Bureau International des Poids et Mesures

Consultative Committee for Thermometry (CCT)

Minutes of the 29th meeting

20 October 2020 to 9 February 2021

Due to the Covid-19 pandemic, the 29th meeting of the CCT was held online.
It was split into five sessions spanning October 2020 February 2021.

Comité international des poids et mesures

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-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 as five separate sessions via the web due to the Covid-19 pandemic crisis. Minutes for each session were issued. This report does not trace the meetings in their chronological order but according to the subject.

The following participants were present at the meeting:

Z. Ahmed (NIST), N. Al Dawood (SASO-NMCC), N. Al Dawood (SASO-NMCC), I. Al Faleh (SASO-NMCC), N. Al Qahtani (SASO-NMCC), M. Anagnostou (EMI), K. Anhalt (PTB), S. Bell (NPL), J. Bojkovski (MIRS/UL-FE/LMK), J.D. Brionizio (INMETRO), C. Byung-Il (KRISS), 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 (IAPWS), X. Feng (NIM), V. Fernicola (INRIM), J.-R. Filtz (LNE), C. Gaiser (PTB), R. Gavioso (INRIM), L. Hanssen (NIST), B. Hay (LNE), M. Heinonen (MIKES), M.-K. Ho (NMIA), B. Il Choi (KRISS), F. Jahan (NMIA), M. Kalemci (UME), L. Kňazovická (CMI), V.G. Kytin (VNIIFTRI), L. Lira Cortes (CENAM), J. Lovell-Smith (MSL), G. Machin (NPL), N. Maphaha (NMISA), 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), A.N. Schipunov (VNIIFTRI), Y. Shaochun (NMC, A*STAR), G. Snijders (VSL), F. Sparasci (LNE-LCM/Cnam), R. Strnad (CMI), R. Teixeira (INMETRO), W. Tew (NIST), A. Todd (NRC), 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), D. Zvizdic (DZM/FSB-LPM).

Invited: P. Blombergen (Netherlands), Å.A. Falnes Olsen (JV), S. Fil (NSC IM), C. Sanchez (INM (CO)), C.M. Tsui (SCL).

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

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

Dr Y. Duan recalled that the 29th meeting of the CCT, scheduled to be held at the BIPM in March 2020, was cancelled due to the pandemic crisis. The 29th meeting of the CCT was therefore held remotely via internet[1], split into five two-hour sessions spanning 20 October 2020 until 9 February 2021. Dr Y. Duan indicated that the International Committee for Weights and Measures (CIPM) had approved the amended version of the CIPM D-01 document (Rules of procedure for the Consultative Committees created by the CIPM, CC Working Groups and CC Workshops) that

[1] Cisco webex

now includes the possibility to hold online sessions. He also informed that the next session will be held at 12:00 UTC instead of 11:00 UTC.

Dr Y. Duan made a call of the nominated delegates. Dr S. Rudtsch (PTB) was appointed *Rapporteur* for the first session; Dr H. Yoon (NIST) was appointed *Rapporteur* for the second session; Dr R. Gavioso (INRIM) was appointed *Rapporteur* for the third session, Dr I. Yang (KRISS) was appointed *Rapporteur* for the fourth session, and Dr P. Rourke (NRC) was appointed *Rapporteur* for the fifth session.

The Director of the BIPM, Dr Martin J.T. Milton, welcomed the participants.

2 CIPM Update

Dr M. Milton, Director of the BIPM reported on the CIPM meeting and described the work being performed at the BIPM [CCT/20-38].

He stated that Belarus has recently joined as a member state and that now there are 102 NMIs, 156 designated institutes and four international organizations which are signatories of the CIPM MRA.

Dr M. Milton spoke about recent decisions of the CIPM that would directly concern the CCT. He stated that rules and procedures for operating Consultative Committees are stated in the document CIPM D-01 and that online meetings have been approved by the CIPM. He clarified that RMO Technical Committee chairs are always invited to participate in Consultative Committee activities and that NMIs of Member States can also request that one person from the NMI participate in the Consultative Committee meeting as observers. The CIPM has restated that decisions made in the Consultative Committees are done by consensus, which was the case all along. The CIPM has also stated that all Consultative Committee meetings can take place online and that those meetings are considered full meetings of Consultative Committees.

Dr M. Milton presented some points on the digital transformation project. The CIPM has a long-term goal to establish a framework for calibrations that are machine readable. These calibration certificates and methods of accessing them should be made to facilitate digital transactions. He stated that this did not consist of scans of physical calibration documents but digital calibration certificates which can be machine read and machine actionable. The KCDB will become machine readable. As an example of this Dr S. Picard has been working on this project and both projects will be beta tested soon. Interested parties are encouraged to contact Dr S. Picard. As part of this transformation, the SI brochure will be converted to machine addressable xml format.

The BIPM was active during the Covid-19 confinement mandated by the French authorities. The BIPM sustained all key activities such as the *Circular-T* (UTC), World Metrology Day 2020 and the roll out of KCDB 2.0. The BIPM engaged in offering online technical courses for capacity building. The BIPM also supported NMIs during the Covid-19 pandemic by acting as a repository of NMIs' Covid-19 response efforts. As an example, the CCQM performed pilot studies for analytes of Covid-19 RNA and antibody systems.

Concluding, Dr M. Milton stated that the BIPM has developed new ways of supporting Consultative Committee meeting activities during the pandemic. The BIPM, for example, hosted 50 online meetings for the CCQM, and the members of the CCTF gave webinars, which were posted on YouTube and available for further comments from their members.

Dr M. Milton stated that the BIPM operated at 100 % efficiency during the lockdown.

Dr Y. Duan thanked Dr M. Milton for his information and expressed his appreciation to the BIPM staff contributions, in particular during the pandemic crisis.

Dr H. Yoon (NIST) asked whether the digital calibration certificate is like blockchain technology. Dr M. Milton stated that use of blockchain might not be ideal as the DCC is computationally intensive. Dr Milton informed that a conference on this topic will be held at the BIPM in February 2021.

3 REPORT OF THE 28TH MEETING OF THE CCT 2014

The Executive Secretary of the CCT, Dr S. Picard, recalled that the report of the 28th meeting of the CCT (2017) had been approved by all delegates by e-mail. The status of the actions which arose from the 28th meeting was as follows:

Actions of 2017

CCT28/A1. T. Herman (NIST) will send CCT-K9 Draft B to participants by October 2017.

Status: Not completed

CCT28/A2. B. Fellmuth (PTB) will address the final version of the *Mise en Pratique* to the CCU for their September 2017 meeting, and appendices by December 2017.

Status: Completed

CCT28/A3. WG-SP shall provide the first revision of the CCT Strategic Planning document by December 2017 (coordinated by J. Fischer (PTB)).

Status: Completed

CCT28/A4. WG-KC will update the CCT President on silent comparisons and plans for their completion by October 2017.

Status: Completed

CCT28/A5. J. Fischer (PTB) will draft a statement to clarify the relationship between the ITS-90 and the kelvin that will be posted on the BIPM website.

Status: Completed

CCT28/A6. B. Fellmuth will add a sentence to the MeP-K to clarify the relationship between the ITS-90 and the kelvin.

Status: Completed

CCT28/A7. S. Picard will move the CCT/08-19-rev document to the restricted area of the BIPM CCT web site.

Status: Completed

CCT28/A8. WG-SP to add a statement related to climate in its revision of the CCT Strategic Planning Document.

Status: Completed

CCT28/A9. WG-CTh Chair will draft ToR and tasks for the TG-CTh-ET (Emerging technologies) and suggest members to the CCT president.

Status: Completed

4 Comparisons

4.1 Report from CCT Working Group for Key Comparisons (CCT-WG-KC), Andrea Peruzzi (NRC)

Dr A. Peruzzi, Chairperson for the Working Group for Key Comparisons, presented the activities of the Working Group for Key Comparisons (WG-KC) since the 2017 CCT meeting [CCT/20-28]. He reminded the participants of the terms of reference and tasks for the WG.

The Working Group presently has 13 members. The former member Dr Y. Yamada (NMIJ AIST) retired in 2019 and Dr A. Peruzzi thanked him for his precious contribution over the years. Shortly before the first session of the 29th CCT meeting the WG-KC was informed that Dr R. White (MSL), also member of the group, will retire at the end of October 2020. It is possible that Dr R. White will contribute to the group on a personal basis after his retirement. To include competence on thermodynamic quantities Dr M. Akoshima (NMIJ AIST) was proposed as a new member of the WG-KC. The members of the WG-KC unanimously agreed that Dr M. Akoshima could become a new member of the WG. If the President of the CCT does not have any objection Dr A. Peruzzi would be happy to welcome Dr M. Akoshima as a new member of the group.

Dr A. Peruzzi gave statistics on the number of comparisons since June 2017: 44 comparisons were treated of which 14 comparisons were approved, one comparison was declared abandoned and four supplementary RMO comparisons did not gain WG-KC approval.

He drew attention to 20 “silent” comparisons for which no progress has been reported to the WG-KC in the last 5 years.

Dr A Peruzzi observes that not all pilots are aware of the review process as described in CIPM MRA-D-05[2] (Measurement comparisons in the CIPM MRA) and the associated specific rules implemented by the CCT:

- The technical protocol and the final report of all CCT and RMO key comparisons, and possible CCT supplementary comparisons, must be formally approved by the WG-KC.
- Supplementary RMO comparisons can be agreed, conducted and evaluated within the respective RMO. However, on request the WG-KC will review both the technical protocol and final report for these comparisons.

Small deviations – for example not registering the comparison in the KCDB before starting – are less serious compared to the lack of submission of the technical protocol to the WG-KC before starting a key comparison and omitting to provide revised versions for approval. These omissions

[2] Now replaced by the G-11 document.

can be reflected as serious flaws in the final reports and even prevent their approval. To assist the pilots, Dr A. Peruzzi suggested adopting a checklist to be made available on the CCT website (CCT/20-51), "Guidelines of CCT comparisons".

