Bureau International des Poids et Mesures

Consultative Committee for Thermometry (CCT)

Report of the 30th meeting
(18 January and 8 February 2022)
to the International Committee for Weights and Measures

Comité international des poids et mesures

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR THERMOMETRY

as of 18 January 2022

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

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

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

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.

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

Laboratoire National de Métrologie et d'Essais [LNE], Paris.

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

National Institute of Metrological Research/Istituto Nazionale di Ricerca Metrologica [INRIM], Turin.

National Institute of Metrology [NIM], Beijing.

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

National Measurement Institute of Australia [NMIA], Lindfield.

National Metrology Centre, Agency for Science, Technology and Research [NMC, A*STAR], Singapore.

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 /TÜBITAK Ulusal Metroloji Enstitüsü [UME], Gebze-Kocaeli.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

Norwegian Metrology Service/Justervesenet [JV], Kjeller.

Physikalisch-Technische Bundesanstalt [PTB], Berlin

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

VSL Dutch Metrology Institute [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 [FSB-LPM], Zagreb.

National Scientific Centre "Institute of Metrology" [NSC IM], Kharkiv.

Standards and Calibration Laboratory [SCL], Wanchai.

1-3 Opening of the meeting; Appointment of the Rapporteur; Approval of the agenda

The thirtieth meeting of the Consultative Committee for Thermometry (CCT) held its first online session on 18 January 2022 and its second online session on 8 February 2022.

The following were present:

S. Bell (NPL), R.A. Bergerud (JV), J.D. Brionizio (INMETRO), D. Cardenas-Garcia (CENAM), J. Cheung (SCL), B.-I. Choi (KRISS), D. Del Campo Madonado (CEM), Y. Duan (NIM / CIPM / President of the CCT), E.K. Ejigu (NMISA), L. Eusébio (IPQ), Y. Fan (NMC, A*STAR), X. Feng (NIM), V. Fernicola (INRIM), S. Fil (NSC IM), V. Fuksov (VNIIM), R. Gavioso (INRIM), B. Hay (LNE), M.-K. Ho (NMIA), F. Jahan (NMIA), M. Kalemci (UME), L. Knazovicka (CMI), S. Kondratiev (VNIIM), S. Kwon (KRISS), G. Kytin (VNIIFTRI), B. Lam (SCL), L. Lira-Cortés (CENAM), J. Lovell-Smith (MSL), H. McEvoy (NPL), G. Machin (NPL), M.I. Maniur (SMU), N. Maphaha (NMISA), M.-J. Martín Hernández (CEM), E. Martines-Lopez (CENAM), A. Merlone (INRIM), C. Meyer (NIST), M.J.T. Milton (Director of the BIPM), R. Mnguni (NMISA), T. Nakano (NMIJ/AIST), H. Nasibli (UME), M. Neto (INMETRO), A.A. Falnes Olsen (JV), M. Panman (VSL), P. Pavlasek (SMU), J. Pearce (NPL), A. Peruzzi (NRC), A. Petukhov (VNIIFTRI), A. Pokhodun (VNIIM), K. Quelhas (INMETRO), A. Rakonjac (MSL), P. Rourke (NRC), S. Rudtsch (PTB), M. Sadli (LNE-LCM/Cnam), N. Sasajima (NMIJ/AIST), P. Saunders (MSL), A Shchipunov (VNIIFTRI), F. Sparasci (LNE), R. Strnad (CMI), S. Tabandeh (MIKES), W. Tew (NIST), A.D. Todd (NRC), C.M. Tsui (SCL), E. van der Ham (NMIA), M. Voldan (CMI), L. Wang (A*STAR), Y. Yamada (NMIJ/AIST), I. Yang (KRISS), S. Ye (NMC, A*STAR), H. Yoon (NIST), J. Zhang (NIM), D. Zvizdic (FSB-LPM).

Representatives of Institutes from Member States invited to attend as Observers: N.M. Alqahtani (SASO-NMCC), C. Sanchez (INM Colombia), M. Vinge (VNIIFTRI).

Invited: H. Abe (NMIJ/AIST), Z. Ahmed (NIST), M. Anagnostou (EMI), J. Bojkovski (MIRS/UL-FE/LMK), F. Edler (PTB), J.-R. Filtz (LNE), C. Gaiser (PTB), K. Thomson (NRC).

Also present: S. Picard (Executive Secretary of the CCT/KCDB Coordinator), S. Solve (BIPM), O. Werhahn (Executive Secretary of the JCRB).

The CCT President, Dr Y. Duan, welcomed the participants to the meeting, remarking that one year had passed since the last meeting and that it was especially nice to meet now after the recent challenges of Covid. He outlined that in 2019, all CCs were asked to revise strategies, aligning with the CIPM 2030+ strategy. In view of the approaching CGPM, this CCT meeting is timely.

BIPM Director Dr M. Milton welcomed participants to the meeting.

The CCT Executive Secretary, Dr S. Picard, added her welcome and “housekeeping” comments. She announced that she is to retire at the end of 2022 and that Dr Stéphane Solve will take over as Executive Secretary, starting after the February CCT meetings.

Dr S. Solve introduced himself, and his relevant background in thermometry, including having worked on CCT-K7 comparison, and then in the BIPM electrical metrology area.

The meeting agenda was approved, with the addition of extra items: 7.6. Report from CCT-WG-CMC; and 10.4 Report on CCT-K8.

Dr S. Bell and Dr J. Pearce were approved as rapporteurs.

4 Status of Actions targeted at the 29th meeting of the CCT

The actions from the last CCT were reviewed (2020 meeting, held in sessions from 20 October 2020 to 9 February 2021).

CCT29/A1. Action: NIST to send the Final Draft A report for the CCT-K9 to participants by 1 December 2020. Status: Completed on 17 February 2021.

CCT29/A2. Action: The pilot institutes of CCT-K1.1 (NIST) and CCT-S3 (NMIJ) to inform the CCT on the timeline for completion. Status: Dr W. Tew reported that Bilateral CCT-K1.1 was at Draft A, awaiting further completion working with NMIJ. The 'silent' comparison CCT-S3 was reported as awaiting approval.

CCT29/A3. Action: WG-CTh and Task Group for Sealed Metal Freezing Point Cells 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. Status: Completed.

CCT29/A4. Action: 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. Status: Completed.

Dr Duan thanked the contributors for their efforts, especially in the face of Covid-related difficulties.

5 News from the BIPM – M. Milton, BIPM Director

Dr Milton thanked Dr Picard for her considerable contribution to the CCT. He thanked Dr Solve for stepping into the role enthusiastically, noting that he is ideally qualified.

Dr Milton announced the forthcoming major workshop on 26 to 30 September 2022 'Metrology for Climate Action' being organized jointly by BIPM and the World Meteorological Organization (WMO). This is the third joint workshop since the start of cooperation with the WMO in 2010. Dr M. D. del Campo and Dr Duan are on the steering committee for the event. Pre-registration via the BIPM website would follow soon after the CCT meeting.

