Bureau International des Poids et Mesures

Consultative Committee for Thermometry (CCT)

Minutes of the 29th meeting
Session 3
17 November 2020

Due to the present pandemic, the 29th meeting of the CCT is held on-line.
It is split into five sessions spanning over October 2020 until February 2021.

These minutes will be incorporated at a later stage into the CCT's Report to the CIPM.

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR THERMOMETRY

as of 20 October 2020

President

Y. Duan, member of the International Committee for Weights and Measures

Executive Secretary

S. Picard, International Bureau of Weights and Measures [BIPM], Sèvres

Members

Agency for Science, Technology and Research [A*STAR], Singapore.

All-Russian Scientific Research Institute of Physico-Technical Measurements, Rosstandart [VNIIFTRI], Moscow.

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

Conservatoire National des Arts et Métiers/Institut National de Métrologie [LNE-LCM/Cnam], La Plaine-Saint Denis.

Czech Metrology Institute [CMI], Brno.

D.I. Mendeleyev Institute of metrology, Rosstandart [VNIIM], St Petersburg.

Instituto Nacional de Metrologia, Qualidade e Tecnologia [INMETRO], Rio de Janeiro.

Instituto Português da Qualidade [IPQ], Caparica.

Istituto Nazionale di Ricerca Metrologica [INRIM], Turin.

Korea Research Institute of Standards and Science [KRISS], Daejeon.

Measurement Standards Laboratory of New Zealand [MSL], Lower Hutt.

National Institute of Metrology [NIM], Beijing.

National Institute of Standards and Technology [NIST], Gaithersburg.

National Measurement Institute of Australia [NMIA], Lindfield.

National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology [NMIJ/AIST], Tsukuba.

National Metrology Institute of South Africa [NMISA], Pretoria.

National Metrology Institute of Turkey [UME], Gebze-Kocaeli.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Slovak Metrology Institute/Slovenský Metrologický Ústav [SMU], Bratislava.

VSL B.V. [VSL], Delft.

VTT Technical Research Centre of Finland Ltd, Centre for Metrology / Mittatekniikan keskus [MIKES], Espoo

The Director of the International Bureau of Weights and Measures [BIPM], Sèvres.

Official Observer(s)

FSB - Laboratory for Process Measurements [DZM/FSB-LPM], Zagreb.

1 OPENING OF THE MEETING; APPOINTMENT OF THE RAPPORTEUR; APPROVAL OF THE AGENDA

The twenty-ninth meeting of the Consultative Committee for Thermometry (CCT) was held in five separate sessions via the web due to the pandemic crisis.

The following were present at the third session:

Z. Ahmed (NIST), N. AlDawood (SASO-NMCC), I. AlFaleh (SASO-NMCC), M. Anagnostou (EMI), K. Anhalt (PTB), S. Bell (NPL), J. Bojkovski (MIRS/UL-FE/LMK), J. Brionizio (INMETRO), C. de Bruin (VSL), D. del Campo (CEM), Y. Duan (CCT President), E. Ejigu (NMISA), L. Eusebio (IPQ), Y. Fan (NMC, A*STAR), R. Feistel (IAWPS), X. Feng (NIM), V. Fernicola (INRIM), S. Fil (NSC IM), J.R. Filtz (LNE), C. Gaiser (PTB), R. Gavioso (INRIM), B. Hay (LNE), M.K. Ho (NMIA), B. Il Choi (KRISS), F. Jahan (NMIA), M. Kalemci (UME), L. Knazovicka, (CMI), V. Kytin (VNIIFTRI) L. Lira-Cortes (CENAM), J. Lovell-Smith (MSL), G. Machin (NPL), A. Merlone (INRIM), M. Milton (BIPM), R. Mnguni (NMISA), T. Nakano (NMIJ, AIST), H. Nasibli (UME), P. Pavlasek (SMU), J. Pearce (NPL), A. Peruzzi (NRC), A. Pokhodun (VNIIM), K. Quelhas (INMETRO), P. Rourke, (NRC), S. Rudtsch (PTB), M. Sadli (LNE-LCM/Cnam), N. Sasajima (NMIJ, AIST), P. Saunders (MSL), Y. Shaochun (NMC, A*STAR), F. Sparasci (LNE-LCM/Cnam), R. Strnad (CMI), R. Teixeira (INMETRO), W. Tew (NIST), A. Todd (NRC), C.M. Tsui (SCL), E. van der Ham (NMIA), M. Vinge (VNIIFTRI), L. Wang (NMC, A*STAR), E. Webster (MSL), R. White (MSL), N. Yamada (NMIJ, AIST), I. Yang (KRISS), H. Yoon (NIST), Z. Yuan (NIM), J. Zhang (NIM).

