants and the pilot laboratory (CEM), and the implementation of mixed delivery-ownership schemes to ensure blind comparisons. Furthermore, the protocols define the statistical and analytical methodologies for evaluating the consistency of results across laboratories.

All ITS-90 auxiliary calibrations of the cSPRTs have been successfully completed. The results have been submitted to CEM, which is now preparing the corresponding ITS-90 interpolating functions. These will be used to compare with thermodynamic calibration results and to determine (T–T_{90}) differences, an important deliverable of the project that will contribute to a deeper understanding of the relationship between thermodynamic temperature and the International Temperature Scale of 1990.

Establishment of capabilities for dissemination of thermodynamic temperature between 300 K and 700 K

Within the DireK-T project, steady progress is being made toward developing accurate primary methods for realizing and measuring thermodynamic temperature above 300 K, an area that remains relatively underexplored. So far, only a limited number of determinations of (T–T_{90}) using Acoustic Gas Thermometry (AGT) have been reported, but ongoing efforts are gradually expanding capabilities in this temperature range.

At **INRiM**, modifications to their high-temperature furnace, including the addition of an aluminium reflective shield, have enabled stable operation up to 700 K without vacuum leaks. Work is currently underway on a large, high-temperature pressure vessel to house the AGT setup, with construction, safety approval, and pressure testing expected to be completed by mid-2025. A preliminary test using a simple argon-filled steel vessel heated to 600 K, to implement a rudimentary constant-volume gas thermometer, showed promising results, with inferred thermodynamic temperatures within 1 K of a standard platinum resistance thermometer (SPRT).

Relevant progress has been reported by **NIM**, that has now completed the construction of its high-temperature AGT system (see Fig. 5), based on a cylindrical resonator constructed in a Fe-Ni-Cr alloy (HR-120), with a cesium heat-pipe to improve thermal uniformity. Initial tests have demonstrated good temperature and pressure stability, with satisfactorily low uncertainty acoustic and microwave resonance frequencies measured up to 809 K. The system also incorporates a radiometric thermometry option as an alternative to SPRT-based measurements.

At **NPL**, a modified AGT apparatus has been designed to cover the 303 K to 505 K range. Procurement and assembly are planned to begin in the forthcoming months, further contributing to the project's broader goal of improving high-temperature thermometry.

Figure 5. Experimental system for room temperature up to 820 K set up at NIM

Dissemination and communication activities

Achieving and sharing "true thermodynamic temperatures" rather than relying on defined scales like ITS-90 is a long-term goal, representing full implementation of the redefined kelvin. This project marks a major step forward by using multiple primary thermometry methods to directly realise and distribute thermodynamic temperatures via calibrated sensors.

This transition marks a major milestone: it replaces over a century of temperature dissemination based on defined scales with a direct, scale-independent approach. To ensure alignment and transparency, key international stakeholders, such as the BIPM and the RMOs' technical committees on thermometry, are kept informed of DireK-T's progress through annual reports.

At the April 2025 meeting of the EURAMET TC-T, Miruna Dobre (**SMD**) presented the project's mid-term progress. Two major events scheduled for 2025, Royal Society workshop on redefined kelvin and Tempmeko 2025 conference will serve as important platforms to showcase the technical achievements of all project partners.

On 24–25 February 2025, more than 70 leading experts in temperature metrology gathered in Glasgow for the Royal Society's Theo Murphy meeting, celebrating 200 years since Lord Kelvin's birth. The event, titled "The Redefined Kelvin – Progress and Prospects", focused on the future of thermodynamic temperature measurement following the kelvin redefinition in 2019. A total of 15 presentations and 20 posters, each including 4 contributions linked to DireK-T activities, highlighted breakthroughs in primary thermometry, and explored strategies for the direct dissemination. Very lively debate ensued after each paper and late into the evening. A record of the meeting will appear in a special edition of Philosophical Transactions of the Royal Society A to be published later in 2025. The meeting was organised and led by Prof Graham

Machin from NPL assisted by co-organisers Dr Dolores del Campo (CEM, President of the CCT), Dr Christof Gaiser (PTB), Prof Roberto Gavioso (INRIM) and Dr Patrick Rourke (NRC).

Looking ahead to 2026, several key events will provide opportunities to highlight the progress and impact of the DireK-T project. One such event is the **EURAMET Workshop on DireK-T**, taking place on 14 April 2026. The agenda includes focused sessions on primary thermometry (4–300 K), dissemination trials, and the development of new capabilities, along with strategic discussions on future directions. It promises to be a valuable forum for knowledge exchange among project partners and the wider metrology community.