The 27th meeting of the CGPM is scheduled for 15 to 18 November 2022 and draft resolutions would be posted on the BIPM website after the CCT meeting. While the 26th CGPM dealt with the redefinition of SI units, the 27th CGPM would concern digitization, and expansion of the membership of the BIPM – an important future initiative. Dr Duan echoed the importance of this, noting the important role of metrology – and of the CCT - in the field of climate, mentioning CCT representation on a number of WMO working groups.

6 CCT Strategic Planning 2021 to 2030 – G. Machin (NPL)

Dr G. Machin thanked the CCT colleagues, especially the WG chairs and the members of the CCT Working Group for Strategic Planning (CCT-WG-SP) for their help with reviewing the

CCT strategic plan. Dr Machin reviewed the outline of the strategic plan. Among the new suggestions were to organize a CCT summer school, ideally by 2030, and for the CCT-WG-SP to consider forming task groups to address digital transformation and new metrology, especially for *in situ* traceability and practical primary thermometry. The full strategy document (36 pages) and a one-page summary are available at https://www.bipm.org/en/committees/cc/cct/publications.

Dr Machin outlined some of the main highlights of the strategy:

- The kelvin redefinition and *mise en pratique* (MeP-K-19) is beginning to stimulate research in this area.
- ITS-90 would remain important, with incremental improvements, but in the medium term may be supplanted by thermodynamic temperature at high and low temperatures.
- There would be developments in disruptive technologies, such as photonic thermometry, *in situ* calibration and *in situ* primary thermometry.
- The CCT would continue to have a key role in thermometry to monitor these developments and to ensure world-wide equivalence.
- In the longer term, the need for a new scale, ITS-XX should be kept under careful consideration.
- Humidity and moisture metrology continues to be driven by issues such as climate, advanced processing, and energy gases such as hydrogen.
- Observations of key climate variables are an important area of collaboration with WMO Global Climate Observing System (GCOS) and International Association for the Properties of Water and Steam (IAPWS). Air temperature is a key work area.
- Body temperature measurement is a strategic area requiring development.
- The wide area of thermophysical quantities remains important especially for energy and advanced manufacturing.

Dr Picard referred the meeting to the later agenda point on digitalization. Dr Sparasci commented on the magnitude of the environment challenge, and the prospect of proposing collaborative projects in the area in the coming year.

Dr Yuan thanked Dr Machin for this enthusiastic presentation on such important topics.

7 Highlights of Working and Task Group progress

7.1 WG for Key Comparisons (CCT-WG-KC) – A. Peruzzi, (NRC)

Dr A. Peruzzi presented a short report from the CCT Working Group for Key Comparisons (CCT-WG-KC), including terms of reference and membership. The WG had reviewed 26 comparisons in the past year. Ten were closed: five of these being approved, three abandoned and two not approved. A further 16 comparisons were active over the period. There remained 18 “silent” comparisons on record. Dr Peruzzi had contacted a few of these but without receiving any feedback. Of the active comparisons, the most pressing were the two K8 comparisons (CCT and EURAMET) and CCT-K9.

Dr Peruzzi had collected feedback on the new draft CIPM MRA guidance document on comparisons – CIPM MRA-G-11.

These comments included:

- The guidance should mention the option of expert review of protocols (for example by a key comparison working group) before the start of measurements. Such reviews can prevent problems in the future.
- Hybrid comparisons could be mentioned in the guidance, including their applicability (as supplementary comparisons, not key comparisons?).
- A declaration of participant traceability could be required at the protocol stage to pre-empt problems with this.
- The guidance should advise that protocols need not, and should not, 'freeze in' obsolete practices - which is a risk when basing a protocol closely on the preceding comparison protocol. The guidance might state which aspects to 'freeze'.
- Checklists for pilots, such as those already available within the CCT-WG-KC, could be shared via the guidance document.
- CCT members have previously discussed 'dark' uncertainty, and the guidance should consider whether or how such an element of uncertainty should be included.

Dr Yang asked whether CCT-K9 was at the Draft B stage. Dr Peruzzi confirmed yes – as far as he recalled, CCT-WG-KC was still reviewing this.

Dr Duan thanked Dr Peruzzi for his report.

7.2 WG for Contact Thermometry (CCT-WG-CTh) – C. Gaiser (PTB)

Dr C. Gaiser reviewed the membership and unchanged terms of reference and highlighted the subgroup working to revise the appendix on SMFPCs. This included the identification of a minimum uncertainty for the calibration of SMFPCs. In addition, Dr Gaiser reported on some other key points:

- The triple point of pure oxygen is more affected by argon contamination than previously thought.
- A draft of revised values of T-T_{90} is being circulated. Above 400 K, new measurements are needed.
- NRC work on ITS-90 reproducibility at the xenon fixed point and new interpolating equations from 13.8 K to 273.16 K.
- Additional discussions in the working group on scale non-uniqueness, and on the possible substitution of the triple point of mercury.
- Dr Gaiser also referred the meeting to CCT document CCT/22-48 on a thermodynamically consistent helium-3 vapour pressure scale.

Dr M. Sadli asked about downwards extrapolation in non-contact thermometry and whether any radiation thermometrists could usefully contribute to the working group, and link to the CCT-WG-NCTh. Dr Gaiser agreed to such a cooperation in future and Dr Sadli offered to find a volunteer from within CCT-WG-NCTh.

Dr Duan thanked Dr Gaiser for his report.

7.3 WG for Non-Contact Thermometry (CCT-WG-NCTh), including (CCT-TG-NCTh-IRT) and (CCT-TG-NCTh-BTM) – G. Machin (NPL)

Dr G. Machin gave an overview of progress.

The comparison CCT-K10 being led by NPL (Miss McEvoy) was reported to be at Draft B stage and is under review by CCT-WG-KC. The expectation was that this review would be completed before the end of March 2022, aiming for publication late in 2022.

Dr Machin and Dr Sadli reported on the CCT Task Group for a Guide on Industrial Radiation Thermometers (CCT-TG-NCTh-IRT), including membership. Four meetings had been held since the last CCT meeting. The outline content of the guide had been defined, and items of work had been assigned to individuals. The content was divided into two parts: (a) low-temperature thermal detectors, and (b) higher-temperature quantum detectors. Thermal imaging was not included but will be the subject of a future guide.

Dr Machin reported on CCT Task Group for Body Temperature Measurement (CCT-TG-NCTh-BTM), including membership and progress. Two best practice guides had been produced, for use of infrared ear thermometers and forehead thermometers, and both were available on the BIPM website. A third guide was in preparation, on thermal imaging fever screening. In addition, a protocol had been prepared for a key comparison of infrared clinical thermometer calibrations, to launch in early 2022. Dr Machin also reported on a number of invited presentations and several publications on this subject.

Dr Machin concluded by presenting a list of work planned before the next CCT meeting.

Dr Duan thanked Dr Machin for his presentation, and in the absence of comments from the meeting invited any comments later by email.

7.4 Guide on Secondary Thermometry – J. Pearce (NPL)

Dr J. Pearce presented the work in progress on the different guides:

- Thermocouples I: General Usage – Rod White *et al*. published online 2021.
- Industrial Platinum Resistance Thermometry – Jonathan Pearce *et al*. published online 2021.
- Metal Fixed Points for Contact Thermometry – Christof Gaiser updated Appendix 1 to reflect new guidance on pressure effect in SMFPCs.
- Specialized fixed points above 0 °C – Jovan Bojkovski updated to reflect new Appendix 1 of Metal Fixed Points for Contact Thermometry guide.
- Thermocouples II: Calibration and reference thermocouples – Rod White and Frank Edler updating.
- Industrial radiation thermometry – in progress, Mohamed Sadli coordinating.
- Thermistor thermometry – Rod White updating.
- Specialized fixed points above 0 °C.