Also present: S. Picard (Executive Secretary of the CCT).

The President of the CCT, Dr Y. Duan opened the meeting and welcomed the participants.

Dr R. Gavioso (INRIM) was appointed *rapporteur* for the third session.

The agenda of the meeting was approved with no changes or additions [CCT/20-03].

2 Report from WG-NCTh, Graham Machin (NPL)

Dr G. Machin (NPL), Chairperson for the Working Group for Non-Contact Thermometry, described the work carried out since November 2017 [CCT/20-41].

He recalled the Terms of reference for the group and anticipated that these will be reviewed for approval in February 2021 at the CCT Session 5 meeting.

He then presented the group membership as agreed at the 2017 CCT and changes occurred since then, including: the retirement of Dr Y. Yamada (NMIJ) which was replaced in his role by Dr N. Sasajima (NMIJ); the new membership of Dr L. Knazovica (CMI) and the co-option of Dr X. Lu (NIM) who will replace retired Mr. Y. Zundong in the group and will also lead a Body Temperature Measurement Key Comparison. Dr J. Brionizio (INMETRO) required a modification

of the member representing INMETRO. Dr G. Machin noted this and asked the CCT if there were other requests on membership. There were none.

Dr G. Machin recalled that the WG-NCTh has met four times since 2017 and presented the newly formed (2020) Task Group on Body Temperature Measurements (TG-NCTh-BTM) which has already met twice.

Dr G. Machin described the activities at a technical workshop of the WG-NCTh group which was held in conjunction with the IMEKO World Congress in Belfast (2018). Several presentations at the Workshop were focused about the use of InGaAs detectors for radiation thermometry.

Four task groups were active within the WG-NCTh during the last three years, of which three have completed their tasks and dissolved (Task Group for primary radiometric temperature uncertainties, Task Group for Non-Contact Thermometry CMCs and Task Group for Non-Contact Thermometry High Temperature Fixed Point uncertainties).

The Task Group for primary radiometric temperature uncertainties completed their work in 2018 by releasing a comprehensive document which was incorporated in the *Mise en Pratique* of the realization of the kelvin (*MeP*-K-19).

The Task Group for Non-Contact Thermometry CMCs revised the Radiation Thermometry CMC Review Protocol, which was then approved in October 2019 by the CCT WG-CMC. The Task Group disbanded by the end of 2019. Dr G. Machin thanked Dr Y. Yamada (NMIJ, AIST), who has now retired, for his excellent contribution.

The Task Group for Non-Contact Thermometry High Temperature Fixed Point uncertainties, led by Dr A. Todd (NRC), completed their work by September 2018 before disbanding. A summary of the TG work was presented at Tempmeko 2019 and was reported in a paper recently submitted to *Metrologia*. Among the outcomes and findings of the TG work are a study of furnace effects by Dr Y. Yamada (2020 *Meas. Sci. Technol.* **32** 015009), while ongoing work aims at the determination of thermodynamic temperature of the eutectic points Fe-C, Pd-C, Ru-C and WG-C. This work will continue within the ongoing Real-K EMPIR Project and will be complementary to the previous determination of the thermodynamic temperature of Co-C, Pt-C and Re-C points which has already been included in the *MeP*-K and was discussed in a paper by Dr D.H. Lowe et al. (2017 *Metrologia* **54**, 390).

Dr G. Machin presented the main purpose of the Task Group for Body Temperature Measurements, whose inception in 2020 was stimulated by the COVID crises but will work with the wider aim to establish reliable clinical thermometry on a global basis. Five objectives were identified: i) to lead a key comparison of calibrators for body temperature measurements, ii) to collect and consolidate best practice of body temperature scanning notably in health services and airports, iii) to collect current best practice of body temperature measurements and develop a summary of the main approaches, iv) to review standards and liaise with appropriate standard bodies (such as ISO/IEC), v) to establish a forum of users and manufacturers to develop practical solutions of identified problems and establish appropriate links to the World Health Organization (WHO). He also summarized the communications made until October 2020, and the next steps until the end of 2021, embracing the launch of the key comparison of calibrators.

The current state of the Key Comparison CCT-K10, piloted by Dr H. McEvoy (NPL), was updated. CCT-K10 covers the realization of ITS-90 from 962 °C to 3000 °C, going beyond the former CCT-K5 which was limited to 1700 °C, thus allowing future CMC support over a

significantly extended temperature range. The Draft A is almost completed and the results[1] are of high quality, with remarkably small uncertainties over the full range of temperatures and a very small number of outliers. Draft B is expected to be completed by the end of 2020.

