Bureau International des Poids et Mesures

Consultative Committee for Length (CCL)

Report of the 18th meeting
(25 – 27 October 2021)
to the International Committee for Weights and Measures

Comité international des poids et mesures

LIST OF MEMBERS OF THE
CONSULTATIVE COMMITTEE FOR LENGTH
as of 25 October 2021

President

Dr I.A. Castelazo, Member of the International Committee for Weights and Measures.

Executive Secretary

Dr G. Panfilo, International Bureau of Weights and Measures [BIPM], Sèvres.

Members

Bundesamt für Eich- und Vermessungswesen [BEV], Vienna.

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

Czech Metrology Institute [CMI], Brno.

D.I. Mendeleyev Institute for Metrology, Rosstandart, [VNIIM], St Petersburg.

Federal Institute of Metrology [METAS], Bern-Wabern.

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

JILA, Boulder.

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

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

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, Australia [NMIA], Lindfield.

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

National Metrology Institute of Japan, Advanced Institute of 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.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

VSL Dutch Metrology Institute [VSL], Delft.

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

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

Observers

Central Office of Measures [GUM], Warsaw.

Industrial Technology Research Institute/Center for Measurement Standards [CMS/ITRI], Hsinchu.

Instituto Português da Qualidade [IPQ], Caparica.

National Institute of Standards [NIS], Giza

FIRST SESSION, MONDAY 25 OCTOBER

I-1 WELCOME AND INTRODUCTION BY THE CCL PRESIDENT

The Consultative Committee for Length (CCL) held its 18th meeting online on Monday 25, Tuesday 26 and Wednesday 27 October 2021. Three sessions were held, one each day, 11:00 – 13:00 UTC.

The following delegates were present:

J.A.P. Alves (INMETRO), M. Aşar (UME), B. Babic (NMIA), P. Balling (CMI), A. Balsamo (INRiM), Y. Bitou (NMIJ/AIST), H. Bosse (PTB), D.A. Brasil (INMETRO), I. Castelazo (CCL President), V. Coleman (NMIA), T. Coveney (NPL), P. Cox (NMIA) D. Czułek (GUM), R. Dixson (NIST), B. Eves (NRC), R. Fira (SMU), Z. Fomkina (VNIIM), T. Fook (NMC, A*STAR), R. França (INMETRO), W.-E. Fu (CMS/ITRI), I. Hernandez (CENAM), A. Hirai (NMIJ/AIST), P.E. Hsu (CMS/ITRI), F. Hungwe (NMISA), H. Hussein (NIS), J. Jin (KRISS), J.-A. Kim (KRISS), N. Kononova (VNIIM), R. Koops (VSL), C. Kottler (METAS), O. Kruger (NMISA), A. Lassila (MIKES), R. Le Targat (LNE-SYRTE), J.Y. Lee (KRISS), I.D. Leroux (NRC), A. Lewis (NPL), J. Li (NIM), F.-H. Lin (CMS/ITRI), I.L. Marques Silva (INMETRO), P. Masina (NMISA), M. Matus (BEV), F. Meli (METAS), I. Merla (UME), M.J.T. Milton (BIPM Director), A. Moskalev (VNIIM), M.d.M. Pérez Hernandez (CEM), E. P. Prieto Esteban (CEM), J.-A. Salgado (LNE), F. Saraiva (IPQ), D. Sawyer (NIST), H. Schnatz (PTB), Y. Shi (NIM), J.R. Stoup (NIST), S.L. Tan (NMC, A*STAR), L.V.G. Tarelho (INMETRO), O. Terra (NIS), K. Thomson (NRC), M.R. Viliesid Alsonso (CENAM), J.P. Wallerand (LNE-LCM/Cnam), S. Wang (NMC, A*STAR), Y. Wang (NIM), T. Watanabe (NMIJ/AIST) and M. Zucco (INRiM).

Representatives from Member States invited to attend as Observers: K.B. Bastida (INTI), J. Buajarern (NIMT), O. Kostrikov (NSC IM).

Guests: S.EG. Bergstrand (RISE), S. Bize (LNE-SYRTE), Z. Xue (NIM), A. Yacoot (NPL), M. Al Senaidi (EMI), F. AlQahtani (SASO-NMCC).

Also present: G. Panfilo (Executive Secretary of the CCL, BIPM)., S. Picard (KCDB Coordinator, BIPM), O. Werhahn (JCRB Executive Secretary).

Dr Castelazo, President of the CCL, welcomed the participants to the 18th meeting of the CCL and thanked Dr Milton, Director of the BIPM. He said that it was a pleasure to see so many participants in this virtual meeting and hoped that the next CCL meeting would be face-to-face.

Dr Panfilo gave some housekeeping information – the meeting was being recorded, and she requested participants to switch off their cameras and microphones during presentations.

I-2 WELCOME BY THE DIRECTOR OF THE BIPM

Dr Milton, Director of the BIPM thanked Dr Castelazo and added his welcome to this 18th meeting of the CCL. He added that a wider participation, at lower cost, were advantages of online meetings, but he hoped that all would be able to meet physically again at the BIPM soon. He commented

that one of the current CIPM focuses was on digitalization. He welcomed the lead being taken by the CCL on aspects of the digitalization agenda.

I-3 APPOINTMENT OF THE RAPPORTEUR

Dr Lewis (NPL) was appointed as Rapporteur after being proposed by Dr Castelazo; Mr Coveney assisted him.

I-4 APPROVAL OF THE AGENDA

Dr Castelazo referred to the tabled agenda. No other business was tabled. The agenda was approved by the attendees with no changes or additions.

I-5 REPORT OF THE 17TH MEETING OF THE CCL 2018 INCLUDING ACTIONS AND DECISIONS

Dr Lewis presented the action list from the previous meeting of the CCL together with the updated status, as reported in the following table.

No	Action	Status
A.1	Dr Castelazo to ask the CCT President to request that CCT issues clear guidance on the issue of temperature scale changes under the new SI and any potential effect on length metrology, which uses a reference temperature of 20 °C for dimensional metrology.	Done.
A.2	The updated *Mise en Pratique* will be circulated by Dr Castelazo to CCL members before approval is given by a decision of the CCL Working Group chairs and the CCL President.	Done.
A.3	Dr Balsamo to approach the ISO/TC213 chair and secretariat informally to propose a possible liaison with the CCL.	Done.

The actions were all complete and approved. There were no outstanding actions.

I-6 OUTCOMES FROM CIPM MEETING

Dr Castelazo informed the delegates of news from the 110th meeting of the CIPM, which he had recently attended. The meeting had been held online over two sessions, 21-23 June 2021 and 18-20 October 2021. The CIPM had granted approval to publish the uncertainty guidance document GUM 6 on the use of measurement models. The CIPM had approved the first edition of the CIPM Rules of Procedure. An MoU had been agreed between the BIPM and the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO, a committee of relevance to colleagues in acoustics and vibration). Another MoU had been agreed between the BIPM and CODATA. The CIPM had supported the plan for a Consultative Committee survey on NMI/DI plans for digital calibration certificates and engagement with the Digital SI Framework.

Several changes to membership of different parts of the Convention had been approved: NRC (Canada) had been accepted as a member of the CCRI; NSC-IM (Ukraine) and SCL (Hong Kong, China) had been accepted as observers of the CCT; Justervesenet (Norway) had been accepted as a member of the CCT; and the Gulf Association for Metrology (GULFMET) had been accepted as a full member of the JCRB; CMS/ITRI (Chinese Taipei) had joined the CCM as an Observer; NSC-IM (Ukraine) had joined several Consultative Committees – as an Observer in the CCM and CCRI, and as a Member of the CCU. The CIPM had decided that it would be appropriate for the Grand Duchy of Luxembourg to accede to the Metre Convention.

The CIPM had decided to establish a Sectorial Task Group on Climate Change and Environment; Dr del Campo, Dr Sené and Dr Duan had been appointed as the founding members to start the group. The CIPM had received the report from the CCU on the Core Metrological Terms and had noted that consensus could not be reached on the matter of three definitions (quantity, quantity value, and unit). The CIPM Task Group on the Digital SI would review the 'machine actionability' of these three definitions and would report to the CIPM at its next meeting; the next CIPM meeting was scheduled for 22-24 March 2022 and it was hoped it would be a face-to-face meeting, rather than online.

Dr Castelazo informed the meeting that the 27th meeting of the CGPM was being planned for 14-17 November 2022, in Versailles – plans were being made for both in-person and virtual attendance. In preparation for the CGPM, resolutions were being prepared concerning: evolving needs in metrology; the SI digital framework; extension of the SI range of prefixes to include the ronna (10^{27}), ronto (10^{-27}), quetta (10^{30}) and quecto (10^{-30}); a roadmap towards the redefinition of the SI second (probably in 2030 or 2034); use and future development of UTC; and universal adherence to the Metre Convention.

I-7 CCL DIGITALIZATION

Dr Lewis presented an outline of the proposed activity regarding the digitalization of the SI metre, having been asked by Dr Castelazo to chair a Task Group in this area. He welcomed the initiative by the BIPM to make the SI Brochure available electronically both as a PDF document and in machine-readable XML format. He noted that although the definition of the metre was stated in the SI Brochure, there were many critical aspects associated with the realization of the metre (both primary and secondary realizations), which were only available in the *Mise en Pratique* (MeP) documents. There was further information given in a paper by Schödel *et al.* (DOI: 10.1088/1681-

7575/ac1456). Practitioners who regularly realized the metre, for example by operating iodine-stabilized He-Ne lasers, would be aware of the information and should have been ensuring that they operate the metre realizations in accordance with the guidelines, observing the stated tolerances on *e.g.* iodine cell temperature. However, there was no automatic mechanism to ensure that any changes to the specifications in the MeP would be promulgated to the lasers in use at the NMIs. Whilst the laser frequency (wavelength) data was clearly traceable to the SI (and the decisions enacted by the CIPM), this was not necessarily the case for the metadata relating to the operation of the lasers.