The WG-KC recommends that the TC-T chairs review the technical protocols and comparison reports before submitting these to the WG-KC.

Dr Peruzzi reported on discussions linked to how to improve the visibility of the recently published document "Uncertainties in the realization of ITS-90 metal freezing points using sealed cells" , presently included as an appendix in "Guide to the realization of the ITS-90" Chapter 2.4 "Metal fixed points for contact thermometry". As many institutes rely on sealed cells for their ITS-90 realization, the question arises as to whether these cells can be regarded as an independent realization of the ITS-90 or if they need traceability. He called for a CCT position on this issue[3].

The need for a repeat of the CCT-K6 concerning humidity was highlighted. The WG-KC position is to complete the key comparisons on humidity that are presently active before a new comparison is started. This will be discussed when the activity from the Working Group for Humidity is reported at a later session.

The WG-KC considers that a key comparison for thermodynamic temperature seems premature.

Dr A. Peruzzi ended his presentation by raising the question of whether there is a need for a common CCT framework on KC analysis.

At a subsequent session Dr Y Duan noted that the "Guidelines of CCT comparisons" was approved unanimously and will be uploaded as a guidance document on the website.

4.2 Discussion

Prof G. Machin (NPL) gave information on the CCT-K10 (listed as a silent comparison) for which a Draft B will be reached by the end of 2021. He will ask his colleague Dr H. McEvoy to send Dr Peruzzi an update about this comparison. Furthermore, he informed the CCT that WG-NCTh is advising a new CMC review protocol for thermodynamic temperatures at high temperatures. Although this review protocol is effectively ready, this comparison will not be initiated before the CCT-K10 has been completed.

Dr H. Yoon (NIST) asked what the criteria had been to disapprove the supplementary comparisons mentioned in the presentation. Dr A. Peruzzi answered that some comparisons were not compliant with the CIPM MRA requirements. He gave an example for the absence of an uncertainty budget.

Dr M. Milton thanked Dr A. Peruzzi and the working group for their hard work. He appreciated the highlight on the "silent" comparisons, which is an issue for the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB). Giving an example of a "silent" comparison, he asked what are the next steps to be taken. Dr A. Peruzzi referred to the TC Chairs and pilots which have been contacted. Dr S. Picard had received feedback on several comparisons where the pilots had requested that the comparisons remain in the KCDB and the reports will be completed soon. Dr M. Milton gave examples of several RMO "silent" comparison still indicated

[3] Sealed metal fixed point cells are discussed in Section 8 and 16.

as “Planned” and suggested to remove these until they start. Dr A. Peruzzi agreed. Dr S. Picard confirmed that the APMP had been contacted on this specific issue. Dr Y. Duan emphasized that, if the pilots persist with these comparisons that started a long time ago, it is necessary that they are either completed soon or removed.

Dr A. Peruzzi asked Dr M. Milton if the JCRB has issued a strict rule that can be referred to as support when treating “silent” comparisons. Dr M. Milton indicated that no strict rule had been issued by the JCRB but the RMOs, which are members of the JCRB, had the possibility to adopt a rule. The JCRB has drawn a limit at 5 years; comparisons dating more than 10 years as listed represent significant work for the institutes that in some cases can be wasted.

Dr H. Yoon gave an example of informal feedback at the most recent meeting of TEMPMEKO in 2019,which stated that if CCT-K9 was not completed in the near future, another institute would do the reporting. Recalling the large amount of work associated with the measurements, analysis and reporting, he asked the WG-KC to consider establishing a plan B to force the pilot laboratory to provide the report. Dr M. Milton recalled that other Consultative Committees had approached this problem by reducing the information requirements in the final report. He suggested that the WG-KC reflect on how to reduce the burden on the piloting institute to speed up the process.

Dr S. Bell (NPL) suggested that the decision of the outcome of the RMO comparison should be in the hands of the RMOs. Dr S. Picard confirmed that this was the outcome of the WG-KC meeting.

Dr I. Yang (KRISS) recalled that in several cases the pilot had forgotten to ask for an update of the information included in the KCDB and had in fact progressed. He encouraged his TC-T colleagues to write to the KCDB Office and ask for an update when applicable. Dr A. Peruzzi thanked Dr I. Yang for his comment. He highlighted that nevertheless, for the comparison listed as “silent”, no feedback to the WG-KC has been made over 5 years – it is not so much about updating the KCDB as contacting the WG-KC and presenting a Draft A or a Draft B report in time.

Dr Y. Duan asked the pilots of CCT-K1.1 and CCT-S3, which started more than 10 years ago, to complete the comparisons as soon as possible and to indicate the time for completion. Dr H. Yoon confirmed, in his role as the NIST delegate, to conclude the CCT-K1.1 with his management. Dr J.-R. Filtz (LNE), chair for the Task Group for thermodynamic quantities, encouraged the pilot of CCT-S3 to complete the comparison soon.

Dr Y. Duan concluded the discussion by inviting new TC-T Chairs to familiarize themselves with the information issued by the CIPM and CCT.

4.3 Status report on CCT-K9, Howard Yoon (NIST)

Dr H. Yoon presented the status of CCT-K9 [CCT/20-30]. The draft of the technical protocol, measurements, analysis and reporting involved four different persons. The comparison has been in progress for a long time and the projected timeline was extremely optimistic; there are lessons to be learned from this comparison. It started in 2011 and the measurements lasted four years. Due to the long duration, many persons who participated initially are no longer involved. The comparison was ambitious, covering repeated measurements at fixed points from Ar (83.8058 K) to Zn (692.677 K). It has been carried out in a collapsed-star shape, initially involving 15 institutes.

Dr H. Yoon drew attention to the fact that, although the participating institutes selected their transfer standards, almost half of all thermometers failed the reproducibility criteria. Furthermore, many people that participated initially are no longer involved in this key comparison for several reasons. This is a challenge for all large key comparisons of this type and needs to be addressed by all CCs. A Draft A was presented to the participants in September 2020. It displayed the results at each fixed point where the institutes were not indicated. The results showed an unexpectedly large number of outliers, in particular at the Zn point, the Ga point and the Ar point. The comparison has allowed increased knowledge of this subject, for example outliers at the Zn fixed point could be explained by an under-estimate of radiative losses, and information on this has been provided by the NPL. He suspected that outliers might be explained by over-optimistic uncertainty budgets of participants and pilot and an error within the argon apparatus of the pilot institute.

Dr H. Yoon underscored the importance of comparisons as a tool to test the uncertainties – you cannot deny what you observe.

Consequently, the NIST is refurbishing the laboratory used for the realization of ITS-90. Nevertheless, and although the issuing of data has taken more time than expected, the results are very useful for the participants. A revised version of the Draft A will be distributed to the participants by the end of 2020. Dr H. Yoon reassured the CCT that the results are imminent.

Dr Y. Duan thanked Dr H. Yoon and invited comments.

Dr D. del Campo (CEM) asked about the origin of the intended changes of some uncertainties in the final Draft A report mentioned during the presentation. Dr H. Yoon explained that it is not possible to arbitrarily alter uncertainty budgets without having a physical reason. He explained that there could be small changes due to uncertainties that were not considered or over-estimated by double counting such as the repeatability at NIST. He did does not believe that by these refined adjustments the results of the participants come closer to the KCRV, or their uncertainties can be expanded so that they overlap the KCRV. Dr Yoon expressed his conviction that there are physical reasons for the outliers, which must be identified by the participants. As an example, he mentioned that at NIST a thermal leak at the argon fixed point was not taken into account.

Dr I. Yang (KRISS) asked about a foreseen date for the Draft B. Dr H. Yoon replied that this is under discussion with Dr A. Peruzzi – it is possible that some additional adjustments need to be made to the uncertainty of the key comparison reference value(s). Dr A. Peruzzi confided that he believed the transition from Draft A to Draft B should not take more than 2 or 3 months. Dr Y. Duan expressed his satisfaction to see this recent progress and is looking forward for to the Draft B.

4.4 Participation on CCT-K7.2021, A. Peruzzi (NRC)

The first comparison of water triple point cells (WTPCs), CCT-K7, was carried out from 2002 to 2004 and the need to repeat this comparison was identified as high priority at the 28th CCT meeting. Although the new definition of the kelvin no longer relies on the WTP, the WTPCs continue to play a fundamental role in the realization of the ITS-90, where many institutes consider the isotopic composition of the water.

The NRC has offered, and has been accepted by the CCT, to act as the pilot institute. This repeat comparison, CCT-K7.2021, has attracted 19 members of the CCT to participate: (CEM, CENAM,

INMETRO, INRIM, IPQ, KRISS, LNE/Cnam, MSL, NIM, NIST, NMIA, NMIJ AIST, NMISA, NPL, NRC (pilot), PTB, UME, VNIIM and VSL[4]. The participants are well distributed throughout the different RMOs [CCT/20-29].

A "kick-off" meeting was held in September 2020 and the draft of the technical protocol is expected to be distributed to the participants before the end of September 2020. A coordinating group composed of A. Peruzzi (NRC), S. Dedyulin (NRC), R. White (MSL) and A. Possolo (NIST) was formed to harmonize the uncertainty budgets, choosing the methods and software tools for the analysis.

The comparison will be carried out in a collapsed-star form where each participant will use one transfer cell. Only national references based on fused silica cells, for which a correction of the isotopic contents is applied, will be considered for the calculation of the key comparison reference value. The transport of the cells is delicate. For this purpose, the NRC has taken part of the contents of "MSL Technical Guide 44: Shipping TPW Cells" [CCT/20-65] and has asked for advice on transportation from Isotech/Fluke.