Dr Y. Duan invited for questions. Dr S. Picard asked to which extent the good agreement between the institutes would influence future estimated uncertainties. Dr G. Machin replied that the uncertainties are probably slightly conservative but represent the estimates reported by the participants.

Dr Y. Duan thanked Dr G Machin for the work accomplished by the WG-NCTh and congratulated for the excellent results of the CCT-K10.

3 Report from WG-Env, Andrea Merlone (INRIM)

Dr A. Merlone (INRIM), Chairperson for the Working Group for Environment, presented the composition of the working group. He welcomed Dr J. Brionizio (INMETRO) as a new member of the group and reported that, in addition the co-opted members, external participants were occasionally invited to the group meetings. He described the work carried out by the WG-Env since 2017 [CCT/20-32rev].

The WG-Env met in Chengdu (China) in 2019 and again in September 2020 (on-line meeting). The activities of the group are organized to cover three main domains, i.e. air, water, and soil/ice, with each domain having its pertaining goals, reference institutions, relevant instrumentations, and issues. Within the World Meteorology Organization (WMO), members of the WG-Env participated in the working groups of the Commission of Instruments and Methods of Observation (CIMO), the Commission of Climatology, and the panels on Global Cryosphere Watch and the Global Climate Observing System. The CIMO has recently been reorganized and WG-Env members will be active in the newly formed Infrastructure Commission (INFCOM). Members of WG-Env are notably involved in several projects covering traceable calibration methods, climate reference stations, comparison of equipment used for meteorological and hydrological services, and these projects overlap with regional projects. Dr A. Merlone drew the attention to the work on radiosonde humidity and surface temperature test facilities realized by KRISS (Korea), and the underwater sensor calibration system developed by NMIJ-AIST (Japan).

The WG-Env was involved in validating high temperature unprecedented records around 54 °C measured in Kuwait and Pakistan in 2016/2017. This validation work was published (2019 *Int. J. Climatol.* **39**, 5154–5169) and evidenced the need to define a suitable validation procedure which can be applied for future reported temperatures extremes.

Measurements of perma-frost temperatures need an uncertainty of 0.02 °C, which requires the establishment of local calibration facilities and best-practice guidelines – example was given of one such facility implemented at 3000 m altitude. A local calibration facility was inaugurated at the arctic meteorological station located in Ny-Ålesund (Norway). An EMPIR Support for Impact (SIP) project coordinated by CEM was started in 2020 to address the intercomparison of thermometers in polar environment.

[1] A graphic representation of the results was displayed by Dr G. Machin where it was not possible to identify the participants.

A pilot-study, in the form of an inter-laboratory comparison of calibration of temperature sensors in air has been initiated in EURAMET, with the objective to develop a guidance document, and Dr A. Merlone emphasized the large number of different types of thermometers that were involved in the comparison. He invited members of the other RMOs to join the pilot study.

As air temperature measurements are still not well understood, a position paper on this topic will be drafted. A task group will be formed within the WG-Env, not limited to the WG members.

It was announced that the 4th edition of Metrology for Meteorology and Climate Conference will be hold next in Exeter (United Kingdom) April 2022. Meanwhile, a webinar will be organized by October 2021.

Dr A. Merlone ended his presentation by underlining the utmost importance of temperature measurements for climate science.

Dr Y. Duan thanked Dr A. Merlone for the instructive presentation and for the collaboration with the groups within the WMO.

Dr J.-R. Filtz (LNE) thanked Dr A. Merlone for the interesting presentation. He observed that much attention was devoted to land-surface and atmospheric temperature measurements and wondered to which extent metrology could contribute to oceanographic measurements. Dr A. Merlone indicated that there is already a well-established link, including ongoing collaborative projects, between WMO and metrological organizations also for measurements taking place in the marine environment. The measurement of temperature underwater, basically in sea and ocean water, but also in rivers, is increasingly drawing attention.

4 On CMC service 2.2.2

Dr J. Bojkovski, Chairperson for the Working Group for CMCs presented the proposal, previously made at the CCT Session 1 meeting, to update the category title of the CCT CMC service 2.2.2, which is presently referred to as “Calibration of industrial platinum resistance thermometers (IPRTs)”, to become instead “Calibration of platinum resistance thermometers (PRTs) by comparison” to avoid problems and delays during the CMC reviews. The WG-CMC have agreed on this and an approval from the CCT is solicited.