Dr Lewis mentioned that Dr Panfilo would present the outcome of a survey amongst CCL members, into aspects of a digitalized metre. This contained responses to a proposal by Dr Lewis that the critical items in the MeP for the metre be made machine readable and downloadable. He showed the current length traceability chain at the level of national realizations of the metre and how there could be an electronic exchange of data between the BIPM server and equipment at the NMI when the metre realization lasers were being used. The BIPM server would be automatically queried to obtain the latest data or validate that no change had been made to previously accessed data. The data exchange could contain not only the MeP 'scientific' data, *i.e.* wavelength and frequency values, uncertainties, tolerances on critical parameters, *etc*., but also metadata relating to the authorization of the data, *e.g.* date of approval by the CIPM. Dr Lewis showed a possible format for the data exchange based on common structures then in use (XML, YAML) and noted that the scheme could offer several advantages: the digital certificate (or data on NMI server) could hold both parts of the traceability of the calibration: the physical data *and* the authority and validity metadata; there would be fewer transcription errors, and the latest values would automatically be used; the process would be fully transparent with all items being traceable (data and authority) to the SI/CIPM/CGPM *via* the NMI services; the BIPM/CIPM/SI would be 'cited' as top level in the chain; and the NMI could add its own metadata (adding value to the process, from the customer perspective); the customer could then integrate all or some of this metadata into their own process *e.g.* to demonstrate the traceability link to accreditors, or to place validity limits on their use of the laser.

The next steps would be to develop a list of items which CCL members wished to see encoded in the machine-readable data (for example, laser frequency information and details of the secondary realization of the metre) and to discuss further with the BIPM webmaster and amongst the CCL DG11 and WG-N, as well as any corresponding groups in the CCTF.

Dr Castelazo thanked Dr Lewis and noted that this area was one where the CCL was taking a lead. Dr Sawyer commented that the presentation did not match the document in the SharePoint site (a link to the mentioned paper was absent). Dr Castelazo asked that all presenters ensured that the most recent versions of the documents presented would be available on the SharePoint site by the end of the meeting **[Action A.1]**.

Dr Milton added his thanks for the work. He noted that this was the first input of this type in the Consultative Committee community. An Application Programming Interface (API) had been developed at the BIPM for accessing the KCDB and other parts of a suitable system were in development – a beta version of an API for accessing data in the time area had been developed.

Dr Bosse added that it was critical to ensure that the secondary realization based on the silicon lattice spacing was included, hence WG-N should be included in the discussion on digitalization. Dr Lewis would start discussions on critical and practical aspects of digitalizing the metre realization with the WG-N, DG11 and CCTF colleagues **[Action A.2]**.

I-8 CCL SURVEY – DIGITALIZED SI METRE

Dr Panfilo presented the outcomes from a recent survey of CCL members concerning the CIPM initiative to make relevant metrology information directly available to computer systems, commonly known as "digitalization of the SI". The survey, containing 13 questions, had been distributed to Members and Observers of the CCL by the Executive Secretary and the RMO TC-L chairs. Five questions had investigated the progress and needs inside the CCL community on digitalization transformation, four questions had looked specifically at machine readable data from the *Mise en Pratique* (as described in the previous agenda point). The responses had shown that: 92 % were aware of the digital SI initiative; 50 % had digitalization projects underway with another 29 % planning to start such activities; 79 % were planning to issue digital calibration certificates; 68 % were planning to offer online services for calibration results (web portals, databases); and 76 % would use such services if available. Regarding making the *Mise en Pratique* data available digitally, the following items had been requested by the stated percentage of respondents:

- wavelength values and uncertainties (100 %);
- date of approval (72 %);
- authority of approval (68 %);
- journal and publication references (32 %);
- other items (14 %), specifically:
    - guidelines on how to ensure traceability from *Mise en Pratique* down to end users;
    - the detailed description of the set-up used to achieve the stated wavelength value and uncertainty, as in the actual *Mise en Pratique* on the BIPM website;
    - associated parameters required to achieve accuracy, *e.g.* cell wall temperature tolerance, intracavity power.

Responding to the question on what information not already present would be needed, the following had been reported:

- in addition to the proposed API (for recommended stabilized laser frequencies) the development of a similar interface to the three guidance documents on the use of the Si lattice constant as a secondary realization of the metre in nanometrology should also be considered;
- last results (lambda, *u*, conditions, ...) of the NMI's laser(s) in comparison CCL-K11;
- the *Mise en Pratique* does not highlight sufficiently that the accuracy of the realizations based on lasers stabilized on molecule in cells depends strongly on the quality of the cell. It is proposed to add this consideration to the available information.

The survey had found several intended uses for the information which could be made available: to check if there are any updates (regularly) and download any changed data; to be integrated into a digitalized format to offer more reliable, robust and useful information for the stakeholders; to use the information in explanation/knowledge of the *Mise en Pratique* metre to society and to the metrology related community; to help to give a clear understanding of various opportunities for realization of the SI unit of the metre; to use it to confirm the *Mise en Pratique* producing the results and to prove the obtained results; to realize the definition of the metre following the set of instructions in the MeP, as an NMI, to realize and maintain standards and to disseminate the metre;

to have an absolute reference for applications like Frequency Scanning Interferometry (FSI) or wavelength meters for telecommunications; to incorporate some of the data in the calibration certificate metadata; to use for traceability and training/exposure; and to check software and to calculate corrections for calibrations.

Most respondents did not think the *Mise en Pratique* would be superseded, or not for many years. There was a need to widely agree the information and data formats. The MeP data were currently published in separate PDF documents. For an API query, the MeP information would have to be arranged in a harmonized data structure, following the FAIR (Findable, Accessible, Interoperable, Reusable) data principles. This data structure should be accessible *via* a unique ID, comparable to the DOI for publications. A cooperation with the CIPM-TG-DSI was recommended. Access to information concerning the secondary realization *Mise en Pratique* data for use in the X-ray interferometry/Silicon lattice realizations, was also needed.

Dr Castelazo noted that digitalization was becoming a reality for the metrology community and the length area was working hard to adopt this. He noted that harmonization would be key to delivering this.

Dr Balsamo commented that dimensional metrology was a good example of the interconnectedness of metrology, noting that the traceability of temperature measurements and other parameters that affect length measurement would be as important as the metre definition information.

I-9 REPORT FROM THE WG-N

Dr Yacoot, the chairman of the Working Group on Dimensional Nanometrology (WG-N) gave the presentation. He reminded the meeting of the Terms of Reference of WG-N:

> *to serve as a forum in which NMI experts in dimensional nanometrology can share their experiences, discuss standardization needs, and identify developing trends and traceability needs in dimensional nanometrology;*
>
> *to promote and rationalise the research into dimensional nanometrology, looking for improving calibration and measurement services within NMIs, so offering new accurate and traceable services as demanded by R&D Institutions, Industry and other Stakeholders;*
>
> *to coordinate (in cooperation with WG-MRA) the completion of previously agreed-upon pilot studies, supplementary, and key comparisons in dimensional nanometrology;*
>
> *to serve as a discussion and development forum for new comparison proposals in dimensional nanometrology and to make recommendations to the CCL when new comparisons are needed; and*
>
> *to serve as a CCL nanometrology contact point for relationships with other CCs and organizations outside CCL.*

Dr Yacoot reminded all of the previous meetings of WG-N which included two meetings occurring since the 2018 CCL meeting – the WG-N had met at the PTB on 17 October 2019 and also online on 4 October 2021.

Discussion Group 7 (DG7) for Nanometrology of the former CCL/WGDM had decided to perform a comparison for five different types of artefacts among interested NMIs and these had then become the pilot studies within WG-N.

- Photomask Linewidth (NANO1) Pilot: PTB/NIST, Planned 2019
- Step Heights (NANO2) Pilot: PTB, Completed 2003
- Line scales (NANO3) Pilot: PTB, Completed 2003
- 1D Gratings (NANO4) Pilot: OFMET, Completed 2001
- 2D Gratings (NANO5) Pilot: DFM, Completed 2008

Detailed planning for the NANO1 comparison had been undertaken by the pilot laboratory, PTB, and a list of participants and details of the measurement artefact were shown together with a proposed timeline; the circulation was planned to start in September 2022.

Subsequent Proposals for comparisons had included a comparison on AFM-measured silicon linewidth (NANO6) piloted by NIST for which the artefact circulation was now complete. The pilot laboratory was analysing the results and had noticed some potential issues. The pilot laboratory believed participant E had inadvertently measured a different target; this would be investigated further. Results of participant D appeared partly impacted by particles, as did the result of participant G. The pilot intended to resample data for more meaningful comparison analysis. The pilot recommended that the comparison remained classified as a pilot study, rather than as a formal CIPM MRA comparison.

The following pilot studies and RMO supplementary comparisons had also been discussed:

EURAMET project 1239 on surface roughness measurements by AFM – the comparison had been relaunched in 2018-2019 and nine European NMIs had made measurements (one had withdrawn) and control measurements had been made by the pilot laboratory, PTB, in late 2019. Closing measurements by NIST had been delayed due to COVID-19.