Dr A. Peruzzi presented information on how the comparison will be carried out, and data reduction.

The comparison is planned to start in April 2021, with the first Draft A report to be issued before July 2022.

Dr Y. Duan thanked Dr A. Peruzzi and invited comments.

Dr M. Sadli (LNE/Cnam) expressed his support for employing a coordinating group, which can simplify the work, but wondered to what extent blindness could be preserved. Dr A. Peruzzi clarified that from the point of view of the results there is no difference. From the point of view of the blindness regarding the results there is also no change. Of course, the pilot laboratory will not be blind, but all the other participants will be blind.

Dr A. Peruzzi (NRC) announced at a subsequent session that the Technical Protocol for CCT-K7.2021 had been approved by the CCT WG-KC and the measurements were being prepared, planned to start in April 2021.

4.5 Notice on the CCT Task Group for Body Temperature Measurement (CCT-TG-NCTh-BTM), G. Machin (NPL)

Dr G. Machin, Chairperson for the Task Group for Body Temperature Measurements, informed the CCT about the recent establishment of this new task group (TG-NCTh-BTM), dedicated to Body Temperature Measurements, tasked under the CCT Working Group for Non-Contact Thermometry [CCT/20-31]. The initial focus will be to improve non-contact body temperature measurements to establish reliable clinical thermometry on a global basis.

The objectives have been split into four different sub-groups concentrating on[5]

[4] During his presentation, Dr A. Peruzzi asked if other members of the CCT wished to participate. The VSL asked to participate. Dr A. Peruzzi did not see a larger problem for this and accepted the request.

[5] Coordinators indicated within parenthesis.

i) piloting a new key comparison for body temperature thermometers (X. Lu (NIM)),

ii) collecting and consolidating best practice/standards of body temperature scanning (I. Pušnik (MIRS/UL-FE/LMK)),

iii) collecting and summarizing best practice/standards of body temperature measurements (M.-J. Martin (CEM)),

iv) reviewing standards and interacting with standardization bodies (L. Wang (NMC, A*STAR)).

Dr D. del Campo (CEM) has accepted to establish a forum of users and suppliers of body temperature measurement devices and to establish an appropriate link with the World Health Organization.

A "kick-off meeting" was held in July 2020, a letter has been sent to *Thermology International*, and a questionnaire is being circulated to all RMO TC-T Chairs about current practice of body temperature measurements.

A preliminary plan for the key comparison is being established where the comparison will be carried out in sub-groups.

Dr G. Machin presented the tasks of each sub-group and the interactions with the RMOs, and the targeted objectives for 2021, stressing the importance of the TG members joining the sub-group on standards to push metrology forward in this field.

Dr Y. Duan complimented Dr G. Machin and the Task Group members for the rapid progress that has been made. He invited comments.

Dr D. del Campo encouraged the TC-T Chairs to ensure a wide source for replies on the questionnaire that has been launched.

5 Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) Update

The Executive Secretary of the JCRB, Dr S. Bergstrand updated the CCT on the actions taken at the 42nd JCRB meeting held in September 2020 [CCT/20-39]. He stated that RMOs should work with Technical Committees to review key comparisons listed in the BIPM website that are older than 5 years. The relevant CCT key comparisons were indicated. This information will also be conveyed to Dr S. Picard, from whom it can be obtained.

The old CIPM MRA documents which were spread across 27 documents are being updated to just six documents: three policy documents and three guideline documents. The information contained in these documents has not changed. The policy documents have been approved by the JCRB and the guideline documents are in the process of being approved. Dr S. Bergstrand anticipates that this second approval will occur in November 2020.

Due to the Covid-19 pandemic the transition to 17025:2017 will occur in June 2021. Dr S. Bergstrand said that the old JCRB CMC website will be closed no later than 30 June 2021. There remain only five active CMC submissions in the old website. The final date will be decided at the 43rd JCRB meeting.

6 Calibration and Measurement Capabilities

6.1 Report from CCT Working Group for Calibration and Measurement Capabilities (CCT-WG-CMC), Jovan Bojkovski (MIRS/UL-FE/LMK)

Dr J. Bojkovski, Chairperson for the Working Group for CMCs, stated that the most recent physical meeting of the WG-CMC was held during TEMPMEKO 2019 in Chengdu (China), and members from APMP, EURAMET and COOMET were present. An online meeting was held on 1 October 2020 and the next online meeting will be held on 26 November 2020 [CCT/20-37].

There are currently 2908 CMCs from 66 countries in thermometry that are published in the database, which is an increase from 2545 in 2017. He stated that there are nine current CMC review protocols with an additional protocol on thermal diffusivity, which needs to be approved by the CCT. The members of this working group consist of TC-T chairs from RMOs.

During this most recent meeting, actions were taken to review submitted and future CMCs. Dr J. Bojkovski discussed proposals to decrease the number of categories and the number of CMCs. He stated that CMCs from AFRIMETS were usually accepted without further review since their submitted uncertainties are higher[6] as compared to other RMOs' submitted values. He stated that APMP and EURAMET undertake yearly reviews of CMCs.

Dr J. Bojkovski considered that to manage the CMC reviews, CMC submissions should be grouped and submitted within time slots. The CCT WG-CMC reviews will be performed once or twice per year. Requests for CMC reviews in the future will need to coordinate the submissions of CMCs with the meeting schedule of the WG. He stated that supporting documents for the CMCs (such as results of comparisons, quality system accreditation and peer review) should be submitted along with the request.

Most of the CMC review protocols are old and need revision. Dr J. Bojkovski highlighted that RMOs treat some of the submissions in a non-harmonized way and that this will be addressed. Furthermore, immediate action should be taken to modify CMC protocols for the industrial category and humidity. A CMC protocol is needed for air temperatures, which should be checked with RMOs. The number of categories should be decreased, and as an example he stated that there are three categories for thermocouples which could be grouped into one single category. The current approach is based on instruments but, in the future, a physical-quantity based approach could be adopted.

New comparisons are needed to support CMCs. The supporting evidence for CMCs relies upon comparisons which are almost 20 years old, but it is not possible to carry out a comparison for every CMC. He asked whether CMCs for SPRTs could apply to thermocouples and what is considered an appropriate time interval for comparisons. He suggested that supporting evidence for CMCs for other types of contact thermometers can be obtained from comparisons of long-stem SPRTs, and that in humidity measurements, comparisons can be used to support measurements of other humidity measuring devices.

RMOs have stated that CMCs in humidity are sometimes approved without any comparison support, and that some comparison should be performed to approve CMCs. Members of the APMP

[6] According to the developed review protocol, note made by the *Rapporteur*.

had conveyed a template for humidity review protocols to the chair of the CCT Working Group on humidity.

Dr Y. Duan observed that CMC review protocol for thermal diffusivity measurements needs to be approved by the CCT. Dr S. Picard noted that the protocol has been on the restricted CCT website since October 2020. Dr J. Bojkovski indicated that the process started 2.5 years ago, and this request is for approval by the CCT. Dr J.-R. Filtz (LNE) stated that CCT Task Group for Thermophysical Quantities will meet in January 2021 where this can be discussed. Dr J.-F. Filtz will distribute the protocol so that the members can review the protocol and vote by January 2021.

6.2 On CMC service 2.2.2

Dr J. Bojkovski, Chairperson for the Working Group for CMCs, presented the proposal 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 D. Zvizdic (DZM/FSB-LPM) stated that one needed to be careful about simplifications in CMC reviews but recognized that the workload in CMC reviews can be difficult to manage.

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 requests are often received from industrial customers to have their SPRTs calibrated by comparison.

Dr V. Kytin (VNIIFTRI) asked if 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.

After a subsequent exchange and vote by e-mail, the proposal was approved.

7 Reports from Regional Metrology Organizations

Dr Y. Duan asked Dr S. Picard to review the reports of the RMO TC chairs. Dr Y. Duan asked whether there were any questions to the CCT in the RMO reports. No questions from the RMOs were recorded. Reports from AFRIMETS [CCT/20-19], APMP [CCT/20-20], COOMET [CCT/20-21], EURAMET [CCT/20-22], GULFMET [CCT/20-23] and SIM [CCT/20-24] were briefly shown.

During the RMO presentation on EURAMET activities in thermometry, Dr D. Del Campo (CEM) said that a Joint COOMET and EURAMET meeting will take place in 2021.

Dr A. Peruzzi (NRC) asked about the APMP hybrid comparisons. Dr I. Yang (KRISS) stated that they are bilateral comparisons but based on commercial calibration certificates of the issuing NMI, structured to reduce the workload on the issuing NMI. This type of hybrid comparison has been approved by the JCRB for other measurement categories. Dr I. Yang stated that in a hybrid comparison the issuing NMI considers measurements to be the same as a commercial calibration. Two individual calibration certificates are then sent to a third party to carry out a blind comparison. The final report is written by the applicant NMI and then posted on the APMP website for comparisons. This database is made accessible for reviewers of CMCs. In this hybrid comparison, the applicant NMI writes the report and reviewers of the CMC will see the report as evidence of their capabilities. Dr I. Yang stated that at present three comparisons are being carried out, and the pilot laboratories provide commercial calibrations. Dr D. del Campo (CEM) stated that this is already being used in EURAMET. Dr H. Yoon (NIST) asked whether the applicant NMI covers the cost of the calibrations. Dr I. Yang stated that the issuing NMI will be paid for the calibrations. Dr S. Rudtsch (PTB) stated that such hybrid comparisons have been performed at PTB for over 10 years. He stated that the applicant NMIs paid for the calibrations and submitted their own results to a third party for a blind, bilateral intercomparison. He confirmed that the PTB was satisfied with this type of hybrid intercomparison.