Dr Pearce gave some details of the guidance on the uncertainty due to the effect of unknown pressure in a sealed metal fixed point cell. The origins of the previous unrealistic uncertainties were outlined, including the use of CCT/17-20 surveyed data with outliers and non-normal distribution, and the basis on best cases (top NMIs), which are not typical. It was emphasized that this new recommendation is for uncertainty contribution due to the pressure effect only in the absence of verification against an open cell operated at a known pressure and checked for drifts. The table of new values was shown, together with the previous (smaller) values for comparison. Ultimately it is recommended that SMFPCs are calibrated against an open cell.

Dr Duan thanked the experts for this work.

7.5 WG for Environment (CCT-WG-Env), including (CCT-TG-Env-AirT) – A. Merlone (INRIM)

Dr A. Merlone outlined the membership of CCT-WG-Env and detailed the participation of WG members in WMO Expert teams, listing a number of contributions to WMO work items. Dr Merlone outlined the aspects of the CCT refreshed strategy relating to environment, especially temperature-derived climate variables.

Dr Merlone drew attention to the importance of air temperature in climate and other contexts, and he reported recent developments in the recently formed CCT Task Group for Air Temperature (CCT-TG-Env-AirT), which had begun its activities with a kick-off meeting in November 2021. The TG is chaired by Åge Andreas Falnes Olsen, with vice-chair Dr Merlone.

Three sub-groups had been initiated, covering air temperature ‘definition’, ‘uncertainty’ and ‘guidance for calibrations’.

The report concluded with a review of the many activities, current and recent, of TG members working on climate related metrology.

Dr Duan thanked Dr Merlone, remarking on the significant level of contribution already achieved.

7.6 WG for CMCs (CCT-WG-CMC) – J. Bojkovski (MIRS/University of Ljubljana)

Dr J. Bojkovski outlined the terms of reference (unchanged) and the membership, noting that a forthcoming change of chairmanship in APMP would result in Dr H. Abe replacing Dr I. Yang on the WG.

Two new CMC review protocols were reported to be in discussion – for infrared spectral emissivity and for thermal diffusivity. Concerning sealed cell fixed points, the review protocol newly incudes specified uncertainty allowance for pressure.

New CMC categories under consideration are for items used for dissemination of thermodynamic temperature, such as resistance thermometers, fixed-point blackbody cells, and variable temperature blackbody facilities.

Looking to the future, the results of CCT-K9 and some supplementary comparisons are expected to lead to new CMC submissions. Some further changes and harmonization of CMC protocols are also planned.

Dr I. Yang raised the question of how accredited CMCs under ISO 17025 would consistently follow the new guidance for pressure uncertainty for sealed fixed-point cells. Dr Peruzzi and Dr Bojkovski commented on the planned dissemination of the guidance, which has only recently become available. Dr Pearce pointed out the availability of the document on the BIPM website and said that he would share it with the National Accreditation Body for the United Kingdom (UKAS), and he encouraged others to publicise the document to their national accreditation bodies.

Dr Duan thanked Dr Bojkovski for the report and thanked all who commented.

8 Information on the CIPM Sectorial Task Group on Climate Change and Environment – D. del Campo (CIPM)

Dr del Campo thanked Dr Duan for the invitation to report, then outlined the role of the CIPM Sectorial Task Group on Climate Change and Environment in addressing Environment - one of the Grand Challenges in the CIPM Strategy (along with Digital Transformation and New Metrology). Dr del Campo and Dr Duan together with Dr M Sené (NPL) are contact persons for the Environment area.

A Draft Resolution to the 27th meeting of the CGPM has been produced to develop forums for the three Grand Challenges, taking a "horizontal" sectoral approach that can span metrology areas. The objectives for the Sectoral Task Groups (STGs) are to provide inputs to the Consultative Committees, and to liaise with the relevant forums in the Regional Metrology Organizations. Envisaged activities are to facilitate dialogue between NMIs and stakeholders, to articulate internationally accepted metrology challenges in the field, and to encourage collaborations between Consultative Committees, NMIs and stakeholders. The STGs will run initially for four years and will then be reviewed by the CIPM for continuation. Membership will combine expertise with breadth of view and will not be limited to NMIs and DIs. This information was provided as background to the early launch of the STG on Climate Change and Environment.

Dr del Campo concluded by highlighting the joint BIPM-WMO workshop 'Metrology for Climate Action' on 26 to 30 September 2022 and encouraged all participants to register their interest.

Dr Duan thanked Dr del Campo for the interesting introduction to an important area of work.

Dr Merlone commented that the current CIPM position on Climate and Environment is the culmination of more than 12 years of work, starting with the CCT taking a lead with a long-term vision relating to climate in particular.

Dr Duan thanked Dr Merlone and invited all present to send any further comments to Dr del Campo.

9 "The dimensions of Metrology" – Y. Duan, CCT President

Dr Duan gave a presentation in which he described his personal understanding of metrology stemming from his wide experience, including being a member of the CIPM from 2010, chairing the CCT from 2012, and developing strategy. He outlined the subject in terms of three strands: evolution of metrology, dimensions of metrology, and development of thermometry in this dimensional conceptual model. He detailed the evolution of metrology through three broad eras: ancient weights and measures, modern measurement systems based on artefacts, and the New SI. He then described a multi-dimensional view of metrology linking different facets such as: theories and principles, standards and traceability, techniques and instruments, effective measurement operations, evaluation of results, and applications of measurement science. He outlined the developments of thermal metrology with reference to the multi-dimension idea, touching on the wide aspects of SI thermometry, finally concluding with an invitation to define the future of metrology in thermometry.

Dr Milton thanked Dr Duan for his insightful presentation. Dr del Campo asked whether the application layers in the dimensional model might include the cross-sectoral groups as set up,

and Dr Duan affirmed this. He proposed that he would possibly submit a version of the presented material to *Metrologia*, remarking that he had already aired these ideas at a gathering two years ago on the occasion of celebrating 40 years of collaboration between PTB and NIM. Dr J. Filtz commented, thanking Dr Duan for the presentation, remarking that success requires excellent metrologists, community, dissemination, and training. Dr Duan added his agreement.

Dr Duan then closed the session and thanked all those involved for their contributions.

10 Welcome to the second session by the CCT President, Y. Duan, and the Director of the BIPM, M. Milton

Dr Duan welcomed participants to the second session.

11 Approval of the agenda Session 2

Dr Duan invited comments on the agenda. Dr S. Picard said that the most recent version of the agenda is available on the CCT website. No comments were forthcoming and the agenda was approved.

12 Reminder of rapporteur

Dr Duan reminded Dr Pearce about his agreement to act as rapporteur for Session 2.