EURAMET.L-S28 on high precision flatness on a 330 mm diameter flat – there were five participants (including one non-NMI as an informal participant). The allocated period of 3 months for each participant's measurements had been found to be insufficient, so the circulation had been delayed slightly, with completion expected in September 2022; the Final Report was expected by the end of December 2023.

Dr Yacoot reminded the meeting that the lattice spacing of silicon had been adopted as a secondary realization of the metre in the 2019 revision of the SI. This had followed after approval had been given by the CCL in the 2018 meeting, with much work being performed within WG-N during the 2018/2019 winter period in order to meet the deadlines for the SI revision. The silicon lattice secondary realization of the metre allows three routes to be followed:

- X-ray interferometry for micro/nano displacement metrology;
- calibration of lattice-resolving TEM on crystalline silicon nanostructures by reference to the Si lattice parameter;
- step height standards based on the lattice constant.

Dr Yacoot referred to a recent publication in *Metrologia* on Algorithms for using silicon steps for scanning probe microscope evaluation (DOI: 10.1088/1681-7575/ab9ad3). The paper had been downloaded over 6200 times since it had been published one year ago – it was one of the most read papers in the history of *Metrologia*. He hoped that the algorithms could be incorporated into

the *Mise en Pratique* for the secondary realization of the metre. Dr Yacoot thought that it would be beneficial to conduct a comparison in step height standards soon, though this would require some prior preparation and characterization measurements.

Aside from the work on metre realization, there had been several activities in standardization with work in International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC) committees. Details can be found in the submitted written report.

As with WG-MRA (which associates with the MacroScale conference, when possible), the pandemic had impacted the plans for the NanoScale conference. Neither conference had been possible in 2020 and with 2021 being a CCL year, neither conference had been rescheduled for 2021. There had been an aspiration to hold a physical NanoScale conference at MIKES in 2022, however due to the proposed rearrangement of MacroScale to 2022 NanoScale had been rescheduled for 2023 but this would depend on the situation regarding travel restrictions and pandemic status in Finland and had yet to be confirmed.

Dr Yacoot confirmed that WG-N had no recommendations to make to CCL at this time.

Dr Castelazo thanked Dr Yacoot and commented on the importance of nanometrology and that it was good to see that work on the use of the silicon had continued during the pandemic. He hoped that key comparisons in nanometrology would soon be developed and that the CCL Strategic Planning document could be updated accordingly.

Dr Prieto commented that the silicon lattice was not to be regarded as one of the artefact-based techniques as used elsewhere in dimensional metrology, which used man-made objects, but was instead the use of a natural physical standard with useful properties. Dr Yacoot added the comment that this mirrored the approach of Richard Feynman, as working “from the bottom up” – counting atoms.

I-10 REPORT FROM THE WG-MRA

The chairman of the CCL Working Group on the CIPM MRA (WG-MRA) Dr Balsamo presented the report. He showed a schema of the structure of the WG-MRA indicating the tasks performed by the WG itself, and by the sub-entities (sWG-KC, sWG-CMC, TG-L). The membership of WG-MRA was confirmed; it consisted of the chair of WG-MRA, the sWG chairs, the TG on Linking, the DimVIM manager, the RMO TC-L chairs, the Discussion Group Moderators, and a small number of nominated experts. Due to retirements, the chair of sWG-CMC had passed to Dr Eves, and the chair of TG-L had passed to Dr Meli. The term of the WG chair had reached its end, but the recommendation from the WG (see WG-MRA recommendation 3) was for reappointment.

The WG-MRA had met annually with meetings on 17-18 October 2018 (PTB, Braunschweig), 7, 9, 10 October 2020 (online), and 1, 4, 5 October 2021 (online). The WG-MRA previously co-located with the MacroScale conference but planning for conferences had been (and was still) disrupted due to COVID-19. The re-arranged plan had been to host MacroScale in Pretoria in 2022 and NanoScale (possibly in Espoo) in 2023, with the WG-MRA meeting at the BIPM in 2024, together with the CCL meeting. Currently nobody knew how the pandemic would evolve; the WG was truly international, and the state of all countries should be considered when planning meetings. Hence, no hard decision had been made on the date/location of the next meetings, and this would be reconsidered in a few months’ time in cooperation with the MacroScale organisers.

The status of the length comparisons was reported. Over the preceding 3 years, 57 comparisons had been active (28 key comparisons, 29 supplementary comparisons). The current status of the active comparisons was shown.

Comparison	Topic area	Status
CCL-K1	gauge blocks (interf.)	Draft A Report
CCL-K1.n01	gauge blocks (interf.)	Planning
CCL-K3.2020	polygon	Planning
CCL-K4.2015	diameter standards	Draft B Report
CCL-K11	laser frequency	Ongoing
AFRIMETS.L-K1.2020	gauge blocks (interf.)	Running
AFRIMETS.L-S5	hand instruments	Planning
APMP.L-K1.2018	gauge blocks	Circulation ended
APMP.L-K4.n01	diameter standards	Planning
APMP.L-K5.2021	step gauge	Planning
APMP.L-K7	line scales	Executive Report
APMP.L-S5	nano particles	Executive Report
APMP.L-S7	step heights	Published
APMP.L-S9	parallel thread gauges	Planning
APMP.L-S3.4.01	angle blocks	Planning
COOMET.L-K3	plane angle	Draft B Report
COOMET.L-S14	micrometer	Executive Report
COOMET.L-S15	flatness standard	Executive Report
COOMET.L-S18	involute gears	Executive Report
COOMET.L-S20	gauge blocks (mech.)	Draft B Report
COOMET.L-S21	20 m tapes	Executive Report
COOMET.L-S22	GPS/GLONASS	Executive Report
COOMET.L-S23	range finder	Planning
COOMET.L-S24	GPS/GLONASS	Planning
COOMET.L-S25	nanometre standards	Planning
COOMET.L-S26	1D coordinates	Planning
COOMET.L-S27	end standards	Planning
COOMET.L-S28	3D surface texture	Circulation ended
COOMET.L-S29	gauge blocks	Planning
COOMET.L-S30	involute gears	Planning
COOMET.L-S31	linear scale	Planning
COOMET.L-S32	EDMs	Planning
EURAMET.L-K1.2019	gauge blocks (interf.)	Draft B Report
EURAMET.L-K1.n01	gauge blocks (interf.)	Planning
EURAMET.L-K3.2009	autocollimator	Executive Report
EURAMET.L-K3.n01	autocollimator	Planning
EURAMET.L-K4.2005.1	diameter standards	Executive Report
EURAMET.L-K4.2015	diameter standards	Published
EURAMET.L-K5.2016	step gauges	Executive Report
EURAMET.L-K7.n01	line scale	Planning
EURAMET.L-K8	surface roughness	Executive Report
EURAMET.L-K8.2020	surface roughness	Planning
EURAMET.L-S26	v-grooves	Executive Report

EURAMET.L-S26.1	v-grooves	Planning
EURAMET.L-S27	steel tapes	Circulation ended
EURAMET.L-S28	optical flat	Running
EURAMET.L-S29	stage micrometers	Running
EURAMET.L-S30	multi-step roundness	Draft B Report
GULFMET.L-S1	gauge blocks (mech.)	Circulation ended
GULFMET.L-S2	gauge blocks (interf.)	Executive Report
SIM.L-K1.2007.1	gauge blocks (interf.)	Executive Report
SIM.L-K3.2019	angle standards	Circulation ended
SIM.L-K7.2016	line scale	Circulation ended
SIM.L-S7	steel gauge blocks	Circulation ended
SIM.L-S8	long gauge blocks	Planning

Dr Balsamo noted that several comparisons were at the planning stage: CCL-K1.n01, EURAMET.L-K1.n01, CCL-K3.2020, APMP.L-K4.n01, APMP.L-K5.2021 and EURAMET.L-K7.n01.

Dr Balsamo described the work of the Task Group on Linking (TG-L). The distributed key comparison scheme raised the issue of worldwide linkage. Dimensional key comparisons (except CCL-K11) were based on artefacts, which suffer from unpredictable systematic errors and instability making numerical linkage difficult. TG-L had been appointed to deal with this issue and had identified three possible linking methods:

> **numerical**: this was mostly not suitable for dimensional KCs and had not been applied so far;
>
> **visual** (common graph): different KCRVs in different KCs; linkage was achieved when the (2-3) linking NMIs got consistent results in either KC;
>
> **distributed**: the KCRVs of different loops were influenced by each other through the linking NMIs; would be possible only for parallel loops (*e.g.* in a same KC), as modifying the results of an already finalized KC would create confusion.

TG-L had completed a linking report for the K1 (gauge blocks) topic in 2019, linking CCK-K1, EURAMET.L-K1.2011, and SIM.L-K1.2007 with pair-wise linking proven amongst the three comparisons. TG-L maintained a list of comparisons which should be linked and had updated the CCL GD-2 *Comparison scheme applied in dimensional metrology*, in 2020. An open question was still how/whether to apply the distributed linking, as this would influence previous KCs already completed.