8 Report from CCT Working Group for Contact Thermometry (CCT-WG-CTh), Christof Gaiser (PTB)

Dr C. Gaiser, Chairperson for the Working Group for Contact Thermometry, presented a combined report of the feedback from the Working Group meeting [CCT/20-68] and thermodynamic temperature data [CCT/20-50] as the two items are highly correlated.

Dr C. Gaiser (PTB) presented feedback from the Working Group meeting [CCT/20-68] and recalled the Terms of reference. The meeting focused on the revision of the consensus values for $T - T_{90}$ from 4 K to 303 K and the status of sealed metal fix-point cells (SMFPCs).

An additional issue was the study of xenon for use in triple point cells where a recent working document by Dr P.M.C. Rourke *et al.* has demonstrated that Xe gas with sufficiently low content of Kr is now available from several providers, but more experience with cells for long-stem SPRTs is needed. [CCT/20-66].

Another issue concerned Ar contamination of O_2, where a sub-group within the WG-CTh will be formed to amend a working document drafted by Dr P. Steur (Italy) and Dr F. Pavese (Italy) [CCT/20-76]. It is likely that Dr B. Fellmuth (Germany), Dr P. Rourke (NRC) and Dr W. Tew (NIST) will take part, who will report the outcome.

Dr C. Gaiser drew attention to the recent publication "Direct comparison of ITS-90 and PLTS-2000 from 0.65 K to 1 K at LNE-Cnam" by Dr C. Pan *et al.*[CCT/20-70]. The outcome of this challenging study indicates that ITS-90 is wrong by 1 mK below 1 K. Therefore, in his conclusion, the recommendation of CCT, using either PLTS-2000 or PTB-2006, is independently

confirmed, and the statement will be transferred to an open access CCT document prepared by the WG-CTh.

Dr C. Gaiser presented a revised draft version of a *Recommendation* that the WG-CTh will present to the CCT [CCT/20-48rev], to be further discussed at the WG for Strategic Planning and at the CCT Session 5.

Returning to the revision of the consensus values for $T - T_{90}$ from 4 K to 303 K, Dr C. Gaiser presented the consensus values of 2011. He gave an overview of recent results obtained using different primary techniques including dielectric constant, acoustic and refractive index gas thermometry. It was clear from the presentations given by WG-CTh members at the occasion of the WG meeting that significant improvements had been made and that there is a need for an update. All WG members agreed that an update of at least part of the temperature range would be useful. However, no consensus was reached on how to use older data, and it was agreed that the PTB should perform different evaluation schemes to extract new consensus values. These schemes should consider the traceability to the 2011 determination, but also simplicity. The first results of this evaluation will be discussed in an additional WG-CTh meeting early spring 2021.

The subject of SMFPCs was discussed at the WG meeting. The question is to what extent sealed cells require calibration, or alternatively if ITS-90 is directly realized using this type of cells. This question was raised because of the Appendix "*Uncertainties in the realization of ITS-90 metal freezing-points using sealed cells*", drafted by Dr R. White (MSL) *et al*. and issued as the Appendix 1 to "Metal fixed points for contact thermometry" within the frame of Guide to the realization of the ITS-90 This latter document notably balances an uncertainty estimation including the possible impact by pressure effects, and the much smaller observed uncertainty of a larger set of fixed-point cells.

The WG agreed at the meeting that SMFPCs can be used to realize ITS-90 (although not at its highest level), the subject should be included in the *Guide* and remain under the responsibility of WG-CTh. Nevertheless, future guidance and documentation should be given by WG-CMC and could also be a subject for the TG-GoTh. The WG concluded by requesting an editorial change to section 2.4 and a revised Appendix 1, stating that either the SMFPC need an internal calibration, or the worst-case uncertainty should be applied. This position should be reflected in the Guides issued by WG-CMC and TG-GoTh.

Dr A. Peruzzi (NRC), being the origin for this question, and in his role as WG-KC Chair, made a survey amongst the CCT delegates in December 2020. This survey showed that most of the delegates that replied (CEM, GULFMET, NIST, NMISA, NPL, NRC) were critical to making a calibration mandatory and only two institutes (NMIA and UME) supported calibration.

A longer discussion took place on pressure effects of SMFPCs. Dr M. Heinonen (MIKES) asked if there has been an observed problem with SMFPCs. Dr A. Peruzzi said that most participants in key comparisons used open cells. Dr D. del Campo (CEM) considered that this is an issue for the WG-CMC and should be studied case-by-case. A user relying on one single SMFPC should take more precautions that the ITS-90 is correctly realized. It should be the WG-CMC to establish the rules how to support CMCs relying on the SMFPCs.

Dr A. Peruzzi expected that if a realistic uncertainty assessment were established there should be no problem. He also noted that open cells are not necessarily pressure-controlled, and the difference between the SMFPCs and open cells is that SMFPCs are attributed a larger uncertainty. Dr D. del Campo emphasized that the CMC review protocol for SMFPCs should clarify this point.

Dr S. Rudtsch (PTB), recalling that depending on the temperature of the cell at the time of the sealing, the deviation can be as large as several millikelvin, noted that finding a realistic estimation

of the pressure effect represents a problem, and in many cases the pressure effect is a major contribution to the uncertainty budget.

Dr A. Peruzzi considered that the estimation is the task of the institute, and the "worst case" should be indicated. Dr S. Rudtsch asked how a user may have any knowledge about the cell when buying it. Which values should be followed?

Dr E. van der Ham and Dr A. Peruzzi exchanged views on the difference in the degree of control of the pressure in the open and sealed cells as a primary realization. Dr S. Picard asked whether the CMC claims using SMFPCs were not supported by a comparison. Dr A. Peruzzi cited the NPL reply "*It is not helpful for NMIs, who have spent their hard-won money buying fixed points to establish their realization of the ITS-90, to be told that they have to spend more money getting their cells certified.*". He highlighted that many institutes could not afford to have an open cell or several cells. Dr J. Zhang (NIM) indicated that NIM has sets of an open cell and four SMFPCs for all metal fixed points and that in intra-laboratory comparisons they have observed consistency within the uncertainties.

Dr C. Gaiser noted that in addition to the pressure effect, contamination is another possible source of uncertainty in SMFPCs. He identified a compromise where the worst-case estimate is a good starting point for uncertainty for both issues.

Dr Y. Duan highlighted that comparison data could support a smaller uncertainty. Dr A. Peruzzi noted that comparison can support uncertainty estimation and check sealed cells, but he noted that the comparison result should not be used to apply corrections to the cells.

Dr J. Bojkovski (MIRS/UL-FE/LMK) asked if explicit information on whether the cell used for the CMC was an open or sealed cell could be retrieved from the KCDB. Dr S. Picard indicated that, if that has been indicated during the review process, that it was possible to retrieve.

Dr Y. Duan emphasized the need to make the realization of ITS-90 available for emerging metrology institutes, and that this should be considered. He added that the WG report was very informative and congratulated for the findings on $T - T_{90}$ and observed that ITS-90 can be realized using SMFPCs.

The discussions converged to actions CCT29/A1 and A2 (see Section 22).

9 On Recommendation T1: thermodynamic temperature data

Dr Y. Duan recalled the draft recommendation on "*Requirement for new determinations of thermodynamic temperature above 400 K*" [CCT/20-48rev] that was evoked in the previous agenda point. He encouraged the formation of a smaller group to agree on the draft recommendation contents, where Dr C. Gaiser (PTB) and Dr G. Machin (NPL), representing contact and non-contact thermometry, will collaborate on a revised draft that will be carried forward to the Strategic Planning Working Group meeting, and ultimately the CCT. They will be supported by a small group of delegates.

Dr M. Sadli (LNE-LCM/Cnam) commented on "Direct comparison of ITS-90 and PLTS-2000 from 0.65 K to 1 K at LNE-Cnam" the comparison of ITS-90 and PLTS-2000 [CCT/20-70],

emphasizing that the users of ITS-90 need to be highly aware the difference between ITS-90 and our current knowledge especially in this low temperature range.

Dr A. Peruzzi asked about the distinction between PLTS-2000 and thermodynamic temperature in this temperature range. Dr C. Gaiser clarified that those two are surely different, but the uncertainty of PLST-2000 is about half of millikelvin while the deviation of ITS-90 from either PLTS-2000 or thermodynamic temperature is about 1.5 mK, and in future there will be more work on T- T_{2000} as well as T-T_{90} in this temperature range.

At a subsequent session, Dr C. Gaiser (PTB) displayed the first revised version of the Recommendation of 25 January 2021 and summarized the modifications that had been made. Part of the initial recommendation was included as a 'noting that' subject, and the primary thermometry and ITS-90 part had been merged, resulting in one single recommendation. He then displayed the present 2nd revised version of 29 January [CCT/20-48rev].

He thanked Dr P. Rourke (NRC) and Dr G. Machin (NPL) for their contribution.

Dr S. Picard indicated that the most recent revised version had been communicated to the CCT delegates in advance so that all delegates could become aware of the new version.

Dr G. Machin (NPL) thanked Dr P. Rourke (NRC) and other colleagues for their work on the recommendation. He considered it to be well expressed and hoped that the other delegates would share his opinion.

Dr Y. Duan asked the CCT delegates if they had any further comments on the Recommendation, and subsequently asked for a vote by hand raising. The CCT approved the Recommendation. Dr Y. Duan thanked the small team for their work on the Recommendation and expressed his approval that, despite the difficult time due to the pandemic, the CCT has still been able to make this important Recommendation.