13 Highlights on CCT comparisons

13.1 CCT-K9 – H. Yoon (NIST)

Dr H. Yoon presented the CCT-K9 intercomparison. He started with a summary, commenting that it involved SPRT calibrations from the argon triple point to the Zn freezing point, and that he would give an update. Each participant, drawn from the different RMOs, prepared SPRTs, calibrated them, and sent them to NIST, who performed their own measurements of the SPRTs, then sent them back to the participants. Unfortunately, due to the extremely long timeline there were some unforeseen issues which caused further delays. The protocol was prepared in 2011, so the intercomparison has been running for more than 10 years. NIST confirmed that the Draft B has been prepared.

One reason preparation of the Draft B took so long is because many of the people involved are no longer working at the participating NMIs. Because of the transition of technical staff, some institutional knowledge has been lost. Due to the nature of SPRTs, this problem would be difficult to alleviate in the future. In a future intercomparison involving SPRTs, the protocol should incorporate mitigations for an inevitable loss of institutional knowledge. Nonetheless, with pressure from the CCT, the pilot laboratory will ultimately write it up. He noted that it is good for the CCT to keep pressure on the pilot laboratory to ensure the work is carried out in a timely manner.

The protocol involved repeatedly measuring the water triple point, stabilizing, and measuring again until the stability was shown to be within 0.2 mK. Many SPRTs still failed to meet this criterion even after careful screening of stability. There had been a careful assessment of which SPRTs will contribute to the KCRV. SPRTs that failed were not included in the KCRV but were still used to compare to others. A large number of failures, i.e. SPRTs not stable within 0.2 mK, were observed. He noted that it is quite sobering that these NMIs could preselect SPRTs very carefully and yet they still failed to meet the stability criteria. Significant instabilities were observed, with some changes amounting to more than 5 mK.

Two examples of comparison results were shown, at Zn and Ar for NPL and NIST respectively, representing the two extremes. The NIST value at the argon point is 6 standard deviations away from the KCRV, and the NPL zinc point is 4 standard deviations away. Dr Yoon said that he had contacted Dr J. Pearce (NPL) who explained that the cause of this was now well established, being due to radiative heat transfer from the re-entrant tube of the fixed point cell. The NPL corrected this issue some years ago, having had (independent) evidence of discrepant behaviour. For its part, NIST had dismantled the argon refrigerator and chiller, and found that there was a thermal leak that led to this failure.

Dr Yoon asserted that despite the problems mentioned, these intercomparisons are valuable and give a reality check as to whether uncertainties are good.

Some of the lessons learnt were summarized:

1. The community has reached limits of the use of SPRTs as transfer standards; fixed point realization uncertainties are lower than (a) variations upon recalibration and (b) changes from shipping.
2. Better protocols are needed to deal with discrepant data with a framework established *a priori*: it was suggested that guidance could be taken from Koepke *et al* 2017 *Metrologia* **54** S34.
3. These key comparisons are still useful to check claimed uncertainties.

Dr Picard queried whether NIST has submitted the Draft B for approval. Dr A. Peruzzi responded that the report had been submitted to the working group on key comparisons a couple of weeks ago. The reviewers are working on it and will provide their comments towards the end of February 2022; it is hoped that approval will be gained in the coming months. He offered his thanks to NIST for bringing this comparison to completion.

Dr Picard asked about linked comparisons, specifically if there are a few subsequent comparisons completed or ongoing which will link to the CCT-K9 reference values and how would that be managed. Dr Peruzzi responded that there is an agreement for those RMO comparisons linked to CCT-K9 that, after the CCT-K9 report is published, they need to write an appendix to their report with the linkage to CCT-K9.

Dr Duan thanked Dr Yoon for his contribution.

13.2 CCT-K10 – H. McEvoy (NPL)

Miss H. McEvoy gave a short overview of CCT-K10. CCT-K10 was a comparison of radiation thermometry from the silver freezing point to 3000 °C. It consisted of two transfer radiation thermometers and a set of metal-carbon high temperature fixed points (HTFPs). The

intercomparison took longer than anticipated, starting in 2014 and finishing in January 2020. NPL was the pilot. There were a number of causes of delays including shipping, customs, and technical delays at NPL.

The current status is that the Draft B report has been approved by all participants. A number of discussions have taken place about how to treat the analysis and the best way to present the data. There were anomalous differences in some of the results. Miss McEvoy agreed with Dr Yoon that there is a need to think in advance about the best way to deal with data that does not fall in line with other data. This needs to be agreed before the comparison starts.

On the whole the results were good, especially with HTFPs which showed much less drift than radiation thermometers, and most participants were in good agreement.

The Draft B report has been submitted to CCT-WG-KC, and the reviewers have provided their reviews. The next step is for Miss McEvoy to address the reviews, and this may result in another online meeting among participants.

Dr P. Bloembergen asked what temperature range had been covered. Miss McEvoy said that the range is 962 °C to 3000 °C.

Dr Bloembergen asked whether fixed points were used. Miss McEvoy replied that two radiation thermometers and a set of high temperature fixed points were used. The radiation thermometers were calibrated with the participants' own systems, for example high temperature blackbodies and reference radiation thermometers. The fixed points were measured with the participants' own radiation thermometers.

Dr Yoon commented that he was a participant. Because of outliers, the reference value was determined from the median instead of the weighted mean, and this caused some discussion about whether this is allowed. Some guidance is needed from the CCT or CCs on what can be done with outliers. He also observed that in the CCT-K9 and CCT-K10 report, the latest CIPM MRA document has not been followed, and some instruction is needed. For example, the latest CIPM MRA document provides guidance on co-authorship, which is not followed for K9 (no authors are listed). CCT-WG-CMC should consider sending information to key comparison participants; specifically, the latest MRA guidance on how to handle outliers, and how to prepare the KCRV.

Dr Duan asked Miss McEvoy to expand on the status of the CCT-K10 Draft B report. Miss McEvoy said that the Draft B report had been sent to CCT-WG-CMC. The reviewers have already commented, and Dr Peruzzi has transmitted the comments to Miss McEvoy. The coordinator needs to address the reviewer comments to improve the report, so the Draft B is still not approved. Miss McEvoy said she is currently in the process of addressing the comments and aims to complete in the next few months.

13.3 CCT-K7.2021 – A. Peruzzi (NRC)

Dr Peruzzi gave a summary of the status of the CCT.K7.2021 key comparison of water triple point cells, which he is coordinating. The technical protocol was approved in January 2021. NRC was charged with coordination of the comparison. There are 19 participating institutes, and a coordinating group was established with the goal of supporting the pilot in the analysis of the key comparison results. The protocol includes a detailed timeline for the comparison, which was accepted by all participants.

The start date was 1 April 2021, following which the participants had three months to select a transfer cell and compare it to the national reference. By June 2021 participants were required to send the selected cell and measurements to the pilot. The pilot had six months from June to December 2021 to compare all cells received. From 1 January 2022 participants could retrieve their transfer cell from NRC and measure it again in the next 3 months. Finally, NRC has until June 2022 to prepare the Draft A report.

Dr Peruzzi presented a table summarizing the status of each partner's progress in the key comparison. Most cells were delivered in July 2021. However, some cells were delivered following months of delay, with the last cells arriving at the NRC in November 2021. Of the 18 cells delivered to NRC only one arrived broken, so the participant was asked to send a replacement cell. So far, only half the expected reports have been delivered; he issued a plea to those who have not delivered their reports to do so as soon as possible.