Dr Balsamo listed the range of Guidance Documents maintained by WG-MRA on behalf of CCL (GD-7 and GD-8 were new documents):

- GD-1 Running of MRA comparisons in length metrology and monitoring their impact on CMCs, v8.0 (2020), v9.0 (2021) ready, including new coding of comparisons
- GD-2 Comparison scheme applied in dimensional metrology, v2.1 (2020)
- GD-3 Guide to preparation of Key Comparison Reports in Dimensional Metrology, v1.6 (2020)
- GD-3.1 CCL Key Comparison - Technical Protocol (template), vA.2 (1999)
- GD-3.2 CCL Key Comparison - Report (template), vA.2 (1999)

- GD-3.2b CCL Key Comparison - Report (for bilaterals, template), vA.2 (1999)
- GD-3.3 CCL Key Comparison – Executive report (template), v2 (1999)
- GD-4 Key Comparison planning, v1.53 (2021)
- GD-5 Guide to formatting CMC entries ('DimVIM Guide') and to their inter-RMO review, v3 (2020)
- GD-6 CMCs of category 'Standards of 1D point-to-point dimensions' – guidelines, v1 (2018)
- GD-7 List of Good Practice Guides and similar sources of information in Length Metrology, v0.3 (2020)
- GD-8 CMCs on frequency stabilized lasers – Guidelines, v1.0 (2020)

Length CMCs used to be reported in the KCDB as *numerical equations*, for example

u = Q[49, 0.083 L] nm = $\sqrt{(49^2 + (0.083L)^2)}$ nm, with L in millimetres

However, this was inconsistent with the format required by accreditation bodies and the new KCDB 2.0 allowed for a more correct format as *quantity equations*, for example

u = Q[49 nm, 83 × 10^{-9} L] = $\sqrt{(49\ nm)^2 + (83\ \times\ 10^{-9}\ L)^2}$

In 2018 the CCL approved the Recommendation from WG-MRA to change to quantity equations for length CMCs in the KCDB 2.0. Work had been done by the WG MRA with S. Picard to achieve this goal. A WG MRA guidance document had been drafted and submitted, then revised and approved for general use. The sWG CMC had prepared a Python programme in support, to check the conversion and sWG-CMC monitored the RMO progress on the conversion of existing CMCs. The situation in the different RMOs, with regards to conversion of CMCs, was reported.

AFRIMETS: NMISA was waiting to coordinate transition with new scope of accreditation. Egypt – surface roughness CMCs transitioned, mechanical gauge block CMC in old format.

APMP: Detailed plan created. Was following EURAMET example of NMIs reviewing CMCs of other NMIs. Expected completion date was November 2021. There were 419 CMCs in total including 171 equations which need transforming.

COOMET: No progress.

EURAMET: Completed.

GULFMET: Completed (no CMCs to convert).

SIM: Equations had been converted and minimum and maximum uncertainty values calculated for smaller NMIs. NMIs needed to check conversions and follow the transformation process. Many NMIs were not responding to the TC-L chair on this issue.

Technical issues had resulted in some of the delays, but it was hoped that the transition will be completed soon.

The WG-MRA had been discussing a revision to the coding scheme used for numbering comparisons undertaken in the CIPM MRA. The document CIPM MRA-G-11 (2021) had introduced a unified syntax for coding comparisons. The current coding incorporated the registration date in the KCDB, however some comparisons were very long and/or started long after registration, so the date mentioned in the code may not be of much interest. Supplementary Comparisons were coded with a simple sequential number; however, they may have been on a

wide range of topics, but the code does not identify the SC topic, making it difficult to identify which Supplementary Comparisons relate to which CMCs.

As a response, a new coding had been developed by the sWG CMC and had been discussed with S. Picard, in line with the CIPM MRA-G-11. In the new scheme, topics were made explicit: the DimVIM class identifier is used (first two levels), *e.g.* 2.2 for end standards (gauge blocks); for Key Comparisons only, the familiar 'K1' format was used instead, as an alias of the DimVIM class. Dates were replaced by sequential numbers, one sequence for each topic. To prevent confusion and extra work, registered comparisons that were running would not be renamed. The changeover to the new scheme was made immediately with this CCL meeting. Coding details have been included in the CCL/GD1 and were the following (items in BOLD are modified to select a new code):

BODY[.]L-K**Alias**.n**XX**[**.X**]

or

BODY[.]L-S**Class**.n**XX**[**.X**]

BODY the operator, *e.g.* Consultative Committee (CC), or specified RMO. A separating dot [.] is added to RMO names for clarity.

Alias a number representing one of the Key Comparison topic areas. Each topic area can relate to one or more DimVIM entries, *e.g.* the K3 topic includes entries 3.1.1 for optical polygons, 3.3.1 for autocollimators, and 3.4.1 for angle blocks.

Class the first two digits, *i.e.* the class, of the CCL Service Category number most representative of the supplementary comparison. The CCL Service Category numbers are defined by the DimVIM.

XX two-digit number, starting at '01', identifying the sequential ordering of comparisons. There is an independent number sequence for each operator (CC or RMO), and topic area (Alias or Class) combination.

[**.X**] Optional single digit number to indicate a subsequent bilateral or multilateral comparison.

Dr Balsamo showed some examples of using the new scheme.

The WG-MRA had also discussed updating of the Competence Matrix. The CIPM-MRA-G11 introduced the requirement of comparison protocols to *'… indicate which CMCs can be supported by the comparison, or criteria to identify such CMCs …'*. There are many Standards and CMCs in dimensional metrology and covering them all with Key Comparisons was not affordable. Key Comparisons were rather aimed at checking the principal techniques, following a so-called competence matrix reported in the CCL Strategy document. The sWG-CMC had carefully scrutinized this document and made a proposal for renewal. Some principal techniques were completely missing: time of flight; secondary realization of the metre; diffraction and imaging effects; and coordinate metrology. The WG-MRA was recommending to CCL to establish a task force consisting of A. Yacoot, A. Balsamo, B. Eves, H. Bosse, O. Kruger, and S. Bergstrand to develop a new competence matrix.

The document CIPM-D-01 "*Rules of procedure for the Consultative Committees (CCs) created by the CIPM, CC working groups and CC workshops*" indicated that the term of office [of the CC WG chair] was not more than 4 years unless reappointed officially. Dr Balsamo had been nominated by the WG-MRA in 2017 and approved shortly after by the CCL, thus his term would

expire at this CCL meeting. The outgoing chair had noted this and called for candidates prior to and during the last meeting of WG-MRA in October, but none came forward. Dr Balsamo had indicated that he was ready to stand for another term as well as step down if necessary (*e.g.* for synchronization with the 3 year CCL meeting pace). The WG MRA nominated Dr Balsamo for another term, subject to approval by the CCL.

a. Recommendations from the Working Group on the MRA

Dr Balsamo mentioned that there were three Recommendations to the CCL from WG-MRA: on the guidance document, on the task group to update the competence matrix, and the reappointment of the WG-MRA chair.

Dr Balsamo asked for clarification on the correct format for the recommendations/resolutions that came from the Working Groups. Informal items could be simply and clearly reported in the minutes; more formal items could be reported as CCL resolutions or Recommendations. There had been insufficient time before the meeting to discuss this, so he proposed showing the recommendations as worded and to discuss the correct approach with these. The wording was as follows:

RECOMMENDATION WGMRA 1 (2021)

On the Guidance Documents

The CCL WG-MRA,

recognizing the importance of the CCL Guidance Documents made publicly available through the BIPM website;
considering that comparison planning needs updating significantly more often than the usual periodicity of CCL meetings;

recommends that the CCL:

approves the amended versions of:

- GD-1 v9.0 (2021) Running of CIPM MRA comparisons in length metrology and monitoring their impact on CMCs;
    - this includes a new coding of the key and supplementary comparison names;
- GD-2 v2.1 (2020) Comparison scheme applied in dimensional metrology;
- GD-3 v1.6 (2020) Guide to preparation of Key Comparison Reports in Dimensional Metrology;
- GD-5 v3 (2020) Guide to formatting CMC entries (‘DimVIM Guide’) and to their inter-RMO review;

approves the new Guidance Documents:

- GD-7 v0.3 (2020) List of Good Practice Guides and similar sources of information in Length Metrology
- GD-8 v1.0 (2020) CMCs on frequency stabilized lasers – Guidelines

delegates

- the WG MRA for approving the current and future versions of GD-4 Key Comparison planning.

Recommendation WGMRA 2 (2021)

On the competence matrix

The CCL-WG MRA,

recognizing the importance of the competence matrix recorded in the CCL Strategy document (§ 5.3.1) as the foundation for selecting the topics of the CCL and RMO key comparisons;

in response to the requirement set in the CIPM-MRA-G11 (§ 4) to state the CMCs supported by any comparison right in its technical protocol;

recognizing that the current competence matrix is not up-to-date and requires adaptation and improvements;

having met the willingness of working at such revision of qualified members of the CCL,

recommends that the CCL:

starts the revision of the competence matrix, resulting eventually in a revision of the CCL strategy document;

appoints A. Yacoot, A. Balsamo, B. Eves, H. Bosse, O. Kruger, S. Bergstrand to a task force with the remit of preparing a revised competence matrix to submit to the WG S for approval.

Recommendation WGMRA 3 (2021)

On the chairperson of WG-MRA

The CCL-WG MRA,

considering that '*The term of office* [of a CC WG chairperson] *is not more than 4 years unless reappointed officially*.' (CIPM-D-1 § 6.5);

considering that the CCL-WG MRA nominated A. Balsamo as chairperson in its meeting in October 2017 and that the CCL approved shortly after;

having the term of its chairperson expired,

recommends that

- the CCL appoints A. Balsamo chairperson of the CCL-WG MRA for another term.

Dr Castelazo commented that the WG-MRA was a large group with a large workload. He added that Working Groups often make recommendations to the CCL and this was often in the formal format, as shown. He thought discussion would continue elsewhere but for now the recommendations were suitable in the format as presented. He asked if there were any comments on the recommendations – there were none, so he moved to accept the recommendations.