10 Report from CCT Working Group for Non-Contact Thermometry (CCT-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 that had occurred since then, including: the retirement of Dr Y. Yamada (NMIJ) who was replaced in his role by Dr N. Sasajima (NMIJ); the new membership of Dr L. Kňazovická (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 had 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 on 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 been 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 its 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 was 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 its 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's 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-19 crisis but will work with the wider aim to establish reliable clinical thermometry on a global basis. Five objectives were identified:

v) to lead a key comparison of calibrators for body temperature measurements,

vi) to collect and consolidate best practice of body temperature scanning notably in health services and airports,

vii) to collect current best practice of body temperature measurements and develop a summary of the main approaches,

viii) to review standards and liaise with appropriate standard bodies (such as ISO/IEC),

ix) 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 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[7] 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 questions. Dr S. Picard asked to what 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 him for the excellent results of the CCT-K10.

At a subsequent session Dr G. Machin (NPL) presented the revised Terms of Reference for the WG-NCTh [CCT/20-71]. It represents a small update and reflects some of the new activities. Notably, the work towards guidance on industrial radiation thermometry has been included, and Dr G. Machin thanked Dr M. Sadli (LNE-LCM/Cnam) for agreeing to lead this work.

The new activities on body temperature measurement have also been included.

Dr Y. Duan commented that the development of guidance of body temperature measurements, one of the new objectives of the group, is very important and useful for society.

Dr Y. Duan commented on the increased workload for Dr G. Machin. Dr G. Machin thanked Dr Y. Duan and commented that this work is a real pleasure and a great honour.

At a subsequent session the CCT approved the new Terms of Reference for WG-NCTh.

11 Report from CCT Working Group for Humidity (CCT-WG-Hu), Stephanie Bell (NPL)

Dr S. Bell, Chairperson for the Working Group for Humidity, started her report [CCT/20-72] by recalling of the Terms of Reference. The members have increased from 18 to 20 since the last meeting, where Dr H. Abe (NMIJ AIST) now contributes as Vice-Chair. The WG met at TEMPMEKO, Chengdu (China) in June 2019 and via an online meeting in December 2020.

She presented a summary of the full set of key and supplementary comparisons of the CCT and the RMOs having progressed, and reached approval for some, from 2014 until end of 2020. Notably, the CCT-K6 was completed in 2015, covering dew point from −50 °C to +20 °C, with ten participants. There are presently two subsequent comparisons linked to the CCT-K6 which are being completed. There is also CCT-K8, covering dew points from 30 °C to 95 °C, also with ten participants, for which the Draft A is in progress.

Dr S. Bell identified the need for a repeat of the CCT-K6, which should of course not clash with other humidity comparisons carried out by the CCT or by RMOs. In fact, the APMP is already carrying out a repeat, APMP.T-K6.2013, that is well advanced.

The WG has discussed how to reduce the work required to carry out the comparison within a coherent time frame; how to reach a fast completion; to carry out linkage when a comparison is staggered in time and how to align key comparisons to the CMC humidity. In addition, it has been

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

observed by the APMP, but is relevant to all RMOs, that the uncertainty analysis is presented using different formats and a non-uniform support. This makes the CMC review particularly difficult. Due to this, some CMCs have mistakenly been approved at RMO level; that approval later being reversed at inter-RMO review.

Furthermore, the present review protocol forces dew-point comparisons to be at small intervals (many measured points) due to the protocol allowing only small ranges of interpolation or extrapolation from comparison values. For this reason, the WG-Hu has been asked by CCT WG-CMC to review and propose amendments to review protocols for the dew point and relative humidity.

Dr S. Bell mentioned a heavy work programme that is ongoing on humidity quantities, units, symbols, and realizations. Notably, the draft of a document on humidity terms and definitions is progressing, to become available on the CCT webpages. Former relative humidity definitions have been unsatisfactory and have previously been discussed in several review papers in *Metrologia*:

- Metrological challenges for measurements of key climatological observables: oceanic salinity and pH, and atmospheric humidity Part 1: overview R. Feistel et al, *Metrologia* 2016 53 pp. R1 – R11

- Defining relative humidity in terms of water activity Part 1: Definition R. Feistel et al, *Metrologia* 2017 54 pp. 566-576

Alternative definitions based on relative fugacity are under consideration, and the relative humidity and its association with SI is in preparation for publication in *Metrologia*.

The WG-Hu is also completing a guide on uncertainty in humidity realizations, led by Dr J. Lovell-Smith (MSL).

A guide on primary humidity realizations is being outlined.

The WG-Hu had a collaborative workshop with IAPWS and the BIPM in 2018 (17th ICPWS, Prague, Czechia). Dr J. Lovell-Smith and Dr S. Bell are both active within the Humidity working group on the Joint Committee on Properties of Seawater.

The CCT WG-Hu has collaborated with the CCQM on trace moisture in gases, within a small overlap of measurement range via the CCQM-K116 and associated pilot comparison, where the results demonstrated satisfactory equivalence.

Dr Y. Duan thanked Dr S. Bell for her presentation and the work of the working group and invited questions.

During Dr S. Bell's presentation, she mentioned the International Symposium on Humidity and Moisture (ISHM) which was originally agreed to be held jointly with TEMPMEKO in 2023. Dr M. Sadli (LNE-LCM/Cnam) commented that the next TEMPMEKO, which was planned to be held in France, is compromised due to the Covid-19 crisis but a decision is still to be taken. Dr H. Yoon commented on the International Temperature Symposium 10 in 2023 and suggested that scheduling conflicts be avoided. Dr S. Bell noted that if the ISHM would be difficult to hold face-to-face, an online event would be organized.

Dr I. Yang (KRISS) referred to the bilateral comparison CCT-K6.1 and asked if the bilateral comparison indeed needs an RMO review, or if they could be reviewed directly by the CCT. Dr S. Bell said that it is not mandatory to go via the RMO as this particular comparison covers participants from two RMOs, but that it is possible.

Dr A. Merlone (INRIM) asked about progress on soil moisture and references. Dr S. Bell indicated the WG-Hu does not work directly on soil moisture. Dr A. Merlone suggested the formation of a group on soil moisture within the WG-Hu and will raise this with the WG-SP.

Dr S. Bell asked about the possibility of starting a new comparison, a repeat of CCT-K6.

Dr Y. Duan suggested to discuss this issue at the WG-SP meeting.

At a subsequent session, Dr S. Bell presented the background for a repeat of CCT-K6 – a key comparison of frost and dew point from −50 °C to +20 °C. The original CCT-K6 had ten participants and measurements ended in 2009, with the report being issued in 2015. She also highlighted CCT-K8, which is presently being completed, that covers dew points above 20 °C; and mentioned that frost points below −50 °C can be covered by supplementary comparisons.

The travelling standard is to be determined by the Pilot (not yet identified) and participants. The revised guidance in CIPM MRA G-11 will be followed and changes from the previous protocol will be considered to improve the speed and effectiveness of the comparison.

The WG-Hu have expressed their wish to avoid overlap, in time, of measurements for the repeat of CCT-K6 with other comparisons.

Dr S. Bell also drew attention to the related problem with the present version of the CMC review protocol for humidity that requires many discrete temperature points and would need a longer comparison exercise if not revised. The comparison will be coordinated alongside a review of, and alignment with, the CMC review protocols.

After hand-raising, Dr Y. Duan concluded that there was significant interest. The CCT approved the request to carry out the repeat of CCT-K6.

12 Report from CCT Working Group for Environment (CCT-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 to 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 (online 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 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 unprecedented high temperature records of 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 permafrost temperatures need an uncertainty of 0.02 °C, which requires the establishment of local calibration facilities and best-practice guidelines. An 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 the polar environment.

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 the Metrology for Meteorology and Climate Conference will be held in Exeter (United Kingdom) in 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 what extent metrology could contribute to oceanographic measurements. Dr A. Merlone indicated that there is already a well-established link, including ongoing collaborative projects, between the WMO and metrological organizations for measurements taking place in the marine environment. The measurement of temperature underwater, not only in sea and ocean water, but also in rivers, is increasingly drawing attention.

13 Report from CCT Task Group for Emerging Technologies (CCT-TG-CTh-ET), Zeeshan Ahmed (NIST)

Dr Z. Ahmed, Chairperson for the Task Group on Emerging Technologies, gave a presentation describing the work of the CCT Task Group on Contact Thermometry for Emerging Technologies [CCT/20-36]. The task group was formed by the CCT 2017 and Dr Z. Ahmed reviewed the terms and tasks of the group. It comprises 18 members and work is progressing in this area in EURAMET member institutes, NRC, NIM and MSL, in addition to the work being done at the

NIST. The task group has sorted measurements into two categories grouped into primary and ITS-90-based thermometers. He indicated that a draft report has been mostly completed where the main points were highlighted in the executive summary and in a table, which listed the different technologies, their figures of merit and whether these are commercially available.

He highlighted various primary thermometers, notably on-chip, Doppler-broadening thermometry, based on wafer cells for time metrology. He said that these are magnetic-field sensitive with further progress expected in the next 5 years. He described opto-mechanical thermometry which can be easily integrated into quantum information science. This is at an early stage of research. He also described light-scattering based thermometry. These sensors can be used for distributed sensing for both static and dynamic measurements, but these sensors are strain sensitive and the detectors are complex.

Dr Z. Ahmed then described ITS-90-based thermometers such as fibre-optic based thermometry. These sensors are easy to package into existing technology but suffer from thermal hysteresis, with long-term drift that is poorly understood. On-chip photonic thermometry with uncertainties which are expected to be comparable to SPRTs or better were discussed, however, low-drift packaging needs to be developed and there is a lack of physics-based models. Furthermore, these devices require user training.

The task group has fulfilled all the set objectives but asked if it could continue with new tasks. These cover publishing the report cited earlier as a review article, continuing the literature surveillance and adding to the current document. The group is also planning to add best practices and develop uncertainty budgets for these new thermometers.

Dr Y. Duan thanked Dr Z. Ahmed for this work and observed that the group has achieved the original goals of the task group and that the new tasks are constructive.