Dr A. Peruzzi (NRC) asked for precision on the problems encountered. Dr J. Bojkovski noted that by the current denomination of the CMC category the calibration of Standard platinum resistance thermometers (SPRTs) by comparison, which is common practice at several NMIs, is not explicitly covered, which would instead be the case after the revision of the category title.

Dr D. del Campo (CEM) pointed out that the revision would avoid the duplication of CMCs, and that the only relevant difference between IPRTs and SPRTs in a calibration by comparison regards the amplitude of hysteresis effects. She added that it often happens to receive requests from industrial customers to have their SPRTs calibrated by comparison.

Dr V. Kytin (VNIIFTRI) asked whether there will be any impact or change on the existing CMCs.

Dr J. Bojkovski replied that no change is foreseen, apart from the future possibility for NMIs to ask for, and possibly achieve, a lower uncertainty for existing CMCs, based on the lower uncertainty which characterizes SPRTs compared to IPRTs.

Dr Y. Duan asked Dr S. Picard to send an e-mail to the CCT delegates on comments and approval of this subject.

It was recalled that the most recent physical meeting of the WG-CMC was held during TEMPMEKO 2019 in Chengdu in China, and members from APMP, EURAMET and COOMET were present. An on-line meeting was held on 1 October 2020 and the next on-line meeting will be held on 26 November 2020 [CCT/20-37].

7 CCT memberships

Dr Y. Duan invited Mr C.M. Tsui to give a presentation to support the application of the Standards Calibration Laboratory (SCL) located in Hong Kong, China, to become observer of the CCT [CCT/20-17, 18 and 40].

Hong Kong is a special administrative region of China, and has its own metrological infrastructure, of which SCL is a part. SCL was founded in 1984, maintains services in thermometry since 1986 and Hong Kong became an associate of the CIPM MRA in 2000. Mr C.M. Tsui recalled the institutional tasks of SCL: i) establish and maintain standards traceable to the SI, ii) ensure their international recognition, iii) provide calibration services and iv) promote good practice through the services. Mr C.M. Tsui also recalled the milestones of SCL in developing primary metrological standards and, particularly, illustrated the history of the Temperature Laboratory.

The SCL currently provides metrological services for contact and radiation thermometry, and humidity. The SCL is accredited and obeys technical assessments every second year. It has participated in 15 inter-laboratory comparisons and has 33 published CMCs for thermometry in the KCDB.

Mr C.M. Tsui presented the work undertaken, the present facilities that are available and issued papers. He motivated the SCL's application to become an observer of the CCT by the possibility to directly interact other metrological institutes with well-established expertise in thermometry and improve their competence in radiation thermometry.

Dr Y. Duan thanked Mr C.M. Tsui for his presentation and communicated his positive impression of their laboratories when visiting the SCL.

Dr M. Milton recalled that the opinion of the CCT on the allowance of observer status to SCL should be presented to the CIPM.

Dr Y. Duan confirmed that the CCT delegates will further consider and discuss the request by SCL outside the meeting and that Mr C.M. Tsui will be then informed about the outcome of this discussion.

8 AOB

Dr S. Picard reminded the participants to give their comments on the minutes for Sessions 1 and 2 meetings not later than 1 December and 15 December, respectively. The final version of these minutes will form part of the CCT meeting report to CIPM.

9 Scientific presentation, Z. Ahmed (NIST)

Dr Z. Ahmed (NIST) gave the presentation "Landscape of Emerging Technologies in Thermometry. Temperature dissemination on a post-redefinition world" [CCT/20-53].

He initially commented about the pervasiveness of temperature measurements and, more widely, on the ongoing change of the metrological approach from being based on a few, sparse, spatially and temporally located measurements, to the future development of measurement networks connecting a great number of deployed sensors. These networks are expected to form a continuous measuring system which is capable to provide massive information, as may be required/exploited for decision-making by some form of artificial intelligence. Obviously, this type of approach requires large costs to maintain measurement and calibration infrastructures, which motivates the quest for new technologies which might reduce the cost of these infrastructures, making these promising perspectives practically sustainable. With regard to sensors, the key technology area identified is that of nano-photonics and quantum devices. With regard to the exploitation of the novel sensors, the relevant technologies being developed are identified to be those of *addictive manufacturing*, *artificial intelligence* and *deep machine-learning*. These technologies might virtuously contribute and open new perspectives along different points of the metrological path going from the innovating measuring device (or method) to the final user of metrological services.