The CCL accepted recommendations WGMRA 1, WGMRA 2 and WGMRA 3, as tabled.

Dr Balsamo commented that the Task Group on updating the competence matrix had not been set up with a nominated leader. He asked if Dr Castelazo wanted to join this Task Group. Dr Castelazo

confirmed interest in joining the group but did not wish to lead it. He recommended the Task Group meets offline to decide the matter of who would be the leader/rapporteur.

II-2 REPORT FROM THE WG-S

[Taken ahead of planned schedule, from the agenda for the second session].

Dr Castelazo reported on recent work in the Working Group on Strategic Planning (WG-S). He reminded the meeting of the terms of reference of the WG-S:

> *to collect and make available information giving evidence for the continuing importance of metrology in Length;*
>
> *to collect and make freely available information from the Member NMIs of the CCL regarding long-term research and development activities in order to encourage collaboration and coordination;*
>
> *to propose long-term plans for future activities of the CCL over the next ten to fifteen years and review and update these plans on a regular basis;*
>
> *to collaborate with the CCTF to continue to establish and support optical frequency sources that are needed for dimensional metrology interferometers.*

The current list of members of the WG-S was confirmed – members were RMO TC-L chairs, the CCL President and Executive Secretary, the CCL WG and TG chairs, and a nominated expert. Several meetings of WG-S had taken place in recent years: 13 June 2018 (at the BIPM), 29 June 2020 (online), and 15 October 2021 (online). The CCL Strategy document had been finalized following the new format, after the CCL meeting in 2018. The document needed to be updated before the next CCL meeting to consider the recent trends and developments in the world of metrology (*e.g*. digitalization).

The WG-S had been involved in the discussion on the proposed CIPM strategy on the 'Evolving needs in metrology' and in the publication of the new *Mise en Pratique*.

Recent discussions in WG-S had concerned topics including: the *Metrologia* Focus Issue on Length; CMC conversion from numerical to quantity equations; requests for Member and Observer status with the CCL (a meeting of the WG and sub-WG chairs was scheduled after the end of this CCL meeting to finalize the CCL recommendation); format of future meetings (virtual format and electronic voting – the CIPM had responded that other Consultative Committees operate a less formal process, and electronic voting can be used); possible revision of CIPM-D-01 (Rules and procedures for the CCs); discussion on 'practical realization of the radian' including adding references in the Guidance Document GD-7 on *List of Good Practice Guides and similar sources of information in length metrology.*

Dr Lewis commented that NPL was close to publishing a good practice guide on Angle Metrology which should meet the need for guidance on the realization of the radian. Dr Castelazo said this would be useful and could be added to the list of Guidance Documents in GD-7. Dr Prieto (member of the CCU) commented that there was a need to extend the angle unit discussion to include angular frequency and angular speed. However, he noted that the radian was not the most used angle unit – the sexagesimal system (degrees, minutes, seconds) was the most prominent. Dr Lewis

will send a copy of the draft of the NPL Guidance Document on angles to Dr Prieto for further comments **[Action A.3]**.

SECOND SESSION, TUESDAY 26 OCTOBER

II-1 WELCOME FROM THE CCL PRESIDENT

Dr Castelazo welcomed all attendees to the second session of the 18th meeting of the CCL. He continued with the agenda.

II-3 REPORT FROM THE WGFS

The CCL chairman of the joint CCL-CCTF Working Group on Frequency Standards (WGFS), Dr Matus, presented the report. He started with the Terms of Reference of this Working Group:

> *to make recommendations to the CCL for radiations to be used for the realization of the definition of the metre and to make recommendations to the CCTF for radiations to be used as secondary representations of the second;*
>
> *to maintain, together with the BIPM, the list of recommended frequency standard values and wavelength values for applications including the practical realization of the definition of the metre and secondary representations of the second;*
>
> *to take responsibility for key comparisons of standard frequencies such as CCL-K11;*
>
> *to respond to future needs of both the CCL and CCTF concerning standard frequencies relevant to the respective communities.*

The membership of WGFS was confirmed. There were two chairs and two secretaries, one each from the CCL and CCTF.

The WGFS had met three times in recent years, on 14 June 2018 (in preparation for the 17th meeting of the CCL), on 25 February 2021 and 8 March 2021 (in preparation for the 22nd meeting of the CCTF), and 27 September 2021 (in preparation for this 18th meeting of the CCL). The report from Dr Matus would only cover items from the most recent meeting.

The recent update of the SI had triggered a need to refresh all the *Mise en Pratique* documents. Significant edits had been performed for the *Mise en Pratique* for the realization of the metre. The documents now went far beyond the simple collection of recommended laser frequencies. A paper giving further guidance had been recently published in *Metrologia* (DOI: 10.1088/1681-7575/ac1456). For the time being there were no requests to include new laser sources to the List of Recommended Radiations for the realization of the metre. However, some updating was expected for the next period. The nature of the List of Recommended Radiations made them an ideal candidate to start the topic of 'Digitalizing the SI metre', as reported under agenda item I-7 on the first day of this CCL meeting.

The WGFS had identified a need to have 'practical' (even commercial) sources for use in the realization of the metre. For inclusion in the List of Recommended Radiations, new and existing sources must be characterized. Frequency measurements could be carried out using combs on a routine basis, but results were rarely published nor collected. CCL-K11 was (contrary to the aims of the prior laser frequency comparison BIPM.L-11) not intended to provide this data. A solution to collate this data in collaboration with the BIPM should be developed and this was to be tabled in the 3rd Recommendation to CCL from the WGFS (see below).

The WGFS had taken responsibility for CCL-K11 and similar comparisons. The Technical Protocol for comparison CCL-K11 had been discussed and slightly updated. The current version was 3.2. This was the subject of WGFS Recommendation 1. Guidance document GD-8 'CMCs on frequency stabilized lasers – Guidelines' had been finalized by the WGFS and was the subject of WGFS Recommendation 2.

a. Recommendations from the Working Group on Frequency Standards

The WGFS tabled three Recommendations to the CCL.

RECOMMENDATION CCL-CCTF-WGFS 1 (2021)

On the revision of the CCL-K11 protocol

The CCL-CCTF Working Group on Frequency Standards (CCL-CCTF-WGFS),

considering that

- in 2018, the CCL requested the CCL-CCTF Working Group on Frequency Standards (CCL-CCTF-WGFS) to develop further the technical protocol for the key comparison CCL-K11;
- an update of the protocol CCL-K11 was developed, taking into account practical experience in the course of the comparison;

recommends that

- the CCL-K11 protocol document is developed further by the CCL-CCTF-WGFS;
- the CCL approves the current version of the protocol for use in the CCL-K11 key comparison of optical frequency and wavelength standards.

RECOMMENDATION CCL-CCTF-WGFS 2 (2021)

On the guidance document CCL-GD-08

The CCL-CCTF Working Group on Frequency Standards (CCL-CCTF-WGFS),

considering that

- in 2018, the CCL requested the CCL-CCTF Working Group on Frequency Standards (CCL-CCTF-WGFS) to develop further and finalize the guidance document CCL-GD-08, which describes alternative arrangements for reviewing CMCs in the laser frequency field, for approval by the CCL;

- a final version of the guidance document CCL-GD-08 was developed by the CCL-CCTF-WGFS;

recommends that

- the CCL approves the guidance document CCL-GD-08 titled 'CMCs on frequency stabilized lasers – Guidelines'.

RECOMMENDATION CCL-CCTF-WGFS 3 (2021)

On the collection of measurement data in support of recommended frequencies and uncertainties for radiations used in the practical realization of the metre

The CCL-CCTF Working Group on Frequency Standards (CCL-CCTF-WGFS),

considering that

- there is a continuing need to develop practical sources for use in the realization of the definition of the metre, both to support new measurement techniques and application areas and to replace obsolescent sources in established application areas;
- several independent examples of a given type of source must be characterized and compared to validate a recommended value and uncertainty for the frequency of the type in the list of recommended frequencies (LoR), which may then be used to establish traceability for length measurements;
- the CCL-K11 key comparison is not intended to provide data for the extension, improvement and validation of the list of recommended frequencies;
- the necessary frequency measurements can now be carried out routinely in certain laboratories using optical frequency combs, but that measurements or calibrations of a source that has already been described in the literature are rarely submitted for peer-reviewed publication;

recommends that

- the CCL encourages NMIs in continuing to support the development and characterization of new radiation sources whose stability, reliability, and simplicity of operation make them suitable as practical standards of length;
- the CCL asks those NMIs to report to the CCL-CCTF Working Group on Frequency Standards (CCL-CCTF-WGFS) the results (frequency and uncertainty) of frequency calibrations of the sources they use or are developing as standards of length;
- these reports include a description of the type of the source, of the relevant operating conditions, and of the realization of the second that was used to establish traceability of the frequency calibration, in order to facilitate subsequent analysis of possible correlated uncertainties;
- in collaboration with the BIPM, a solution will be found to collate these reports in a restricted-access area of the BIPM website.

There were no objections to the three recommendations.

The CCL accepted recommendations WGFS 1, WGFS 2 and WGFS 3, as tabled.

Dr Castelazo drew a parallel between the proposed collation of frequency data from MeP lasers and the collation of *Circular T* by the CCTF. He asked for further discussion on the implementation of WGFS 3.

Dr Lewis commented that there was current research into characterizing the spectroscopy of hydrogen cyanide ongoing in several European NMIs, as only a single published measurement from NIST existed and the CCL-CCTF-WGFS had previously indicated that multiple measurements would be required before being accepted in the List of Recommended Radiations.