Dr P. Rourke (NRC) asked that optical refractive index gas thermometry be removed from the table in the report since it is already in the *Mise-en-Pratique*. Dr Z. Ahmed replied that this has already been addressed in a revised version of the document.

At a subsequent session Dr Z. Ahmed (NIST) requested that TG-CTh-ET be renewed for another cycle in order to continue its work under the same overarching Terms of Reference, but with updated tasks [CCT/20-73rev]. He highlighted a big change for the upcoming cycle: a new task regarding best practices for calculating figures of merit for emerging technologies, since different groups are evaluating the merit of new thermometry technologies in different ways, making it difficult to compare them. The objectives will be to guide which data to report, how to calculate it and which representation will be useful; to establish homogeneity when reporting new technologies and instruments, often developed directly at the institutes, so that the methods and results can be understood by everyone. The TG seeks to promote fair and open communication between all researchers. There is also a task to review and report on emergent technologies specifically for primary thermometry.

Dr Z. Ahmed announced that the TG had proposed to write a review paper on emergent technologies for thermometry. This has been presented to several metrology journals: *Measurement Science and Technology* has accepted the offer to write a review article and suggested some modifications. The TG will put together a team to write this review paper.

The CCT approved the new cycle and tasks for TG-CTh-ET.

14 Report from CCT Task Group for Thermophysical Quantities (CCT-TG-ThQ), Jean-Rémy Filtz (LNE)

Dr J.-R. Filtz, Chairperson for the Task Group for Thermophysical Quantities, said that all State economies that are represented in the Task Group for Thermophysical Quantities were represented at their meeting [CCT/20-83]. He recalled the supplementary comparisons in the field that have been completed – CCT-S1 (infrared spectral normal emissivity) and CCT-S2 (thermal conductivity) – and indicated that the CCT-S3 (thermal diffusivity) Draft B and CMCs had been submitted for review.

The group had discussed strategy at its meeting. They have been active in providing guidance for CMC review, *CMC review protocol for thermal diffusivity measurements, Part 1: solid materials by the flash method* (to be published) and *CMC review protocol for infrared spectral emissivity measurements, Part 1: normal emissivity (emittance)* (in progress). They also discussed potential next comparisons and had converged towards the suggestion to compare the determination of thermal expansion of monocrystalline silicon and Sitall CO-115M[8] for the temperature range from 273.15 K to 773.15 K. NIM, NMIJ AIST and VNIIM have standards for absolute measurements. LNE, NPL and UME, who carry out relative measurements, may link to this same comparison.

The comparison activities in the RMOs for thermophysical quantities were displayed. APMP had been active in supplementary comparisons of thermal diffusivity and thermal conductivity. COOMET had activities on bomb calorimetry involving six institutes and measurements within the frame of a gas calorimetry comparison were about to start. EURAMET had several ongoing projects. One of the collaborations concerns emissivity measurements of reflective insulation materials. A second project concentrates on the optimization of industrial processes through improved metrology of thermophysical properties.

The online communication was unfortunately interrupted near the end of the presentation.

15 Report from TG-GoTh, Rod White (MSL)

Dr R. White reported from the meeting of the Task Group for Guides on Thermometry who met in December 2020 [CCT/20-81]. He recalled the terms of reference, focused on the revision of "*Techniques for Approximating the International Temperature Scale of 1990*" .

The group communicates with ease via e-mail and met earlier at the TEMPMEKO 2019 conference in China. Two guides for secondary thermometry have been published: "Thermistor Thermometry" and "Specialized Fixed Points above 0 °C".

A third guide, "*Guidance on Thermocouple thermometry Part 1 (General usage)*", will be posted online before the end of February 2021 and will be open for comments until 30 March 2021. A draft of "*Guidance on Thermocouple thermometry Part 2 (Reference thermocouples and calibration)*" is 50 % complete. It notably treats ambiguities about annealing Type R and S thermocouples, reporting of the calibration state and the uncertainty budget. An additional guide

[8] Crystalline glass-ceramic with ultra-low coefficient of thermal expansion

on industrial platinum resistance thermometry is almost complete and may be ready for CCT approval in about two months.

A sixth guide on industrial radiation thermometry is about to be initiated, led by Dr M. Sadli (LNE-LCM/Cnam), as a task group of CCT-WG-NCTh. The author group is to be determined.

Dr R. White mentioned an issue related to the document "*Uncertainties in the realization of ITS-90 metal freezing-points using sealed cells*", drafted by Dr R. White (MSL) *et al*. and published as the Appendix 1 to "Metal fixed points for contact thermometry" within the frame of Guide to the Realization of the ITS-90 (see Section 8). He recalled that the report issued by the Task Group for Sealed Metal Freezing Point Cells (closed in 2017 after having met the objectives) was based on comparison of world-class NMIs and included a recommendation for calibration and verification for lowest uncertainties [CCT/17-20]. However, there was no guidance for use and uncertainty evaluation (for example, due to non-ideal thermal environment). As a result, some guidance needs to be added to the "*Specialized Fixed Points above 0 °C*" guide sealed metal fixed point cells.

He also recalled that the work on establishing an online database for secondary fixed points had not progressed.

Dr R. White informed that he has now retired from MSL (New Zealand) but will continue to contribute to current activities. He also outlined how the future group on guides will be organized (cf. Section 17.1 below).

Dr R. White thanked all his colleagues, present and former members and Dr S. Picard who had contributed to the realization of the guides.

Dr M. Sadli said it was his pleasure to lead the author group on industrial radiation thermometry and would do his best to ensure that this guide would be completed soon.

16 Report from CCT Working Group for Strategic Planning (CCT-WG-SP), Yuning Duan (NIM)

Dr Y. Duan presented the outcome of the Working Group for Strategic Planning that met on 26 January 2021 [CCT/20-80] after all the Working and Task Groups had met. Dr G. Machin (NPL) had been tasked as *Rapporteur* and had provided the report [CCT/20-77].

The WG-SP supported the request expressed by WG-Hu to carry out a repeat of CCT-K6. They considered it possible to start preparing the exercise while the reporting was concluded for CCT-K8.

The future of TG-GoTh was discussed. Since Dr R. White stepped down as Chair of TG-GoTh, the WG suggested that TG-GoTh be closed down and replaced by smaller author groups. Each relevant activity would be spun-out to the related WG which would then create a TG when a particular guide was needed. A coordinator would survey the work of the Task Groups and make sure that the revision was completed. Dr J. Pearce, active member of TG-GoTh, had been asked by WG-SP to carry out that role and had accepted to do so.

The TG-CTh-ET had carried out their objectives as planned during their first cycle from 2017 to 2020. The group, supported by several CCT delegates, suggested to start a new cycle with updated

Terms of Reference. The WG-SP supported this initiative and encouraged TG-CTh-ET to include expertise on fibre optic technology from the PR community.

A new TG for Air Temperature had been proposed by WG-Env and will be discussed as a separate agenda point (cf. Section 17.2 below).

The draft recommendation on measurements above 400 K that had been discussed by WG-CTh was discussed by CCT delegates in January. The draft had converged to include a single recommendation and will be discussed in a separate agenda point (cf. Section 9 above). It was distributed to the CCT delegates before the fifth session.

The CCT Strategic Plan needs to be revised, based on a 4-year cycle. Dr G. Machin (NPL) has been invited by Dr Y. Duan to coordinate the revision and liaise with the other WG and TG chairs. This revision will take place in the first half of 2021, in view of the upcoming 27th meeting of the CGPM (2022).

Dr Y. Duan presented the approach for the next CCT meeting. He considered the world situation still problematic with regards to the Covid-19 pandemic and that a face-to-face meeting would be unlikely to be held for the next one or two years. He proposed to hold the 30th Meeting of the CCT as two online sessions in early 2022. Future meetings could also give access to virtual laboratory visits to give an insight into laboratory work while travelling is difficult.

He indicated that NMI activity reporting is not consistent. Based on a suggestion made at the WG-SP meeting, a template will be drafted and distributed to all delegates before each coming meeting, which they will fill out with the relevant activities engaged by their respective NMIs.

Dr G. Machin (NPL) indicated that he will contact the WG Chairs for input on refreshing the CCT Strategic Plan.

17 Working Group and Task Group issues

17.1 Dissolution of TG-GoTh and Creation of four new Task Groups for Guides on thermometry

The dissolution of TG-GoTh was approved by the CCT.

The creation of smaller author groups in the form of TGs for guidance on secondary thermometry, coordinated by Dr J. Pearce (NPL) was approved by the CCT [CCT/20-75]. The membership will be decided via e-mail. Each person who joins one of these TGs should contribute to the draft of the guidance document being prepared by that TG.

17.2 Proposal for the creation of a new Task Group for Air temperature

Dr A. Merlone (INRIM) presented the proposal for a TG dedicated to air temperature measurements. Air temperature measurements are important not only for the environment, but also in dimensional metrology and industry. He presented a draft proposal for the objectives – to propose a practical definition for air temperature, to advise on evaluating uncertainty in air temperature measurements and to develop guidelines for the calibration of thermometers in air [CCT/20-74].

Parts of these objectives are the subject of EURAMET activities, but Dr A. Merlone requested a coherent approach among the RMOs. He said that these issues are also incorporated in the CCT Strategic Plan. He recommended co-opting members from TG-CTh-ET and the dimensional metrology community.

Dr Y. Duan commented on the importance of trustworthy air temperature measurements.

Dr S. Picard suggested that this task group include representation from all RMOs and asked for the timeline of the objectives. Dr A. Merlone estimated that 2 to 3 years would be needed to draft the guidelines, which also will involve technical work and investigations.

Dr Y. Duan clarified that this group will be under the umbrella of WG-Env.

Dr S. Picard asked to what extent the guide will be different from the EURAMET work.

