Consultative Committee for Thermometry

21 May 2014 9:00 – 13:00

Half-day workshop on topics related to thermometry

Revision of the GUM: why and how?

W. Bich (INRIM, Italy)

The *Guide to the expression of uncertainty in measurement* (GUM), published in 1995 by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML has now served well for almost twenty years, providing a common, universally agreed procedure for uncertainty evaluation. During this period, some drawbacks have emerged which, whilst not affecting the sound architecture of the GUM method, needed to be overcome. The most important concerns the construction of a coverage interval for the measurand, for which in the current GUM a procedure is suggested that holds in a limited number of cases. In addition, the GUM is focused on a scalar measurand, whereas in metrology several cases exist in which many measurands are determined simultaneously by using a common experimental setup. To overcome these drawbacks, the WG1 of the Joint Committee for Guides in Metrology (JCGM) published two supplements to the GUM, specifically devoted to these topics. These supplements represent an evolution in the conceptual scheme underpinning uncertainty evaluation. As a consequence, the GUM is not aligned with them and needs maintenance in order to establish mutual consistency.

In my talk I will explain why the GUM needs a revision and show how it is being revised. I will outline the conceptual evolution, and focus on what will change from the viewpoint of the practitioner. I will try to reassure that the new procedures for a) the evaluation of a standard uncertainty and b) the construction of a coverage interval (or region) compare favorably with the current ones in terms of simplicity (the former) and generality (the latter).

Bayesian Uncertainty: pluses and minuses

R.White (MSL, New Zealand)

The *Guide to the Expression of Uncertainty in Measurement* (GUM), published in 1993 has served the metrology community well for twenty years. One of the most significant changes in the science community in the last decade or two, especially in the non-physical sciences, has been a move away from frequentist statistics to Bayesian statistics. At a superficial level, a Bayesian GUM revision can be seen as an increased range of applicability for a modest loss in accuracy. However, despite nearly a century of efforts on the part of theoreticians, Bayesian and frequentist statistics remain fundamentally at odds. Indeed, the Bayesian paradigm is fundamentally at odds with models of measurement employed by physical scientists, and the adoption of Bayesian uncertainty treatments will require corresponding changes in our measurement philosophy. It is not clear whether a Bayesian GUM revision will serve the metrology community well. This talk highlights differences in the frequentist and Bayesian approaches to uncertainty and how these relate to measurement.

Current status of the redefinition of the kelvin

J. Fischer (PTB, Germany), K. Hill (NRC, Canada), G. Machin (NPL, UK), R. Gavioso (INRiM, Italy), M. Moldover (NIST, USA), L. Pitre (LNE-CNAM, France), A. Pokhodun (VNIIM, Russia), O. Tamura (NMIJ, Japan), R. White (MSL, New Zealand), I. Yang (KRISS, Korea), J. Zhang (NIM, China), S. Picard and Y. Duan

The General Conference on Weights and Measures agreed at its 24th meeting in October 2011 on new definitions for four of the seven base units of the International System of Units (SI). Kilogram, ampere, kelvin, and mole will be defined in terms of fixed numerical values of the Planck constant, elementary charge, Boltzmann constant, and Avogadro constant, respectively.

A refined value of the Boltzmann constant suitable for defining the kelvin is determined by fundamentally different primary methods such as acoustic gas thermometry, dielectric constant gas thermometry, noise thermometry, and the Doppler broadening technique.

Within the CCT, the Task Group on the SI (TG-SI) monitors closely the results of new experiments relevant to the new definition of the kelvin, and identifies necessary conditions to be met before proceeding with changing the definition. At the 2013 meeting of TG-SI it was concluded that, with the acoustic gas thermometry and the dielectric constant gas thermometry, two independent methods would contribute to an adjusted value of the Boltzmann constant. Hence, the conditions in recommendation T2 (2010) of the 25th meeting of the CCT would be fulfilled. Within the 2014 CODATA adjustment, the possibility exists of achieving a relative standard uncertainty for the value of the Boltzmann constant well below one part in 10^6.

Details of the measurements, progress to date, and further perspectives will be reported.

The European Project "Novel techniques for traceable temperature dissemination"

D. del Campo (CEM, Spain), P. Castro (Univ. of Cantabria, Spain), J. Bojkovski (Univ. of Ljujnana, Slovenia), M. Dobre (FPS, Belgium), E. Filipe (IPQ, Portugal), M. Kalemci (TUBITAK-UME, Turkey), A. Merlone (INRiM, Italy), J. Pearce (NPL, United Kingdom), A. Peruzzi (VSL, Netherlands), F. Sparasci (LNE/Cnam, Franc), R. Strnad (CMI, Czech Republic), D. Taubert 5PTB, Germany) and E. Turzó-András (MKEH, Hungary)

In the frame of the European Metrology Research Program the project NOTED (NOvel techniques for traceable TEmperature Dissemination, www.notedproject.com) runs from June 2012 to May 2015. The project focuses on developing new techniques for improved traceability to the kelvin supporting wider and simpler dissemination to the users. It also aims to solve perceived weaknesses with the current International Temperature Scale of 1990 (ITS-90) identified by the Consultative Committee for Thermometry.

This project has two main objectives:

- The development of new interpolation sensors and techniques and, through implementing *practical* primary thermometers, the calibration of standard platinum resistance thermometers directly to the new kelvin definition.
- Solve current outstanding questions related to the ITS-90 defining temperature fixed points, such as the role of trace impurities, to enable a reduction in their uncertainty.