Dr Panfilo commented that a secure part of the CCL website could be used to store the data. Dr Matus responded that all of the frequency data should be collected in a formatted way, to enable the digitalization efforts – it was not just uploading of a paper or document – the data needed to be formatted.

Dr Leroux commented that even unformatted calibration reports would be an improvement over the current lack of data being submitted. Over the longer term, it would be very valuable to have a more automated way of capturing the necessary data. Dr Castelazo thought that it would be good to prepare a formal Recommendation on the formatting of the data. Dr Matus commented that in the early stages, simply sending the reports would be a good start, before an agreed format was available. Dr Eves added that NMIs have unformatted historical data, which could be submitted to rapidly generate a considerable amount of data.

Dr Balsamo asked for clarification – was the intention to add new recommended frequencies to the current list. Dr Matus responded that this was the case, but there was also an intention to be able to reduce the uncertainties of *e.g.* the 633 nm radiation, by looking into the large amount of laser calibrations which had been performed but without results having been submitted to the working group in recent years. Dr Balsamo asked if the uncertainty for new radiations such as those from commercial laser suppliers would be based on statistical processing. Dr Matus reported that this would follow the existing process – the user would still need to characterize the device, by measurement using a frequency comb.

Dr Sawyer commented that calibration data may need anonymizing due to customer confidentiality, in this respect templates would be helpful. Dr Castelazo echoed that this would be useful but suggested that customers may like to help with this work if they could see a specific benefit. Dr Prieto echoed Dr Sawyer's concern regarding the use of customer data but noted that results from K11 calibrations may be of use for obtaining data for the working group. Dr Panfilo noted that only the final data for these comparisons was provided to the BIPM, not the full details of the measurements.

Dr Viliesid asked about the intrinsic standards (*e.g.* krypton lamps, free-running lasers) and asked whether it would be possible for the 633 nm iodine stabilized laser to have an uncertainty value ascribed that was applicable without the need for calibration. Such a statement would be useful for many applications. Dr Lewis cautioned that there were many reservations voiced when the working group was discussing the free-running 633 nm laser. There were likely to be more stringent reservations regarding a lower accuracy (higher uncertainty) iodine stabilized laser – it may not be possible to reach a middle ground between the full accuracy iodine stabilized laser and the free-running laser. Dr Castelazo suggested that there were similarities for the atomic clock operations in the CCTF. Dr Milton added that there were fewer caesium clocks than He-Ne lasers in the world and that applying a similar calibration model could be very complex and difficult, without much benefit.

Dr Viliesid responded to Dr Lewis, clarifying that he had referred to operating the 633 nm iodine stabilized lasers within their MeP specifications, but without calibrating them using a frequency comb, to see what level of accuracy could be achieved. Dr Castelazo moved to continue the discussion offline and proposed the formation of a small group to look into how the data for laser

frequencies should be formatted for submission to the CCL-CCTF-WGFS. Dr Lewis noted that there was a significant crossover with the digitalization task force and the data going into the review should be in the same format as end users would want to be able to download in machine-readable format. Dr Castelazo, Dr Leroux and Dr Matus, Dr Bosse and Dr Lewis asked to join the group. Dr Panfilo would also join. Dr Castelazo will contact the group after the meeting **[Action A.4]**.

II-4 KCDB

Dr Picard showed the latest information from the KCDB office. She recalled that the KCDB 2.0 had been operational since October 2019. A number of resources had been developed and were made available on the BIPM website. Several capacity building and knowledge transfer sessions had been delivered, mainly online due to the pandemic. The software had been updated and bug fixes applied. A number of improvements had been made, including the possibility to act within the CMC form, improved navigation, and the creation of an NMI management profile with read-only access. The transformation to quantity-based equations, coming from the need to align with ILAC rules, was ongoing, as previously reported in agenda item I-10 of these minutes. A total of 665 CMCs had not yet been fully transformed. It was noted that APMP was about to complete their CMC transformations and EURAMET had already completed theirs. A guidance document on how to format the equations had been made available. The KCDB office had developed an API to enable software to access CMC data in a machine-readable format. The API accesses the same database as the conventional web-based search function. The API would allow users to integrate the KCDB search in other websites, for example websites in languages other than English. It could also: generate statistics; allow for Big Data approaches; and was a precursor for the move to Digital CMCs. Beta testing of the API had been performed by METAS, PTB, VNIIM, CENAM and NRC and implementation had been concluded in June 2021. Direct access to the API was *via* the link at the bottom of the KCDB screen, after logging in.

Dr Eves asked if the API had access to more data than was available in the main web interface. Dr Picard said that only a small amount of extra data was available to the API only as limited additional data was stored (for example confidential data relating to the CMC review process). The main difference between the access routes was that the unique CMC identifier was available using the API. Dr Eves mentioned that it would be beneficial to see which CMCs were supported by what comparison evidence. The new KCDB allows direct upload and then linking to comparison reports and other support data, so supporting evidence for newer CMCs was available. But this was not the case for the 3200+ entries already in place before KCDB 2.0 had come into operation. Dr Balsamo asked if there were any statistics available concerning the queries people made using the KCDB, either *via* the website or the API. Dr Picard responded that Google Analytics was being used on the website and the data was being collected.

Ms Tan asked about the migration of the CMCs - some of the entries for traceability were missing. Dr Picard responded that these were not present in the former version, so they had not been migrated; this field was thus only required to be filled when submitting new CMCs.

II-5 JCRB MATTERS

Dr Castelazo introduced the new JCRB Secretary, Dr Werhahn who gave his report. He introduced himself as a laser spectroscopist from PTB. He had taken over the JCRB Executive Secretary role in July 2021.

There had been an update to the documents steering the CIPM MRA with three new policy ('P-series') documents being issued together with three Guidelines ('G-series'). An update to MRA-G-13 was foreseen to better align with the CMC greying out practice being used.

There were 25 887 CMCs in the database. About 1400 had been edited and published exclusively on the new KCDB 2.0 platform. The CCQM was the final area to adapt to full compatibility with the KCDB 2.0 platform. In terms of total numbers of CMCs, EURAMET had over 11 000, followed by APMP, SIM, COOMET and AFRIMETS. GULFMET had no CMCs so far. However, the length area had the fourth smallest number of CMCs compared with other unit areas. Length CMCs had mostly been stable in terms of numbers submitted each year with a rise in 2020 where three times more CMCs were submitted than usual (later Dr Bergstrand attributed this to the transformation of CMCs to the new quantity equation format). There were three length CMCs which had been greyed out and had been close to the 5-year limit; all had been resolved.

Inter-regional JCRB review of length CMCs typically takes 45 days (60 days average for all CMCs), having decreased from 140 days in the old system, however intra-regional RMO review typically takes 174 days. The number of comparisons was also shown, although Dr Werhahn stated that more detailed information was available *e.g.* as reported in section I-10 of the agenda.

II-6 REGIONAL METROLOGY ORGANIZATIONS

AFRIMETS

The report from AFRIMETS was presented by Dr Kruger. The AFRIMETS TC-L had met on 13 July 2021, the virtual meeting having been attended by nine NMIs. Topics discussed at the meeting had been comparisons, CMCs, and research and development activities. The agenda of the meeting was presented. Four CIPM MRA comparisons were reported. AFRIMETS.L-K1 (gauge blocks by interferometry) was being piloted by NMISA. A related comparison, AFRIMETS.L-S1 on mechanical calibration of gauges blocks was to be piloted by NIS. Comparison AFRIMETS.L-S5 on hand-held measuring instruments was also being piloted by NIS, with 13 NMIs participating. A former SADCMET comparison, SADCMET.L-S5 was also being run on hand-held instruments and had four separate pilot laboratories; the comparison had nine participants.

AFRIMETS had several PTB-sponsored capacity building projects underway or being planned: a workshop on laser metrology combined with EDM calibration (pending the easing of travel restrictions); a project on additive manufacturing which involved supplying 3D printers to six NMIs; a project on design, construction and training in operation of tape tunnels at two NMIs; and a planned project on calibration of levels.

NIS had submitted 18 CMCs over the last year, but these had not yet been reviewed (one of the CMCs had been noticed as being in an incorrect format). Other NMIs from Kenya, Zimbabwe,

Tanzania, and Zambia were interested in submitting CMCs. The NMISA CMCs needed reviewing and to be updated to the quantity equation format. During participation in CCL-K11, NMISA had noticed that their uncertainties needed updating – this was awaiting work at the accreditation body.

APMP

The report from APMP was presented by Dr Xue. She started by showing the status of length comparisons in APMP. She noted that there had been delays due to the COVID-19 pandemic. In total there were nine comparisons active during the period. Two comparisons had been finished (line scale, step heights), four were running (gauge blocks, step gauge, surface texture, parallel threads) and three were in the planning stages (diameter, CMM hole-plate, angle block). Additionally, two pilot studies were in the planning stage (areal roughness, EDMs).

In 2021, four sets of CMCs had entered the intra-RMO review within APMP: 20 CMCs from Singapore, four from Ukraine, two from Germany, and eight from Egypt). Due to the impact of COVID-19, some NMIs, which had originally planned to conduct on-site peer review in 2020-2021, had postponed this work. Some NMIs would conduct remote reviews in 2022. Over 200 CMCs with quantity equations had been updated and needed approval in the KCDB.

A total of five CMCs had been greyed out due to performance in comparisons; of these, four had subsequently been deleted, and the remaining CMC had been reinstated.