Dr A. Merlone replied that there are presently no existing guidelines. The calibration issue is one aspect, and the uncertainty is another part. Since there are no guidelines, it is important to collect information on how other institutes solve these problems, and the more participants there are the more ideas will be fed into development of the guidelines.

Dr Y. Duan observed that many institutes of the CCT were interested to participate. The CCT approved the creation of TG-Env-AirT.

17.3 Update of WG and TG Chairs

Dr Y. Duan has reviewed the Chair positions for the working and task groups. The present Chairs will remain for a new term, except Dr R. White (MSL) who will step down as Chair of TG-GoTh

18 Requests for becoming a member or official observer of the CCT

18.1 NSC “Institute of Metrology”

Dr Y. Duan invited Dr S. Fil (NSC “Institute of Metrology”) to give a presentation to support the application of NSC “Institute of Metrology” (Ukraine) for full membership of the CCT [CCT/20-63].

Dr S. Fil presented the historical work of her institute in Kharkov (Ukraine). In 1947 they developed an optical pyrometer for work in high temperature plasma measurements. There are six national standards for thermometry, and she reviewed capabilities in contact thermometry and in radiation thermometry. The institute has participated in comparisons within COOMET and have 73 published CMCs.

Dr J.-R. Filtz (LNE) asked whether they have any activities in the field of thermophysical quantities. Dr S. Fil replied that they can measure the heat of combustion and specific heat of solids.

Dr A. Pokhodun (VNIIM) stated that the institute has a good scientific school and that he supports Ukraine’s application to be a full member of the CCT.

Dr H. Yoon (NIST) asked why did the institute wish to be a full member? Dr S. Fil replied that the institute would be able participate in CCT key comparisons. It would hence also be able to participate as a second linkage laboratory in the COOMET region for KCs. Dr Duan stated that he also supports this application and the establishment of a second lab in COOMET for key comparisons.

Dr A. Todd (NRC) asked about the staff in the thermometry lab. He asked about their technical qualifications and whether they perform calibration work or research work. She replied that there are ten people working in the field of thermometry and that they perform both research and calibrations.

18.2 Standards Calibration Laboratory (SCL)

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 official 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 and has maintained services in thermometry since 1986. Hong Kong Special Administrative Region of China became an Associate Economy of the CGPM. 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,

iv) promote good practice through the services.

Mr C.M. Tsui 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 published 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.

18.3 Justervesenet

Dr Y. Duan invited Dr Å.A. Falnes Olsen, Justervesenet (Norway), to give a presentation to support their request for full membership of the CCT [CCT/20-78, 79 and 82].

Dr Å.A. Falnes Olsen has worked within the thermometry department of Justervesenet (JV) for almost a decade and has mostly worked with radiation thermometry. JV is the NMI of Norway and has around 30 staff members working in seven different areas on national standards. It is in charge of disseminating the SI to national clients, supporting traceability for legal metrology, and also carries out research and development.

There are five full-time employees in the thermometry department. There is a primary standard laboratory with fixed points from Ar to Ag and Cu. There is also a secondary standard laboratory covering a temperature range from −196 °C to 1200 °C. JV has activities for contact and non-contact thermometry, and for humidity. The humidity laboratory is being upgraded and JV thermometry staff are constructing their own new dew point generator. The JV thermometry department issues around 160 calibration certificates annually.

Dr Å.A. Falnes Olsen reviewed the EURAMET key, supplementary and European comparisons in which JV has participated, and noted that they have acted as pilot and/or coordinator for some. He also listed European research and development projects in which JV is active. He displayed their motivation for requesting to become member of the CCT, where JV wish to contribute in developing

i) industrially relevant thermometry at a global level;

ii) environmentally relevant standards, techniques and recommendations;

iii) the framework of international equivalence.

Dr Y. Duan thanked Dr Å.A. Falnes Olsen and asked for the list of publications, which was displayed [CCT/20-78].

Dr Y. Duan invited comments from the delegates.

Dr P. Rourke (NRC) recalled the previous requests to become member and observer from NSC IM (Ukraine) and SCL (Hong Kong, China) and asked why JV wishes to jump straight to member status rather than starting as an observer. He considered the presentation of Dr Å.A. Falnes Olsen to be strong but asked for clarification on the distinction of where to start when joining the CCT.

Dr Å.A. Falnes Olsen emphasized that JV is eager to get involved in the CCT in order to contribute and not only observe. He related that he can understand if there is a two-stage process involved in joining the CCT, but that their reason for applying for membership is that they intend to get involved and work straight away.

Dr A. Merlone (INRIM) commented that he would welcome a membership of JV, appreciating their previous contribution, so that they can immediately start working.

Dr Y. Duan indicated that the delegates will be contacted by e-mail for feedback on the request to grant CCT member status to JV.

18.4 CCT recommendations on member and observer status

Based on feedback from the CCT delegates he concluded that the CCT discourage a full member status for NSC IM (Ukraine) but instead encouraged NSC IM to become an Official observer while increasing their research activities. The CCT supported SCL (Hong Kong, China) to become an official observer. The CCT supported Justervesenet (Norway) to become member of the CCT. Dr Y. Duan will forward these recommendations to the CIPM for their consideration at their meeting in June 2021.

19 Scientific presentations

19.1 Presentation given by C. Gaiser (PTB)

Dr C. Gaiser gave the presentation “The future of contact-thermometry after the redefined kelvin” [CCT/20-52].

Dr Y. Duan thanked Dr C. Gaiser for his interesting presentation.

19.2 Presentation given by P. Rourke (NRC)

Dr P. Rourke gave the presentation "Temperature dissemination in a post-redefinition world" [CCT/20-53].

Dr Y. Duan thanked Dr P. Rourke for his interesting presentation and invited comments and questions.

Discussion

Dr W. Tew (NIST) commented that although the use of the xenon point would resolve issues with interpolations, no one has built an immersion type xenon cell to accommodate long-stem SPRTs. In his experience, non-immersion non-metal cells are more difficult to operate than a metal-immersion points. Dr P. Rourke agreed with Dr W. Tew's concerns, pointing out Dr W. Tew's work on SF_6 cells and encouraged NMIs to perform research into immersion type xenon cells, perhaps modelled on similar argon cells.

Dr M. Sadli (LNE-Cnam) asked whether we can fix the high temperature region with corrected values of silver, gold, and copper fixed points in ITS-XX 'light' and would this then be considered ITS-XX 'deluxe'[9]? Dr P. Rourke stated that if any of the three points were to be changed then it would also affect the lower temperature SPRT reference points and would result in a larger disruption than at just the higher temperatures above the silver point.

Dr H. Yoon (NIST) asked whether we can fix the high temperature region and low temperature region separately? Dr P. Rourke replied that this could be possible but would need to be broadly discussed and coordinated with the CCT.

Dr S. Rudtsch (PTB) asked if we make a new scale with ITS-XX what are the costs associated with this action? He stated that it would impact the quality management of some 10 000 laboratories around the world, and approximately 100 000 instruments would be subject to changes of the intrinsic or external software, as well as associated operational manuals. He stated that only small number of users would be able to take advantage of such changes. Dr P. Rourke replied that the argument is quite valid and since the ITS-90 is deeply imbedded in the global measurement system, if the CCT follows its 2014 Declaration and in some years moves toward a new temperature scale, there are important issues, including downstream disruption, that should be kept in the forefront to shape the discussions.

Dr Y. Duan concluded the session by thanking all the presenters and attendees for their contributions and active participation.

19.3 Presentation given by Z. Ahmed (NIST)

Dr Z. Ahmed (NIST) gave the presentation "Landscape of Emerging Technologies in Thermometry" [CCT/20-53].

[9] 'light' and 'deluxe' referring to the presentation.

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

Discussion

Dr M Sadli (LNE-LCM/Cnam) asked for a prevision about the timescale by which it can be expected that any of the sensors presented in the talk will start 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 fibre 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 about the performance of these new sensors, specifically 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. This will enable them 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 fibre 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.

19.4 Presentation given by G. Machin (NPL)

Dr G Machin presented “Realizing the redefined kelvin – a EURAMET perspective” [CCT/20-73].

Dr Y. Duan thanked Dr G. Machin for his interesting presentation and invited comments and questions.

Discussion

Dr F. Sparasci (LNE-LCM/Cnam) highlighted the part on “improvement of the ITS-90 to extend its lifetime” in Dr G. Machin’s talk, and pointed out that such an approach could be included in

the CCT recommendation. Dr G. Machin responded that he and Dr C. Gaiser (PTB) together will find a way to add this point to the draft CCT recommendation.

Dr M. Heinonen (MIKES) commented that even primary realizations still need to demonstrate the traceability of the measurement.

Dr H. Yoon pointed out the wording of "life extension" of the ITS-90, suggesting more positive wording could be used. He highlighted that there are existing commercial systems, especially in the low temperature range, in which primary thermometry such as noise thermometry is incorporated, and thus no additional calibration is required. Dr M. Heinonen responded that the traceability requires demonstration of correct uncertainty assessment and the level of uncertainty concerned matters.

Dr C. Gaiser commented on the magnetic field flux thermometer, which is already used as a relative primary thermometer. It was noted that PTB is working on an absolute primary thermometer using the same technique. He commented that they have traceability in both cases.

19.5 Presentation given by Andrea Peruzzi (NRC)

Dr A. Peruzzi (NRC) presented "Time evolution of the thermodynamic temperature scale" [CCT/20-56], a reflection on the historical development of the concept of temperature and its measurement scales.

Dr Y. Duan thanked Dr A. Peruzzi for having reminded CCT colleagues about the evolution of temperature scales and thermodynamic temperature measurement. He invited questions and comments.

Discussion

Dr H. Yoon (NIST) referred to the history. He observed that it is difficult to predict the future but, nevertheless, asked Dr A. Peruzzi what he believed would happen to the temperature scale.