Out of 17 cells delivered, NRC has already measured 15 cells in three different batches. Out of these cells, three showed anomalous behaviour (i.e. drift). The owners of those cells were informed and some sent replacement cells, while one participant withdrew from the comparison.

The plan to bring the comparison to a conclusion is to complete the measurements in the last batch, which will finish two months late, but it is still believed the Draft A report can be delivered on time.

Dr Duan commented that everybody is happy with the progress of this intercomparison.

13.4 CCT-K8 – D. del Campo (CEM)

Dr del Campo presented CCT-K8, which is a comparison of realizations of local scales of dew-point temperature of humid gas coordinated by INTA. The data treatment has been completed, and all degrees of equivalence have been calculated. The pilot is now working on the wording of the report and expects to have the Draft A report completed in a couple of months at the latest. This will be distributed to the participants in the first trimester of 2022.

13.5 CCT-K6 – S. Bell (NPL)

Dr Bell presented CCT-K6.2021 as chair of CCT Working Group for Humidity (CCT-WG-Hu). CCT-K6.2021 is a key comparison of dew-point temperature measurement. It was agreed at the 29th meeting of the CCT to start this intercomparison. It is not yet registered in that name. The measurand and range is as in the previous CCT-K6 i.e. local realizations of the dew point in the range −50 °C to +20 °C (CCT-K8 covers the measurand above this range, and there are supplementary comparisons below this range).

The travelling standards, institutes participating, and other details are to be decided. The timing will need to be coordinated around other comparisons in progress (CCT-K8 and RMO counterparts, and APMP.T-K6.2013). The key comparison will be designed alongside, and aligned with, CMC review protocols for humidity.

There has been early discussion of the comparison protocol, aiming to design for (a) the quickest and most effective completion, while staying consistent with past CCT-K6 and (b) the KCRV and linkage with other intercomparisons.

The aim is to design the comparison alongside the review and revision of the CMC review protocol for the dew point, so that a future CMC protocol does not force the key comparison to be overly detailed.

A pilot has not yet been identified from within CCT-WG-Hu. The chair has approached the group, and individuals, even with the possibility of joint piloting, but has received no offers from the WG. The travelling standard(s) have not yet been identified. Dr Bell has begun to approach companies for the loan of travelling standards, but the commercial landscape has changed and companies may not readily lend equipment.

Overall, the most important issue is to find a pilot for the comparison. This could hold the community back as there is a risk that the CCT key comparison may fall behind associated RMO key comparisons.

In view of the absence of a volunteer to pilot the comparison from within CCT-WG-Hu, Dr Bell would like to open up an invitation to the wider CCT in case there is a potential pilot, who is not a member of the CCT-WG-Hu, who might volunteer.

Dr Peruzzi commented that in the past it had been suggested that if no other institutes came forward as a volunteer, NPL could consider being a pilot.

Dr Bell responded that having piloted CCT-K6, she did not have a strong inclination to do it again. In spite of that, she did consider it, but it is difficult to prioritize funding when there are so many other projects including important areas such as climate, which inevitably result in compromises over what the NPL can do.

Dr Duan commented that there have been several RMO comparisons associated with K6 and asked whether there is any possibility to find a pilot laboratory among those RMO comparison participants. Dr Bell said that she can ask the question, although she remarked that it is a significant burden to place on one laboratory.

Dr Bojkovski reminded the plenary that the CMC review protocol was built on the CCT-K6 protocol. Changes are welcome if they simplify the process.

Dr Duan asked the CCT members to consult colleagues in their respective institutes to discuss whether one or more of them can be volunteers, and if so, they can send an email to Dr Bell. He encouraged all members present to discuss the matter, in particular with their humidity colleagues.

Dr Duan asked whether Dr Bell had asked members of the WG. Dr Bell confirmed that this had been done and remarked in response to this and the previous question that the participants had not been decided, as the intercomparison first needs a pilot. It is the responsibility of a pilot to propose a protocol for the participants to accept. She stressed that if somebody offers to do this, it will be with support from all participants, especially those who have piloted comparisons before. The CCT would not ask for a volunteer to do this without any help.

Dr Duan thanked Dr Bell for her contribution.

Dr Duan summarized the presentations on key comparisons by appreciating the good news that CCT-K9 has almost reached Draft B status, and thanked NIST colleagues' contributions, as well as those of Dr Picard and Dr Peruzzi. Dr Duan also appreciated the good news about CCT-K10 which has almost reached Draft B status, and thanked Miss McEvoy and all CCT-K10 participants. He remarked on the news that the CCT-K8 Draft A report will be ready in the near future and hoped that CCT-K6 members will pay attention to the problem of identifying a pilot.

14 On the addition of new CMC entries – J. Bojkovski (MIRS/University of Ljubljana)

Dr Bojkovski briefly summarized new CMC entries which essentially represent a harmonization arising from the fact that CCT-WG-NCTh upgraded the radiation thermometry CMC review protocol. This means a change to the classification of services, to incorporate items used for the dissemination of thermodynamic temperature, and this should be formalized. The new category will be in line with the CMC review protocol. This needs formal approval by the CCT.

Dr Peruzzi said that these new services are acceptable, but it is necessary to establish CMC acceptance criteria for these new services.

Dr Bojkovski replied that these are already part of the CMC review protocol for non-contact thermometry, which provides a series of steps on what to do for each particular category.

Dr Machin commented that this will become urgent if it is not done soon. It is clear that dissemination of T is going to become more widespread, and a comparison of T dissemination is needed; to have the protocol soon would be welcomed.

Dr Duan said that these points are important for radiation thermometry (blackbody fixed-point cells, radiation thermometers, and variable T sources), and that if there are no objections, the CCT formally accepts these three points. No objections were raised.

15 On the Establishment and Corroboration of a Thermodynamically Consistent Helium-3 Vapour-Pressure Scale – C. Gaiser (PTB)

Dr C. Gaiser gave a presentation on the establishment and corroboration of a thermodynamically consistent helium-3 vapour-pressure scale, which is described in CCT/22-48. He observed that most people in this field have retired or otherwise moved on, so it is helpful to remind ourselves of the work to maintain the knowledge. This is concerned with the temperature range below about 1.2 K. The analysis is in three parts, namely primary thermometry, a careful check of the results with thermophysical properties data, and a comparison with PLTS-2000 and ITS-90.

In 1992, PTB and NIST used CVGT at 2.6 K and extrapolated to lower temperatures with magnetic thermometry, with measurements augmented by Johnson noise thermometry at 0.5 K. An increasing deviation from T and T_{90} was observed, amounting to up to 1 mK at T = 0.65 K.

An analysis of the thermophysical properties data for helium-4 and helium-3 offered further understanding of the deviation. Recent measurements at LNE in 2021 offer further insights, which were consistent with the PTB and NIST results.

These three checks with independent methods by different institutes have shown that the ITS-90 deviates from thermodynamic temperature by about 1 mK at the low temperature end of the scale. In a future temperature scale, coefficients defined in the PTB-2006 study (which is already recommended by the CCT below 2 K) will replace coefficients defined in ITS-90.