The transformation of CMCs to quantity equations format had started in August 2021. 13 NMIs or economies had 419 CMCs in total in the KCDB, of which 222 numerical uncertainty equations needed to be transformed. A detailed set of conversion instructions and schedule, based on the CCL MRA guidance document and EURAMET example of mutual reviews between NMIs had been formulated and provided to all members. Most NMIs had responded positively. A few NMIs had completed the transformation ahead of schedule. Common problems encountered included: the format of CMC Excel file (but Dr Xue noted that Dr Picard had provided a solution for this); how to express the same unit and two significant values in the columns for U_{max}, U_{min} and the uncertainty equations. Some NMIs' CMCs were still in mutual review, and some had just started the transformation this week due to the impact of COVID-19; a lot of work had accumulated. It was estimated that the final completion date will be delayed from November 2021 to the end of December 2021. Ms Tan raised a query concerning the CMCs from NMC A*STAR and this was clarified by Dr Xue.

Dr Prieto commented that the issue regarding the significant digit conversion/truncation required during the CMC conversion process had been solved by EURAMET TC-L, which had offered detailed guidance information to its members – he offered to make the same information available to APMP **[Action A.5]**.

COOMET

The report from COOMET was presented by Dr Kostrikov. He gave an overview of the COOMET length comparison status. The two active key comparisons, one in angle and one in diameter were at the reporting stage. Out of eleven Supplementary Comparisons, one had the Final Report approved, two were in the Draft A reporting stage, five were still running and three were being planned.

In 2021, eight CMCs from Kazstandart had entered the Intra-RMO review. New CMCs had been received from BelGIM (ten), VNIIM (two), and Kazstandart (two).

EURAMET

The report from EURAMET was presented by Dr Bergstrand. The EU's Joint Research Centre had recently joined EURAMET, which then had 38 NMIs of which 33 were members of EURAMET TC-L; there were also 71 DIs with one being a member of TC-L. NIS, NMISA, COOMET and the BIPM had Observer status with EURAMET TC-L. The EURAMET 2030 Strategy and the Partnership on Metrology responds to the strategic priorities set out in Horizon Europe, specifically: Green Deal; Digital Transformation, European industrial strategy; and Health. The strategic priorities included the new SI with associated technological developments, regulation analysis, and capacity building needs.

Since the 17th CCL meeting in 2018, TC-L had organized four annual meetings (France 2018, Germany 2019, online *via* Denmark 2020, and online *via* Montenegro 2021). The 2019 meeting was co-located with NanoScale, the CCL WG-MRA and WG-N meetings. TC-L had responded to several research calls and several NMIs were active in Joint Research Projects in the EMPIR research programme. The workload of the TC-L chair was shared with three convenors: for CMC review; for capacity building; and for research programme coordination.

The follow-on programme to EMPIR (the European Partnership in Metrology- EPM) was being finalized and expected to have several research calls: 2021-Green Deal, 2022-Health, Digital, Integrated European Metrology, 2023-Fundamental, Industry, 2024-Green Deal, Digital Transformation, 2025-Health, Integrated European Metrology, 2026-Fundamental, Industry, 2027-Green Deal. Calls for normative projects and projects developing research potential were expected each year. The calls were being opened out to countries outside EURAMET – details were available: https://msu.euramet.org/current_calls/documents/List1b.pdf

Several European Metrology Networks were being created with the objective to create sustainable structures in areas of strategic importance for the future of European metrology. Both TC-L and the Metrology Networks were considered as sustainable structures. The Network with closest relation to the work of TC-L was the Advanced Manufacturing Network, chaired by Dr Bosse.

GULFMET

The report from GULFMET was presented by Mr AlSenaidi. A map showing the members of GULFMET was presented together with the Associate members such as UME (Turkey). EMI had recently moved to a new building and together with delays due to the pandemic, the TC-L activities had been limited in the preceding year. TC-L continued to participate in RMO activities. The new chair of TC-L will be from SASO and will start in 2022.

SIM

The report from SIM was presented by Dr Bastida. Two SIM TC-L meetings had taken place since the last CCL meeting: a face-to-face meeting at IBMETRO (Bolivia) in June 2019, and an online meeting in October 2020. The 2021 TC-L meeting would also be online and is scheduled for November 2021.

Several NMIs had submitted CMC revisions: in 2016 Mexico, Peru, Brazil; in 2017 Colombia, Canada; and in 2018 Uruguay. For the comparison topics, the gauge block bilateral comparison

(SIM.L-K1.2007.1) had been published; the line scale bilateral (SIM-L-K7.2016) had reached Draft B stage; the angle comparison (SIM.L-K3.2019) was at Draft A stage; the comparison on gauge block measurements by comparison (SIM.L-S7.2019) and the comparison on long gauge blocks (SIM.L-S8) were both running.

As a result of EURAMET.L-K8 results, CENAM had decreased the scope of their CMC and INTI had greyed out the parameters Rx and Rmax. Results in comparison APMP.L-K8 had caused LATU to be invited to participate in a new comparison (it had an affected CMC).

Several research collaboration projects had been completed: Improvement and updating of interferometric systems for traceable dimensional nanometrology at SIM (CENAM, INTI, INMETRO, LACOMET, LATU); Large scale dimensional metrology (CENAM, INTI, INMETRO, INCACAL, LACOMET); and Calibration of standard reference material for use in calibrating the magnification or scale of optical microscopy and scanning electron microscopy (CENAM, INTI, INMETRO, INACAL, LACOMET).

With funding from the Inter-American Development Bank, three virtual meetings had been proposed covering: gauge calibrations; tomography; and nano scale metrology. The nano scale project had received funding – funding for the other items was being sought.

II-7 REPORTS FROM THE DISCUSSION GROUPS

The Discussion Group (DG) moderators presented short reports from their respective DGs. There was a mixture of both tabled documentary reports, and presentations.

DG1 - Gauge blocks. The report, presented by Dr Lewis, was a brief summary of the tabled formal DG1 report to the CCL. The Discussion Group sent best wishes to former DG1 members Dr Bergmans and Dr Thalmann who had left the Discussion Group since the last CCL meeting. There had been several detailed discussions on topics including: uncertainties for measurands other than central length (*e.g.* flatness, variation in length); example uncertainty budgets; auxiliary influence quantities and whether or not traceability for these from accredited laboratories was permitted; a (temporary) lack of supplier for laser tubes used with gauge block interferometers; whether mechanical measurements of gauge blocks were better for industry than interferometric measurements; and differences in interpretation of the definition of central length of gauge blocks.

A new cycle of comparisons was due to start in 2022 with CCL-K1.n01 and EURAMET.L-K1.n01. The list of publications relating to gauge blocks had been updated; it now contained 416 items. UME had reported capacity building activities in the gauge block field; NMC A*STAR had a new gauge block interferometer; and NPL reported a further sale of an NPL-Hexagon gauge block interferometer and confirmed that these were still being manufactured by Hexagon ,Telford, UK (details were available from Dr Lewis, if required).

DG2 - Thermal expansion coefficient. The report was presented by Dr Hirai and was a brief summary of the tabled formal DG2 report to the CCL. She had taken on the role in 2019. Since the previous CCL, three new members had joined DG2. There had been no change in the number of CMCs listed in the KCDB (13 CMCs from six NMIs). The most recent comparison supporting these CMCs had been in 2004 so there was a clear need for a new thermal expansion measurement comparison. In particular, low thermal expansion materials should be included in this comparison

as the development of such materials had become more active in recent years. It was noted that a supplementary comparison on thermal expansion was planned by CCT TG-ThQ, but this planned to use a temperature range from room temperature to 500 °C and was far from the scope of the CCL.

The issue raised at the previous CCL meeting regarding the difference between ITS-90 and thermodynamic temperature had now been resolved, with ISO 1 being under revision to state that the reference temperature for geometrical product specification and verification uses ITS-90 as its temperature scale. This work was being carried out by ISO/TC213/WG2 under the leadership of Dr Balsamo.

DG3 - Angle standards and equipment. The report presented by Dr Kruger was a brief summary of the tabled formal DG3 report to the CCL. Technical discussions since the last CCL meeting had focused on organizing international comparisons. A review of CMCs had indicated that the artefacts with the lowest uncertainty CMCs in the KCDB were autocollimators and rotary encoders. However further discussions had determined that rotary encoders were not well tested in intercomparisons. AIST (Japan) had proposed a pilot study on using encoders, this was now in the planning stage. For the upcoming comparisons polygons and autocollimators would be used. Some work was planned on ensuring that CMC entries and DIMVIM categories were using correct terminology, and on how to have a reference standard for level calibrations.

Discussions at CCL-WG-S about a *Mise en Pratique* for the radian had determined that this was not suitable as the radian was not a base unit. An alternative of producing a practical guide on the radian as a CCL guidance document had been proposed. This guide could also include items such as levels and determination of True North.

DG4 – Diameter standards. The report had been tabled by Dr Viliesid. Current comparisons in the area were entering the report stage and these had been discussed. NIST had proposed a comparison on measurements of piston/cylinder ensembles for deadweight pressure balances with interest expressed by six other NMIs. Other potential topics identified had been high accuracy contact and non-contact sphere measurements and the application of using different techniques and a data fusion approach.

DG5 – Step gauges. The report had been tabled by Dr Prieto. No new discussions had taken place since the last CCL meeting. The inter-RMO comparison EURAMET.L-K5.2016 had been approved, with a number of recommendations and some corrective actions. New comparisons were in the planning stage in APMP and a new comparison in EURAMET was planned as a follow up to the recently completed comparison. The main potential discussion topic for this group was the issue of instability in step gauge artefacts observed during comparisons.