Last but not least we are pleased to announce the **Summer School "Contemporary Issues in Primary Thermometry"**, taking place from 13–15 May 2026 at UIMP Las Llamas, Santander. This three-day course is designed to provide early-career metrologists and researchers with advanced knowledge on the realisation and dissemination of thermodynamic temperature. Participants will gain insights into gas-based and other primary thermometry techniques, and explore how these approaches relate to traditional scales like ITS-90. The course is timed to precede the biannual Consultative Committee for Thermometry (CCT) meeting in Paris, making it ideal for international attendees already planning travel. Stay tuned for registration details!

Dissemination of project results

Explore the DireK-T Project Online

Want to learn more about the latest advances in thermodynamic temperature dissemination? Visit the official website of the DireK-T project – Dissemination of the redefined kelvin – to access news, publications, event updates, and technical insights from Europe's leading metrology institutes.

🔗 **www.direk-t.org**
Stay informed and follow the journey toward next-generation primary thermometry!

Access Direk-T Project Publications and Data

The scientific outputs from the Direk-T project, including papers, presentations, and datasets related to the dissemination of thermodynamic temperature, are openly available on **Zenodo**. This dedicated repository, part of the EU Open Research platform, ensures long-term access to research funded under Horizon Europe. Interested readers can explore the **Kelvin community on Zenodo**, where all relevant materials from the project are published and regularly updated.

Visit the repository here: Zenodo Kelvin Community

Published papers

- Machin, G., Gavioso, R. M., Underwood, R. J., Gaiser, C., Dobre, M., & Martin Hernandez, J. M. (2025). European partnership in metrology project: Dissemination of the redefined kelvin (DireK-T). Measurement Sensors. https://doi.org/10.1016/j.measen.2024.101620
- Liu, S., Song, Y., Zhang, H., GAO, B., & Han, Z. (2025). Active phase and amplitude temperature control method for cryostat: A case in the thermodynamic temperature international comparison system. In Applied Thermal Engineering (Vol. 258, Numéro Part A, p. 124562). Zenodo. https://doi.org/10.5281/zenodo.15297343
- Zhang, H., Song, Y., Kong, X., GAO, B., Plimmer, M., & Pitre, L. (2025). Repeatability of a primary thermometer and calibration of resistance thermometers between 5 K and 25 K at the sub-millikelvin level. In Metrologia: Vol. 62 015005 (Numéro 1, p. 015005). Zenodo. https://doi.org/10.5281/zenodo.15297581
- Liu, S., Yaonan, S., GAO, B., Zhang, H., & Han, Z. (2025). Achieving High Stability in Cryostat: A Study on Optimal Thermal Link Parameters. In International Journal of Refrigeration: Vol. Volume 167 (Numéro 2024, p. 13-22). Zenodo. https://doi.org/10.5281/zenodo.15295276

Conference presentations

- C. Gaiser, The challenges of primary thermometry from 300 K to 1235 K, presentation at The Royal Society - Theo Murphy Meeting - The redefined kelvin: progress and prospects, 24 – 25 February 2025
- R. Gavioso, Dissemination of thermodynamic temperature below 300 K, presentation at The Royal Society - Theo Murphy Meeting - The redefined kelvin: progress and prospects, 24 – 25 February 2025
- B. Gao, Ultra-low uncertainty primary thermometry below 25 K, presentation at The Royal Society - Theo Murphy Meeting - The redefined kelvin: progress and prospects, 24 – 25 February 2025
- X. Feng, Progress on future temperature dissemination using high temperature acoustic gas thermometry, presentation at The Royal Society - Theo Murphy Meeting - The redefined kelvin: progress and prospects, 24 – 25 February 2025
- G. Machin, M. Dobre, R. Gavioso, C. Gaiser, M-J. Martin, R. Underwood, “Dissemination of the redefined kelvin”, poster presented at 26th IIR International Congress of Refrigeration: Paris , France, August 21-25, 2023.
- R. Gavioso, M. Dobre, C. Gaiser, R. Underwood and G. Machin, “Dissemination of the redefined kelvin”, poster presented at 22nd Symposium on Thermophysical Properties, Boulder, CO, USA, June 23–28, 2024
- G. Machin, R. Gavioso, M. Dobre, C. Gaiser, M-J. Martin, R. Underwood, “European Partnership in metrology project: Dissemination of the redefined kelvin (DireK-T)”, paper accepted for presentation at XXIV IMEKO World Congress “Think Metrology” August 26 - 29, 2024, Hamburg, Germany

Consortium and contact information

The consortium consisting of national metrology, research institutes and universities brings together a critical mass of recognised world leaders in the field.

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To register as a project stakeholder, contact Miruna Dobre (miruna.dobre@economie.fgov.be). An updated edition of this newsletter will be distributed every nine months until the project conclusion in August 2026.

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