Dr F. Sparasci commented that during discussions about the implications of this for the *mise en pratique*, Dr C. Gaiser showed Dr Sparasci a paper published by the Royal Society where there was a recommendation to use PLTS-2000 instead of ITS-90 in the overlapping temperature

range. This paper was the basis for the *mise en pratique* document. Dr Sparasci recalled that this specific recommendation was skipped in the formal document, and asked Dr Gaiser to check if this recommendation exists in the official document.[1]

Dr Duan expressed satisfaction with this scientific research, which suggests that the redefined kelvin, and primary thermometry, enables us to find and quantify weaknesses of ITS-90. If it becomes necessary to establish a new temperature scale, this will act as important underpinning work.

16 Highlights on RMO activities

Dr Duan invited TC-T chairs from the RMOs to give a brief outline of their activities since the last CCT meeting.

APMP: Dr H. Abe, APMP TC-T chair, presented the APMP activities. He took over from Dr I. Yang in November 2021. The APMP online meeting in November 2021 had 61 participants from 20 economies. The APMP has working groups specializing in SPRTs, fixed points and the water triple point, radiation thermometry, humidity, industrial thermometry, thermophysical properties, and industry strategy. The APMP has been concerned with six key comparisons and ten supplementary comparisons, as well as three hybrid comparisons. It carried out 40 CMC reviews in total over the last year. In the first half of the year, ten inter-RMO CMC reviews from AFRIMETS were completed, and in the second half, 16 from EURAMET and seven from AFRIMETS were completed.

There is a dedicated Covid-19 response programme, with activities around thermal imagers (NMIA and NMS A*STAR) and forehead infrared thermometer calibration, proposed by NML-ITDI, currently being evaluated by APMP. The APMP TC-T work plan was presented. APMP has been involved with EURAMET-BIPM training on comparisons; in particular, Dr Yang participated as a lecturer, and presented on hybrid comparisons. A workshop on SI realization was also held.

AFRIMETS: Dr E. Ejigu, AFRIMETS TC-T chair, presented the AFRIMETS activities. TC-T virtual meetings are held annually. Intercomparisons included: supplementary comparison AFRIMETS.T-S2 on industrial PRTs, for which the final report has been published; AFRIMETS.T-S3, also on IPRTs, had been postponed but was restarted; and AFRIMETS.T-S7 on the comparison of noble metal thermocouples.

Participation in CCT/APMP intercomparisons includes CCT-K7.2021, APMP.T-K4.2 on the aluminium fixed point, APMP.T-S11/S12 on radiation thermometers from the indium freezing point to 2800 °C, and the S17 supplementary comparison on air temperature thermometers. CMCs submitted include the LPEE/LNM (Morocco) on PRTs with display units, NIS PRT on pure-metal thermocouples at fixed points, Kenya Bureau of Standards on PRTs, and the Ghana Standards Authority have undergone peer review of their quality system prior to CMC submission. CMCs that have been approved and published in the past five years were Zimbabwe

[1] This question was subsequently answered in Section 20.

(13), Zambia (11), Botswana (3), Morocco (4), Egypt (1), making a total of 32. AFRIMETS is an active participant in inter-RMO CMC review.

COOMET: Dr A. Pokhodun, COOMET TC-T chair, presented the activities of COOMET.

COOMET key comparison activity includes:

- Supplementary comparisons of national standards of the unit of thermal coefficient of linear expansion 273.15 to 773.15 K, pilot VNIIM;
- COOMET 826/MD-a/21 Supplementary comparisons of standards for the unit of relatively humidity, pilot NIM (Moldova);
- COOMET 704/RU-a/16 Regional key comparisons of national standards at the triple point of mercury, pilot VNIIFTRI.
- COOMET 787/UZ/19 Pilot comparisons of calibration of platinum resistance thermometers at fixed points in the range from the triple point of water (0.01 °C) to the solidification point of aluminium (660.323 °C), pilot NIM (Moldova);
- COOMET 771/MD/18 Pilot comparisons of measurements in the field of calibration of platinum resistance thermometers at fixed points in the range from the triple point of mercury (−38.8344 °C) to the melting point of gallium (29.7646 °C), pilot NIM (Moldova);
- COOMET 744/RU-a/18 Pilot comparisons in the field of measuring the calorific value of coals with different sulfur values, pilot VNIIM;
- COOMET 780/Ru/2019 Pilot comparisons of national reference gas calorimeters on samples of gas mixtures, pilot VNIIM.

The CMCs of COOMET members were presented and consisted of BelGIM (54), NSC IM (73), KazInMetr (17), INIMET (8), INSM (69), GEOSTM (31), VNIIM and VNIIFTRI (143), Azerbaijan (24).

Research included improvement of the primary standard of the unit of heat in the field of calorimetry of dissolution and reactions, to improve capability for supporting measurements of small thermal effects in liquid media in the pharmaceutical industry and other physical and chemical processes.

A technical workshop is being planned to discuss the problems of realizing the redefined kelvin, and also comparisons of realizations of the redefined kelvin by absolute primary radiometric thermometry and relative primary radiometric thermometry are anticipated.

COOMET TC-T members participated in a plenary meeting, and also participated in some EURAMET TC-T working group activities and meetings. It is preparing joint meetings of COOMET TC-T and EURAMET TC-T technical committees in 2022.

EURAMET TC-T: Dr del Campo, EURAMET TC-T chair, presented the activities of EURAMET. More details on the EURAMET TC-T activities are available on the EURAMET website, so the presentation was restricted to key activities. Dr del Campo will step down as chair in 2022 and will be replaced by Dr S. Rudtsch. Dr del Campo expressed her gratitude for being able to represent the EURAMET TC-T community and WGs.

She described the launch of the European Partnership on Metrology, sponsored by the European Union, which will have a duration of 7 years and a budget of 600 million euros. Its aim is to create a sustainable and effective system of metrology at the European level, providing

metrology that is fit for purpose, and to stimulate European inovation, support regulation and standards to underpin policies and to address societal challenges.

An online training workshop was organized on 26-27 April 2021 on comparisons in thermometry, in collaboration with the BIPM. The workshop featured speakers from different RMOs, as well as being open to other RMOs. There were more than 80 attendees. Due to the success of this training in 2021, a similar workshop is being planned, but this time on CMC preparation and submission with the aim of homogenizing the interpretation of CCT review protocols. This workshop will be held on 25-26 April 2022. Currently the agenda is being prepared, with speakers anticipated from different RMOs, and as before it will be open to other RMOs. In cooperation with COOMET, EURAMET is organizing a workshop coordinated by Dr Pokhodun and Dr Machin on realizing the new definition of the kelvin. This will also be open to other RMOs, and information will be distributed soon. EURAMET plans to run a second thermometry summer school in 2023 in Ljubljana, hosted by Dr Bojkovski and his team, which will also be open to other RMOs.

SIM: Dr A. Todd, co-chair of SIM WG3, presented the activities of SIM WG3 Thermometry, which is co-chaired by Dr C. Sanchez. A virtual meeting of WG3 will be held on 15 February 2022. Discussion items will include a short workshop on CCT CMC review protocols, a focus on developing and implementing a more robust process for submission and review of CMCs, and review and planning of regional comparison activities, in particular with developing NMIs.