In the main central part of his talk, Dr Z. Ahmed then illustrated the perspectives of (nano)photonic devices and methods as the driver of innovation for temperature measurements. These perspectives have their roots in temperature measurement methods which are being developed, or have been already developed, at a macroscopic scale, like for instance gas refractometry, Doppler broadening, light scattering, Raman, optomechanical, with on-chip nano-scale devices based on the same principles which can be in some cases already be envisaged.

Dr Z. Ahmed proceeded by illustrating progress in cavity enhanced gas refractive index thermometry first. He recalled that this method was initially developed for length metrology, and looks currently promising for primary pressure metrology, and highlights that the transversality of application is an important characteristic of several photonic technologies.

He then discussed the relevant features of Doppler-broadening thermometry, and the suitability of this primary method for on-chip implementation, with further progress expected in the next 5 years. He also addressed the basic features of light-scattering thermometry, highlighting the versatility of this method which is suitable to both static and dynamic measurements, though the sensitivity to strain and the complexity of the detection system representing open issues.

With regard to fiber-optic based thermometry, Dr Z. Ahmed reviewed the state of the art and open questions for several types of sensor technologies spanning from Fiber Bragg Grating (FBG) to on-chip silicon waveguide Bragg grating, to optical ring resonators, with some of these technologies being ready on the market and others at an earlier stage of development. Devices such as waveguide-micro-ring Fano resonance and techniques such as spectral pattern recognition fall in the latter category. He recalled the wide operating temperature range and the extreme compactness of some of these sensors, as well as the promising performance of Si based microscale devices. On the other hand, solving issues like poorly understood long-term drifts, hysteresis and packaging problems still represent a stimulating challenge.

Following, Dr Z. Ahmed presented opto-mechanical thermometry, a quantum-based intrinsically primary method based on the measurement of correlated interactions of laser light with the vibrations of a nanomechanical beam, a system extremely interesting from a scientific point of view, though still at a too early stage of research to be applicable for precise thermometry.

Two other quantum-based methods were finally discussed, namely tunnel junction shot noise thermometry, which proved particularly precise in the cryogenic range, and nitrogen-vacancy diamond thermometry which is expected to work up to about 1000 K with uncertainties between 10 mK and 100 mK.

Dr Z. Ahmed concluded by speculating about the future perspectives of a machine learning approach to thermometry applications, discussing the possible impact of this approach in various areas, from the development of new materials to the calibration of sensor distributed networks. He finally lists the challenges awaiting before a full metrological exploitation of the new thermometry technologies and methods will take place.

Dr Y. Duan thanked Dr Z. Ahmed for his interesting presentation and invited for comments and questions from the audience.

Dr M Sadli (LNE-LCM/Cnam) asked for a prevision about the timescale by which it can be expected that the any of the sensors presented in the talk will become as performing as platinum resistance thermometers (PRTs) and in this case when they will become available to end-users.

Dr Z. Ahmed responded by making a distinction between technologies like fiber optics based which are already available to end-users, with effort made to simplify detection technology, and more sophisticated on-chip sensors which are currently being developed to cover a wide temperature range.

Dr M. Sadli (LNE-LCM/Cnam) asked again about the performance of these new sensors, asking if and when they will perform as well as PRTs in terms of their characteristic uncertainty, especially those based on Si technology, there is evidence that they will have very small uncertainties, comparable to PRTs.

Dr P. Rourke asked about the issues which might affect sensors which are not only sensitive to temperature but, for instance, also to strain or pressure, especially when they are embedded in a single measuring infrastructure which might not be able to distinguish between the signal induced by the variation of each of those parameters.

Dr Z. Ahmed responded that the design of the sensors can be optimized to be mostly sensitive to only one parameter at a time, and more widely, there are types of filtering techniques which can be applied to analyze data from a large array of deployed sensors to be able to account and distinguish the stimulus induced on the sensor by the variation of different parameters.

Dr Y. Duan asked to Dr Ahmed to indicate, among the several types of sensors and technologies which he illustrated, what are the most mature from a practical point of view.

Dr Z. Ahmed responded that probably Doppler broadening thermometry on a chip is the most promising because of the advanced implementation of fiber coupling to vapor cells, which may lead to commercial products on a two-to-five-year timescale.

Dr Y. Duan thanked Dr Z. Ahmed again, he thanked all the participants and closed the session meeting.

10 Actions and Decisions

The following actions and decisions were identified during the session:

Actions

CCT29/A1. S. Picard to send e-mail to the CCT delegates on comments or approval of the revision of service 2.2.2.

CCT29/A2. Y. Duan to ask for feedback from the CCT delegates on member and observer status requests.

Dr R. Gavioso, Rapporteur

November 2020