**European Partnership on Metrology**
**Call 2022 – Digital Transformation, Health, Integrated European Metrology, Normative and Research Potential**

Selected Research Topic number: **SRT-s02**
Version: 1.0

# Title: Dissemination of the redefined kelvin

## Abstract

Current approaches to thermodynamic temperature dissemination below 300 K are approaching maturity, but for temperatures above 300 K and especially above 400 K very little work has been performed to enable the thermodynamic temperature traceability framework to be expanded.

This SRT is to develop the wider use of a robust thermodynamic temperature framework to 300 K with suitability for use at emerging NMIs to ensure reliable temperature traceability throughout the EU and to provide an understanding that will enable the demonstration and quantification of the degree of equivalence between temperature dissemination by either thermodynamic means or one of the defined scales. In addition, a suitable capability for the dissemination of thermodynamic temperature above 400 K is to be proposed.

## Keywords

Redefined SI, redefined kelvin, thermodynamic temperature, primary thermometry, SI traceability

## Background to the Metrological Challenges

The redefinition of the kelvin in May 2019 initiated a large and comprehensive research phase for the realisation and dissemination of thermodynamic temperature to replace the ITS-90/PLTS-2000 scales currently used. CIPM (International Committee of Weights and Measures) Consultative Committee for Thermometry (CCT) CCT/28 issued a recommendation T1 (2017) for member state National Metrology Institutes (NMIs) “to take full advantage of the opportunities for the realisation and dissemination of thermodynamic temperature afforded by the kelvin redefinition and *the mise en pratique* for the definition of the kelvin”. Moreover, the research need for the temperatures above 300 K and especially above 400 K was highlighted by the 2021 CCT recommendation T1 encouraging National Metrology Institutes to establish capability to determine $T\text{-}T_{90}$ above 400 K. In addition, research is needed to establish capability for dissemination of thermodynamic temperature to closer to 700 K with target uncertainties of less than 0.6 mK (300 K) – 7 mK (700 K) to extend traceability.

The EMPIR project 18SIB02 Real-K has made a start in transitioning to disseminating thermodynamic temperature for high temperatures above the freezing point of silver (1235 K) and low temperatures below a few tens of kelvin, but particularly below 5 K. It also laid the foundations for disseminating T above 25 K by thermodynamic temperature. However, measurement research is still needed to ensure that thermodynamic temperature can be realised and disseminated effectively, to room temperature and beyond. In addition, a longer-term activity for determining low uncertainty $T\text{-}T_{90}$ above 300 K will establish foundational capability for disseminating thermodynamic temperature at higher temperatures in the future.

Although the MeP-K allows for the dissemination of temperature either by thermodynamic means or one of the defined scales, many open questions remain about how the two interrelate and how to demonstrate and/or quantify the degree of equivalence. To address this, a method for calibrating practical temperature sensors using independent thermodynamic methods made available for circulation in a comparison exercise to NMIs who do not have primary thermometry capability is required to enable determination of the lowest calibration uncertainties achievable. A target uncertainty of 0.3 mK across the range 5 K to 25 K, 0.25 mK at 25 K and 0.6 mK at 300 K is the aim. In addition, there is a need to explore and document a recommendation to the CCT on the relationship between the defined scale (ITS-90) and thermodynamic temperature for realisation and dissemination, including uncertainties and compatibility.

This research should establish, within the EURAMET region, a highly integrated research and metrology infrastructure for realising and disseminating thermodynamic temperature and inclusion of a range of NMIs, with a range of capabilities that will ensure that the methods and processes that are developed are appropriate for NMIs at different stages of development. A strong cooperation between NMIs in this research will contribute to a sound and secure realisation of the kelvin across the EURAMET region from the mid-2020s and beyond.

## Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the traceable measurement of thermodynamic temperature from 5 K to at least 300 K and putting in place a framework to ensure reliable temperature traceability whilst building capability to enable thermodynamic temperature traceability at higher temperatures in the future.

The specific objectives are

1. To demonstrate practical thermodynamic temperature dissemination in the range 5 K to 25 K using at least three independent thermodynamic methods to, at least, two NMIs without primary thermometry capabilities by using as transfer standards practical temperature sensors with a target uncertainty in the temperature dissemination of 0.3 mK (k=1).
2. To demonstrate practical thermodynamic temperature traceability in the range 25 K to 300 K using at least two independent thermodynamic methods to, at least, two NMIs without primary thermometry capabilities by using as transfer standards practical temperature sensors with a target uncertainty in the temperature dissemination of 0.25 mK at 25 K and 0.6 mK at 300 K (k=1).
3. To develop a coherent framework for thermodynamic temperature dissemination which should ensure consistency of the dissemination of temperature from NMIs over the temperature range 5 K to 300 K whether it is by thermodynamic temperature or the defined scale (the International Temperature Scale of 1990, ITS-90) and to develop a recommendation to CCT about the measurement uncertainties and the level of equivalence between these approaches to ensure that users have a clear understanding of the relationship between the two.
4. To establish a capability for the dissemination of thermodynamic temperature between 300 K and 700 K with $T$-$T_{90}$ target uncertainty of 0.6 mK at 300 K and 7 mK at 700 K (k=1).
5. To demonstrate the establishment of an integrated European metrology infrastructure and to facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrument manufacturers), international and European technical committees on thermometry (CIPM Consultative Committee for Thermometry (CCT), EURAMET and other RMO TC-Ts) and end users (CERN, quantum computing and fundamental materials science communities).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources both within and outside Europe, plus engagement with existing European research infrastructures and European Partnerships is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry and end users.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMRP and EMPIR projects SIB01 InK, 15SIB02 InK 2 and 18SIB02 Real-K and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.6 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 25 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

## Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the ‘end user’ community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the ‘end user’ community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Develop an integrated self-sustaining European metrology infrastructure,
- Transfer knowledge to the quantum computing and fundamental materials science communities.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of the Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

## Time-scale

The project should be of up to 3 years duration.