Together with the CCT WG-KC chair, the SIM ‘silent’ comparisons (reported at the first session) were reviewed. It was noted that SIM will not participate in the CCT comparison for body temperature measurements.

Two upcoming meetings were highlighted: CENAM will host its *Simposio Metrologia* virtually on 26-28 October 2022, and NIST will co-sponsor the 10th International Temperature Symposium (ITS-10) jointly with MSC on 3-7 April 2023.

GULFMET: Dr M. Anagnostou presented the activities of GULMET. The current Chair will step down in 2022 and the new chair, Dr N. Dawood (SASO NMCC) will take over. TC-T meetings are held twice a year.

Participation of GULFMET in TC-T comparisons were outlined, including EURAMET.T-K7-4 (comparison of triple point of water cells), GULFMET.T-K9 (SPRT calibration at fixed points from mercury to zinc), GULFMET.T-S1 (relative humidity comparison from 11 %rh to 95 %rh, at 0 °C, 23 °C and 70 °C), GULFMET.T-S2 (radiation thermometry calibration from −20 °C to 1600 °C), GULFMET.T-S3 (platinum resistance thermometer calibration from −70 °C to 250 °C). Future comparisons include those for calibration of noble metal thermocouples, comparison of IR ear thermometer calibration facilities, aluminium fixed-point, and dew point temperatures from −20 °C to 65 °C.

It was noted that GULFMET has participated in APMP meetings.

No CMCs were submitted for review, and no comparisons, until very recently, were at Draft B status. This is mainly beause the quality systems of the relevant institutes were not in place until recently or not fully developed (apart from EMI). Only two labs have primary measurement capabilities and they are well developed; one additional lab is currently developing such

capabilities. The GULFMET TC-T roadmap was presented, which is concerned with building up members' calibration facilities so that routine publication of new CMCs, starting research projects, and participation in comparisons would be operational by 2025.

Dr Duan offered his thanks and commented that this is a good opportunity for all of us to share information from different RMOs, and that the CCT is a good forum for such exchanges.

17 News from the JCRB – O. Werhahn, JCRB

Dr O. Werhahn, JCRB Executive Secretary gave an update on JCRB matters.

He presented details of the recent update of CIPM MRA documents; in January 2021 the previous documents were replaced by three policy documents (P-series) and three guides (G-series). An adaptation on the CIPM MRA-G-13 document is foreseen to better align the 'greying out' practice with the KCDB 2.0 platform. Following an update of the BIPM website and the launch of the KCDB 2.0 platform, the former JCRB website has been closed. Since 2021 all CCs have been submitting, reviewing and maintaining CMCs exclusively on the web-based KCDB 2.0 platform. The former JCRB website has been closed.

The JCRB governance of the Mutual Recognition Arrangements was described. Three actions were described:

1. Action JCRB/44-1 (2021) The JCRB requests the Executive Secretary to include the possibility of up to two additional observers from each RMO when issuing the convocation for future online JCRB meetings.
2. Action JCRB/44-2 (2021) The JCRB requests the Executive Secretary to include an agenda item for the 45th meeting of the JCRB regarding the validity of RMO-approved quality management systems, to coincide with the end of the extension period granted at the 43rd meeting.
3. Action JCRB/44-3 (2021) The JCRB requests the Executive Secretary to upload proposed draft changes to CIPM MRA-G-13 onto the JCRB site, and requests that the RMOs review these minor changes, with a view to approving the revised text at the 45th meeting of the JCRB.

There are 25 887 CMCs published in the KCDB. This has levelled out over the last decade, probably due to the recent use of broader scope CMCs. A total of 2 942 CMCs are from the CCT community. The number of new approvals in the thermometry area showed a large increase in 2020 when submissions tripled in comparison to the two previous years. About 1 400 CMCs have been edited, reviewed and finally published using exclusively the new KCDB 2.0 platform. All CCs are now fully compatible with the KCDB 2.0, including the CCQM. The distribution of CMCs across all RMOs was shown, with EURAMET contributing the most. Notably, only one CMC was greyed out. An update on CIPM MRA-G-13 regarding the greying out practice is being discussed by the JCRB.

The KCDB 2.0 now gives performance evaluations for intra-RMO and JCRB review. The JCRB review duration has decreased from about 140 to 60 days (median) across all metrology areas. For thermometry, the median is 67 days. Across all 31 published CMCs in thermometry in 2021, the median review time was 221 days.

Dr Duan offered his thanks for the summary report from the JCRB. He was happy that the relatively small number of CCT key comparisons support a large number (more than 2 900) of CMCs, so it is quite efficient. He asked for more explanation about the 'greying-out' practice.

Dr Werhahn replied that if an NMI or other institute has some reason why they cannot provide a service backed up by a CMC, they can grey it out, which means that it is still in the system, but it will not be available to customers. The CIPM MRA permits a maximum period of five years at that status; after four years it becomes necessary to make a decision. The JCRB Executive Secretary is responsible for this process.

Dr Duan commented that if an institute applies for a 'grey-out' it is simple to do. However, if an institute asked for a grey-out, then after several years wanted to re-instate this capability, do they have to follow the normal procedure for re-evaluation of their capabilities before they can re-establish CMCs? Dr Werhahn replied that the procedure is described in the CIPM MRA-G-13 document. Essentially the TC-Chair and the JCRB representative must agree a plan with the institute, which is completed within five years of the time at which the CMC was greyed out.

Dr Duan asked if an institute wants to reclaim capability, does it need to undergo peer review. Dr Werhahn replied that the purpose of greying out is that this is not necessary. Reinstatement and agreement that it is the same CMC must be agreed with the TC-T chair, and full review is not required.

Dr Duan offered his thanks.

18 News from the KCDB – S. Picard, BIPM

Dr Picard, KCDB coordinator, gave an overview of KCDB matters. The KCDB software was upgraded and the KCDB 2.0 was launched in October 2019. To assist users with the upgraded software, help documents, 14 video clips and FAQs are available on the KCDB website. Capacity Building and Knowledge Transfer sessions have been used to give advice to RMOs, Writers, TC Chairs and Pilots. Further improvements are being made on a regular basis.

On quantity-based equations, there are 36 CMCs in thermometry which need to be converted to improve compliance with ILAC methodologies. There are some examples in the FAQs on how to do the conversion. Dr Bojkovski and others concerned will be given more information.

The KCDB can be accessed either through the website, or through an Application Programming Interface (API), which makes it more amenable to digitalization and inclusion in other websites or programs and allows a 'big data' approach for gathering statistics. This is a precursor for digital CMCs. The API was made available in June 2021. There is a possible future need for harmonization of quantity, instrument under test and calibration method expressions, and work is currently focusing on those items.

Dr Duan offered his thanks for this introduction of digitalization for the KCDB and its part in the more general trend towards digitalization. It was suggested to defer questions and comments until after the session on 'Issues on digitalization'.

19 Issues on digitalization

Dr Duan invited Dr Milton to provide an introduction. Dr Milton expressed his thanks and said that the introduction given by Dr Picard had been sufficient.