Achieving these objectives will help establish a practical link between thermodynamic temperature, T, and T_{90} and solve problems associated with high level practical temperature metrology, in the temperature range, from –218 °C to 1000 °C.

This presentation summarizes the main activities carried out in the project together with the most significant findings and developments up to now.

This work is part funded by the EMRP. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Experimental Determination of the Isotopic Correction Constants for the Triple Point of Water

A. Peruzzi (VSL, Netherlands)

The isotopic correction constants for the triple point of water (TPW) allow calculate the triple point temperature realized by water departing from VSMOW (Vienna Standard Mean Ocean Water) isotopic composition. The numerical values and the uncertainties of such constants, currently recommended by the CCT in the Technical Annex for the ITS-90, were inferred from measurements based on different physical principles: 1) solid-liquid isotopic fractionation factors, 2) enthalpies of fusion and freezing points of the relevant water isotopologues and 3) triple point temperatures realized by TPW cells containing water of different isotopic compositions.

The present work generated experimental data of unprecedented accuracy from type 3) measurements. Ten gravimetric mixtures of demineralized tap water, Deuterium-depleted water, Deuterium-enriched water, ^{17}O-enriched water and ^{18}O-enriched water were prepared by CIO (Centre for Isotope Research, Groningen, NL). Each mixture was used to manufacture a different TPW cell. The triple point temperature realized by each manufactured TPW cell was measured by the VSL. The isotopic composition of the water sampled from each manufactured TPW cell was measured by CIO using OF-CEAS (Optical Feedback Cavity Enhanced Absorption spectroscopy). New values for the isotopic correction constants and their corresponding uncertainties were derived.

Joint work with the IAPWS

M. Heinonen (MIKES, Finland), J. Lovell-Smith (MSL, New Zealand), Rainer Feistel (Leibniz Inst. For Baltic Sea Research, Germany), Stephanie Bell (NPL, UK)

Relative humidity is one of key parameters in climate modelling. It is also an important parameter in controlling environmental conditions in buildings and various industrial processes. However, there are several definitions for relative humidity in use, and these definitions are ambiguous or limited in temperature and/or pressure range. Since 2010, CCT-WG6 has been collaborating with the International Association for the Properties of Water and Steam (IAPWS) to formulate a harmonized definition for the relative humidity that can be accepted and applied widely across scientific disciplines and applications. The main scientific challenges in this work are: 1) to ensure a sound physical basis of the definition, and 2) to extend the applicability to the full range of realistic physical conditions for water vapour.

In this presentation, we give a summary of unsolved scientific problems related to the definition of the relative humidity, and outline progress so far. We also discuss about the future and the importance of collaborating beyond metrology community.

Thermal Metrology for Meteorology and Climate

A. Merlone (INRiM, Italy)

For a few years now, a fruitful collaboration has been growing between the metrology and meteorology communities. A key event was the signing of the CIPM[1] Mutual Recognition Arrangement by WMO[2] on 1st April 2010. The main need expressed by top level stakeholders was for the availability of robust data for meteorological studies and for the benefit of the present and future generations of climatologists. This was translated by the metrology community into two key objectives: traceability and uncertainty.

Essential Climate Variables (ECVs), as defined by GCOS[3], are continuously recorded by a multitude of different sensors on satellites, balloon radiosondes, aircraft, surface weather stations, buoys, and deep sea devices; all of them working in different operating environments and affected by different influence quantities. Among those ECVs several of them are of interest and competence for the thermal community and many others can be considered as interdisciplinary and multidisciplinary research areas for metrologists. The inclusion of measurement uncertainty in present, historical and future temperature data series represents a fundamental step towards greater public confidence in evaluations of climate change.

This talk reports on the challenges and opportunities opened in recent years for the thermal metrology community in establishing permanent and long lasting cooperation with the climatology and meteorology communities. A general vision on the creation of ad hoc task groups, addressing the several aspects of metrology for environmental sciences, is also discussed.

Dickensian climate metrology: The ghosts of meteorological observations past, present and future

Dr Peter Thorne (Nansen Environmental and Remote Sensing Center)

Evidence abounds that our climate is changing both globally and regionally. This evidence is multi-faceted and compelling. As concluded by IPCC:

> "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia."

Climate change is evidenced in glacier reductions, in increases in temperature and humidity and in rising sea-levels, amongst others. But knowing the direction of travel and the global picture is only a small part of the problem. We need to know with a high degree of confidence how the climate has changed and to monitor how it will change in future. The atmosphere is not a laboratory so the measurement of changes is far from simple.

Historical records are littered with data artifacts that serve to obfuscate the true signal and limit our ability to adequately quantify changes in many aspects of the climate system. Even today many of the measurements are far from perfect and most lack even cursory traceability. This talk will concentrate upon two case studies which are benefitting from substantial and sustained metrological input:

[1] Comité international des poids et mesures – (International Committee for Weights and Measures)
[2] World Meteorological Organisation
[3] WMO Global Climate Observing Systems

1. The International Surface Temperature Initiative is a backward looking project where renewed efforts to create land surface air temperature records are being made. In this project aspects such as data stewardship, field comparisons of instruments and software testing are being applied.

2. The GCOS Reference Upper Air Network is a forward looking effort to instigate truly reference quality, traceable measurement capabilities of the atmospheric column characteristics. All measurements are envisaged to be commensurate with GUM best practices.

Case studies of the benefits of interaction with the metrology community will be highlighted. Further input from and engagement by metrologists in both initiatives and similar efforts is strongly encouraged.