Dr A. Peruzzi agreed that predicting the future is difficult, and that is why he had deliberately avoided this subject in his presentation. He referred to the excellent presentations given at earlier sessions by his CCT colleagues. However, Dr A. Peruzzi shared his own opinion, that the ITS-90 or another International Temperature Scale (depending on what the CCT will decide to do) will still be used for decades in the middle temperature range. He expected that thermodynamic temperature measurement will become increasingly practical, but he does not expect this to happen in the short term. Therefore, he believes it will take decades, not just a few years, for direct dissemination of thermodynamic temperature to completely replace defined scales.

Dr G. Machin (NPL) thanked Dr A. Peruzzi for his talk which he enjoyed. He commented about Thomson's 1854 formulation, that Thomson was almost immediately forced to abandon the Carnot approach used for his earlier proposal of 1848 because it did not conserve energy. By discussions with Joule, Thomson realized that he had to conserve energy to make it work, and this led to his final proposal of 1854.

Dr A. Peruzzi agreed that at the start Thomson was driven by the Carnot theory until 1848, when he began to become influenced by Joule. Dr A. Peruzzi realized that Thomson walked a twisted path to reach his final formulation for thermodynamic temperature and expressed that he had

enjoyed reading the original works by Thomson. He also mentioned a recent discussion on the topic with Dr R. White (MSL).

Dr A. Merlone (INRIM) thanked Dr A. Peruzzi and desired that the recording would be made available afterwards. He asked if Dr A. Peruzzi believed that temperature really exists.

Dr A. Peruzzi does, and referred to the mathematical theory that he had displayed earlier in his talk.

Dr A. Merlone explained that his original provocation was not on the term "temperature" but rather on the term "belief." He compared with length as a proportion of space and mass as an amount of material, but for temperature it is more abstract and harder for people to understand the link between high-level science and practical applications. He recalled his earlier point about the lack of a definition of air temperature (cf. Section 17.2 above) and noted that every time we measure temperature, we actually measure something else.

Dr A. Peruzzi commented that you do not measure temperature directly, but you always measure something else that is related to temperature.

Dr D. Zvizdic (DZM/FSB-LPM) said that Thomson was the first person to define an absolute zero and that the definition appears paradoxical at first glance: he said it is the temperature of the reservoir to which an ideal Carnot process cannot deliver any heat. Dr D. Zvizdic explained that Thomson reasoned that the next highest reservoir had so little energy that it would all be converted to mechanical work by the ideal Carnot process, leaving no heat or energy to pass to the reservoir at absolute zero, and that Thomson importantly concluded that absolute zero can never be reached because of that.

Dr Z. Ahmed (NIST) thanked Dr A. Peruzzi for the wonderful talk. He wondered how temperature can be defined at a nano-scale, reaching an increasingly finer structure.

Dr A. Peruzzi considered that when reaching ultra-low temperatures, you have to distinguish between the temperatures of each part – for example, the temperature of the electrons, the temperature of the nucleus, the temperature of the phonons – and temperature is no longer a microscopic quantity. It then becomes difficult to say which one is the "real" temperature.

Dr Y. Duan assured that the talks will be made available on the CCT webpages.

20 Next CCT meeting

Dr Y. Duan announced that the CCT meetings, as well as the WG and TG meetings, will continue online until the pandemic situation has improved world-wide. WGs and TGs may meet when necessary and will receive meeting arrangement support from the BIPM.

He proposed to the CCT that the 30th meeting of the CCT will be organized as two online sessions in the beginning of 2022, in order to be able to report the most up to date progress to the 27th meeting of the CGPM in late 2022. Exact dates will be communicated later. The Strategic Planning WG will also meet on that occasion. There may be the possibility for a "cyber" visit to some laboratories.

Dr A. Merlone (INRIM) asked if the opportunity for hybrid meetings could be considered in the post-pandemic future, *i.e.* people who are available for travel would be on site at the BIPM, and others may join online.

Dr M. Milton thanked Dr A. Merlone for this question. He said that the CIPM, and the CIPM President in particular, are considering this idea, but need to be careful on how meeting participation might be affected. It is not desirable, for example, to have meetings where only members from Europe are on site in Paris, while all others from the rest of the world are relegated to participating online. Nevertheless, the CIPM are considering these topics and doing their best to progress the issue.

Dr Y. Duan said that his term as a CIPM member will end in 2022 and he would like to meet in person before his term ends, where a hybrid meeting might allow colleagues to meet face to face. However, this is presently unlikely due to the ongoing pandemic.

21 Closure of the 29th meeting of the CCT

Dr Y. Duan thanked Dr R. White (MSL) for his work and constructive contribution over the years. The CCT delegates and experts joined the CCT President in applause.

Dr Y. Duan thanked Dr S. Rudtsch (PTB), Dr H. Yoon (NIST), Dr R. Gavioso (INRIM), Dr I. Yang (KRISS) and Dr P. Rourke (NRC) for their role as *Rapporteur* at the five sessions.

Dr Y. Duan thanked the invited speakers of the five sessions for their interesting talks. He thanked Dr S. Picard for her excellent support of the CCT, its WGs and its TGs, and the organization of the many meetings.

Dr Y. Duan finally thanked the CCT participants for having contributed to making the 29th Meeting of the CCT successful, and declared the meeting closed.

He said that the Chinese New Year will soon start, which is the year of the ox – a strong year. He wished all participants and the world an end of the pandemic crisis to allow in-person meetings again soon. Dr Y. Duan wished a successful and happy new year to all.

22 Actions and Decisions

22.1 Actions

The following actions are to be undertaken:

Actions

CCT29/A1.	NIST to send the Final Draft A report of the CCT-K9 to participants by 1 December 2020. (Action completed on 17 February 2021.)
CCT29/A2.	The pilot institutes of CCT-K1.1 (NIST) and CCT-S3 (NMIJ AIST) are invited to inform the CCT on the timeline for completion.

CCT29/A3. WG-CTh and Task Group for Sealed Metal Freezing Point Cells[10] to update the appendix on SMFPC in the Guide to the ITS-90 to include considerations on uncertainty assessment using worst case deviation using SMFPCs.

CCT29/A4. WG-CMC to consider revising the relevant CMC review protocols to consider new information and outcome of the discussion on the realization of ITS-90 using SMFPCs.

Decisions

CCT29/D1. The recommendation CCT T 1 of 2021 was approved by the CCT.

CCT29/D2. The Service 2.2.2, presently expressed as "Calibration of industrial platinum resistance thermometers (IPRTs)", to become "Calibration of platinum resistance thermometers (PRTs) by comparison"

CCT29/D3. To dissolve the TG-GoTh.

CCT29/D4. To create smaller author groups in form of TGs for guidance on secondary thermometry, coordinated by Dr J. Pearce (NPL).

CCT29/D5. To create a new Task Group for air temperature measurements, linked to the WG-Env.

CCT29/D6. To carry out a repeat of CCT-K6.

CCT29/D7. The revised terms of reference of WG-NCTh were approved by the CCT.

CCT29/D8. To renew a cycle for TG-CTh-ET.

CCT29/D9. The revised tasks of TG-CTh-ET were approved by the CCT.

CCT29/D10. Dr M. Akoshima (NMIJ AIST) to become member of the Working Group for Key Comparisons.

CCT29/D11. The "Guidelines of CCT comparisons" were approved by the CCT.

Dr S. Rudtsch, Dr H. Yoon, Dr R. Gavioso,

Dr I. Yang and Dr P. Rourke Rapporteurs

March 2021

[10] To become active again.

RECOMMENDATION OF THE CONSULTATIVE COMMITTEE FOR THERMOMETRY SUBMITTED TO THE INTERNATIONAL COMMITTEE FOR WEIGHTS AND MEASURES

RECOMMENDATION T 1 (2021)

Requirement for new determinations of thermodynamic temperature above 400 K

The Consultative Committee for Thermometry (CCT), at its 29th meeting in 2020/2021,

recalling

• the CCT Declaration on the 27th meeting in 2014 "Requirement for new determinations of thermodynamic temperature",

• the CCT Recommendation to the CIPM in 2017 "For a new definition of the kelvin in 2018", CCT T 2 (2017);

welcoming

• the Resolution 1 of the 26th meeting of the CGPM (2018) "On the revision of the International System of Units (SI)", which now links the unit of temperature to the Boltzmann constant;

considering

• the discussions held at the 27th, and 28th meetings of the CCT in 2014 and 2017,

• that experimental progress has allowed the development of a *Mise en Pratique* for the realization of the kelvin (*MeP*-K), which has been extended to cover direct measurement of thermodynamic temperature, T, after the redefinition of the kelvin;

noting that

• Resolution 1 of the 26th meeting of the CGPM (2018) stated "that Member State NMIs take full advantage of the opportunities for the realization and dissemination of thermodynamic temperature afforded by the kelvin redefinition and the *MeP*-K",

• in the last years, primary thermometry by acoustic gas thermometry, dielectric-constant gas thermometry, and refractive-index gas thermometry have yielded low uncertainty thermodynamic-temperature data and so improved considerably the knowledge on $T - T_{90}$ below 400 K (T_{90} is the temperature according to the International Temperature Scale of 1990, ITS-90),

• above 400 K, there is a dearth of new accurate measurements of thermodynamic temperature, which are urgently required,

• primary thermometry approaches to facilitate implementation of the *MeP*-K by thermodynamic thermometry and to evaluate $T - T_{90}$ in this important temperature region need significant further development;

recommends

• that Member State NMIs improve their capabilities in primary thermometry, by various means, above 400 K to improve determination of $T - T_{90}$, accompanied by appropriate research to ensure that International Temperature Scale realization remains fit for purpose, allowing access to lower uncertainty thermodynamic temperature values over a wide range for a broader community.