Dr Picard said that digitalization for the CCT is needed to keep up with the increasing trend towards information being digitalized and made accessible to machines. The CCT is concerned with the *mise en pratique* for support of the SI brochure. There is a need to make the SI brochure machine readable and it has a number of appendices (*mise en pratique*), to which many of the CCT members have contributed high-level scientific contributions.

CCT guidance documents on how to realize the ITS-90, others that are in progress on secondary thermometry, as well as published papers should also be identifiable or machine readable. One way to approach this is to have all publications identified by DOIs, so they possess a label, which could be taken further to provide information on the contents of the publications.

Data on the *mise en pratique* was shown, such as definition of the kelvin (to be taken up by the SI brochure); the aim would be to cite the redefinition by text and by identifier. The CODATA values relevant to the redefinition of the kelvin could also be included. In the ITS-90 there are a number of interpolation functions, which should be discussed in terms of how it could be made machine readable. Estimates of $T - T_{90}$ could also be included.

Dr Picard suggested the possibility of creating a group to examine what information could usefully be made available digitally.

Dr Gaiser (in his role as CCT-WG-CTh chair) was invited to comment. To make the ITS-90 document machine readable is beneficial. However, extracting coefficients from ITS-90 documentation is not easy. $T - T_{90}$ estimates, updates, and functions could be included. The API should be capable of yielding the value of $T - T_{90}$ at a specific temperature. A sub-group should be set up to discuss these issues, perhaps in CCT-WG-CTh, or possibly CCT-WG-NCTh.

Dr P. Rourke asked whether DOIs are for archival or living documents. Dr Picard suggested they are probably only for archival documents but noted that she is not an expert on that topic.

Dr Milton remarked that Dr Picard is working on a policy for all these issues for the BIPM. Whilst most metrologists are working at the cutting edge, there are always relevant archival items (for example fundamental constants). The BIPM is building the need to create references that would refer back to archived data into its strategy, for example, a method of linking back to previous international temperature scales. The BIPM is investigating the development of a policy for numbering; a type of version control. Another example is that it could be useful to make previous versions of CMCs available.

Dr Machin commented that, linked to what Dr Milton was saying, high temperature fixed point values are in the documents that Dr Picard mentioned (the *mise en pratique*), which can be used as references. These will change with time, and are needed in electronic form, to stream into automatic calibration systems. He questioned whether it is the intention of the task group to identify which things will be done and who does them.

Dr Picard said that it would probably be useful to establish a TG now, whose membership could be approved by correspondence, and to try to launch that group here if everybody agrees.

Dr Milton encouraged the CCT to go ahead and set up this group. The BIPM is developing its strategy, but wants the CCT to establish its ideas. In other words to establish what needs to be done, but not to execute it; the BIPM will help with the implementation.

Dr Gaiser said that he will talk to the CCT-WG-CTh about this issue and will then discuss it with CCT-WG-NCTh.

Dr Machin said that he is happy to participate, and will also discuss within CCT-WG-NCTh to identify other possible members.

Dr Picard re-affirmed that the TG would recommend what to include, but would not need to carry out the technical realization.

Dr Duan asked whether it was preferable to set up a separate sub-task group in each of CCT-WG-CTh and CCT-WG-NCTh. Dr Machin said there should be one TG which is independent of the WGs.

Dr Duan commented that a representative from humidity should be included and asked whether the TG leader should be identified in this meeting; he suggested Dr C. Gaiser. Dr Gaiser said that he could do this and asked whether Dr S. Bell would like to join.

Dr Duan said that those interested in joining the TG can send an email to Dr Gaiser to express their interest.

Dr Milton said that these are generous offers, and thanked people for coming forward. He encouraged the CCT to ensure good coverage from other RMOs, to make sure this does not become a EURAMET task group.

Dr Picard reminded the participants to place Dr S. Solve in copy so that he is informed.

Dr Gaiser said that he could approach CCT-WG-CTh and perhaps a chair can be identified from another RMO (not EURAMET).

Dr Duan recommended that all participants discuss the matter with colleagues in their institutes, then send an email to Dr Gaiser expressing an interest in joining this TG and making a contribution to this work.

Dr Duan said that there is a new task group on digitalization and Dr Gaiser will be coordinator/chair.

Dr Gaiser asked whether it is necessary to search for another chair outside of Europe. Dr Milton said that was not his intention, only that the TG should include participants from around the world. Dr Duan said that members from all RMOs should be invited. Dr Machin recalled that the WGs have members from all RMOs so that should not be a problem. Dr Duan suggested that colleagues working in humidity and thermophysical quantities should also be included.

Dr Picard observed that this activity is in line with the CCT strategy / planning.

20 AOB

Dr Gaiser answered a question raised by Dr Sparasci in Session 15 about PLTS-2000. On the BIPM website under ‘Guide to the Realization of the PLTS-2000’, there is a comment on the helium-3 vapour pressure and the use of PLTS-2000 in the low temperature range, which is included in the document.

21 Approval for open access

Dr Picard said that all documents associated with the 30th CCT meeting will be made public unless there is a particular reason to keep them confidential.

Dr Duan said that all documents will be approved for open access.

22 Next meeting

Dr Duan opened the discussion about the date of the next meeting.

Dr Picard suggested 2024, the main objective being to avoid the years of the ITS-10 conference (2023) and Tempmeko. Dr D. Zvizdic added that the next Tempmeko conference will be in France in 2025.

Dr Duan commented that 2024 is a good time for everybody.

Dr Milton said that 2024 was fine and asked whether it should be scheduled between February and April as has been done recently. He added that there are already many CC meetings in May and June. The preferred period is March or April. September and October are also busy in 2024.

Dr Duan expressed a preference for April.

23 Closure of the meeting

Dr Duan thanked all participants for their contributions and observed that the Chinese spring festival is from 1 February to 15 February and is currently in progress. He wished everybody a strong year and hoped that the CCT would have the opportunity for a face-to-face meeting. He declared the 30th meeting of the CCT closed.

Dr Milton recalled that the meeting started by introducing Dr Solve who will take over from Dr Picard as Executive Secretary. The meeting finished by thanking Dr Picard. Dr Milton thanked Dr Picard for her enthusiasm and energy, and knowledge of the details and the processes. Even in this difficult time with online meetings, Dr Picard organized the meetings efficiently, together with Dr Duan, and everything worked well.

Dr Picard thanked Dr Milton and Dr Duan, and all members of the CCT and collaborators, and expressed pleasure in meeting everybody and seeing all the work they have been doing.

Dr Duan said that Dr Picard would be missed, and that working together had been a pleasant experience.

23.1 Actions

The following actions are to be undertaken:

Actions

CCT30/A1. WG-CMC should consider sending information to key comparison participants; specifically, the latest MRA guidance, how to handle outliers, and how to prepare the KCRV.

Decisions

CCT30/D1. The new CMC entries associated with the radiation thermometry CMC review protocol upgraded by CCT-WG-NCTh were approved by the CCT.

CCT30/D2. To create a new Task Group on digitalization with Dr Gaiser as the Chair. Participants interested in joining the Task Group to contribute are invited to contact Dr Gaiser.

Dr S. Bell and Dr J. Pearce, Rapporteurs

March 2022