DG6 – Coordinate metrology. The report had been tabled by Dr Balsamo. The abandonment of the K6 comparison topic (ball plates) over ten years ago had presented an issue for NMIs who wish to re-establish CMCs in this area. A new APMP supplementary comparison on ball plates was planned to begin in the next few years. The CMC type *Standard of 1D point-to-point dimensions* (DimVIM 2.5.1), primarily intended for CMMs had been introduced; to date no CMCs in this category had been registered in the KCDB. It was expected that DG6 would feed into the review of the competence matrix as coordinate metrology had been identified as one of the principal techniques currently missing in the competency matrix.

DG7 – Line Scales. The report had been tabled by Dr Bosse. Technical discussions had focused on planning a 2D grid plate comparison and issues of optical size metrology of structures (bidirectional optical measurements). An APMP comparison had been completed and an inter-RMO comparison EURAMET.L-K7.2021 was due to start soon. This would include two new test scales supplied by Heidenhain, as proposed 'next generation' line scale comparison artefacts, alongside more conventional scales. A separate supplementary comparison on stage micrometers was running. Other activities in support of optical CMM and optical measuring microscopes were planned. Potential topics raised within the group included improving the traceability infrastructure for optical size references, extending analysis of line scales to allow better linking, extending the capability of high precision line scale comparators, calibrations of length encoders, the use of interferometers in addition to scales in measurement and manufacturing equipment, line width and edge to edge calibration and new types of line features.

DG8 – Surface Texture. The report was presented by Dr Baker. An issue around 2D stylus measurements had been raised in the discussion group. Some laboratories used mathematical corrections for the physical size of the stylus tip. These corrections were small but could be considerable as a proportion of the measurement uncertainty. The effect of the correction was being investigated as part of comparison APMP.L-K8.2021. Lists of current and completed comparisons were presented. Suggested topics for future discussion include linking comparisons, measurement of areal parameters and how to perform intercomparisons for them, simplification of CMC listing, addition of areal parameters to the KCDB, industry needs including support for additive manufacturing, and the effect of the stylus tip correction issue mentioned earlier.

DG11 – Lasers. The report had been tabled by Dr Matus. He reported that activity in DG11 was usually very low. The recent WGFS meetings had triggered three non-comparison related discussions. Work was underway at several laboratories in the Czech Republic, Sweden, and the United Kingdom, into precision measurement of the HCN spectrum in the 1.5 μm region. The wider region covered by HCN (*cf.* C_2H_2) enabled a range of interferometry techniques for large volume dimensional metrology and in applications in the telecommunications industries. Inclusion of the HCN spectrum in the MeP would be considered in 2022.

There had been a discussion about whether improved measurements of stabilized lasers (as routinely delivered to clients requesting calibration of their laser) could justify a reduction in the associated uncertainty for MeP lasers. A counter-point to this was that reducing the uncertainty would likely have more stringent requirements on operating the lasers, which would be detrimental to their ease of operation (with no advantages to dimensional metrology as the metre realization uncertainties are typically the lowest contributions in uncertainty budgets).

A lack of available suppliers of laser tubes for laser sources used in gauge block interferometers had been a concern a few years ago. However, a new commercial supplier had started up, using staff from a former supplier, and was now commercially manufacturing these important laser tubes, so this problem had been resolved.

A total of 39 NMIs had now participated in CCL-K11, some multiple times. With a CCL repetition period having been set as 10 years, this meant around four to five laser measurements being needed each year. The report on the comparison was compiled each year by the pilot (BEV) and published in *Metrologia*. The report for 2020 was pending publication. Due to the pandemic, all work had stopped in March 2020 and only restarted in August 2021 with an anticipation that three NMIs

would take part in 2021. The work was distributed between five node laboratories supported by host laboratories. The comparison protocol had been drafted in 2007 based on the former BIPM-K10 and BIPM-K11 comparisons. Updates to both the protocol and a new guidance document on laser frequency CMCs were tabled for CCL approval.

THIRD SESSION, WEDNESDAY 27 OCTOBER

III-1 WELCOME FROM THE CCL PRESIDENT

Dr Castelazo welcomed all participants to the third session. He continued with the agenda.

III-2 ISO/TC213

Dr Balsamo presented the situation regarding a proposal, made at the previous CCL meeting to form a formal liaison with the ISO/TC 213 committee. He mentioned that ISO has a detailed and formal procedure to initiate a liaison, which requires a formal application. This is what he would describe at this meeting. He mentioned that CCL was particularly interested in the verification side of the ISO-GPS (Geometrical Product Specification) model, verifying that a specific part complies with its specification such as the tolerances state in the drawing or CAD model. The ISO-GPS also standardizes measuring instruments, their metrological characteristics, and their calibration. With measurement being essential to ISO GPS, the viewpoints of CCL and ISO are complementary.

In geometrical measurements, the definition of the measurands was not trivial; as the real geometry deviates from the nominal geometry, the definition becomes more and more complicated – it required concepts, terms and definitions, and a graphical language – the ISO-GPS fulfilled this role. The ISO-GPS was a common language for designers, production engineers and metrologists.

He foresaw several benefits of a formal liaison with ISO/TC 213: metrology was an essential part of the ISO-GPS; no manufacturing was possible without dimensional inspection; in the specification/verification duality, the measurements occur in the latter, the measurand definitions in the former; as soon as technology evolves, the ISO-GPS catches up by adding provisions; it was good for metrologists to monitor the evolution of the ISO-GPS, as it reflected new needs and trends in manufacturing; and dimensional metrologists are continually referring to ISO-GPS standards, specifically to define the measurands they are seeking. Dr Balsamo gave two examples, that of the recent discussions on ISO 1, the reference temperature for dimensional metrology; and the definitions relating to gauge block lengths in ISO 3650. In both cases, issues initially identified by CCL members had or would need to be addressed by working groups within ISO.

Dr Balsamo noted that liaisons with ISO are for legal entities – the CCL is not such an entity, but the BIPM is. In fact, the BIPM is already liaising with ISO, through other technical committees. From the viewpoint of the BIPM, the liaison would be internally allocated to the CCL, with a liaison officer to be appointed. Of the different types of liaisons permitted by ISO, the proposal was for the fullest liaison, type A, in line with the other liaisons between the BIPM and ISO. Dr Balsamo showed a completed copy of the application form that would enable the BIPM to

establish a liaison with ISO committee TC213.The form would need to be signed by the BIPM Director and then the formal application process would be followed, ending with a vote of acceptance by ISO/TC 213. Dr Balsamo suggested that a formal statement from the CCL would underpin this involvement. Dr Balsamo confirmed that he would be happy to serve as the liaison officer for the CCL/BIPM.

Dr Milton acknowledged that he had received the completed form and was prepared to sign it on behalf of the BIPM. Dr Prieto supported the proposed liaison and the appointment of Dr Balsamo as the liaison officer. He noted some subtle changes of terminology between the ISO and CCL communities and the liaison would benefit this. He asked if ISO/TC 229 in nanotechnologies would also benefit from a liaison. Dr Castelazo thanked Dr Balsamo for his long-standing work in the ISO committee. Dr Sawyer supported the liaison and mentioned areas of confusion regarding the use of uncertainties and the difference of approach in metrology laboratories and industry. He asked if the liaison would help solve these areas of potential conflict. Dr Balsamo responded that this topic was one he had been involved with for several years. He indicated that he was co-authoring a paper on this topic, which he thought would be published soon. He was the convenor of WG4, which was responsible for this topic and would be pleased to take views from the CCL to that working group. Ms Tan asked for clarification concerning the A, B and C liaison types. Dr Balsamo responded that the full details are available on the ISO website. Type B is reserved for intergovernmental organizations – this could have been used, but Type A is at the TC level and gives the most rights within ISO. Type C was a lower level with fewer rights. Dr Castelazo concluded that the form would be signed by Dr Milton and the application would then proceed through the process within ISO.

[As an aside at this point, Dr Castelazo mentioned some correspondence outside the meeting concerning a proposal by Dr Balsamo on numbering of meeting documents and asked to ensure that this was included in the minutes. This would be discussed offline within WG-S].

III-3 APPLICATIONS FOR NEW MEMBERS OR OBSERVERS (INTI, NIMT, NIS, NSC IM)

Dr Castelazo informed the meeting that the CCL had received applications to join the CCL with Observer status from INTI (Argentina), NIMT (Thailand) and NSC IM (Ukraine).

Additionally, NIS (Egypt), which was already an Observer, had applied to join as a full Member.

Dr Castelazo invited each of the applicants to make a short presentation.

INTI (Argentina)

Dr Bastida, the team leader of the optical metrology department, gave the presentation.

Due to the large size of the country, INTI's length section was spread over four sites, with work covering metre realization, materialization, and length dissemination. Current research included: developing frequency combs; stabilized solid lasers with the aim to create a green reference laser; development of software to support gauge block interferometer measurements using phase-stepping and preparation of digital calibration certificates; calibration of standards for microscopes

and scanning electron microscopes; improvements to flatness interferometry; and developing calibration methods for 2-D and 3-D instruments for complex and freeform geometries. Many of these research interests were being carried out collaboratively with other NMIs from the SIM region and most had a regional capacity building objective. Staff secondments were described. INTI had 17 current CMCs in the length area and had participated in a number of comparisons, including EURAMET.L-K4.2015, SIM.L-K7.2016, SIM.L-K1.2007.1, SIM.L-S8, SIM.L-S7, SIM.L-K3.2019, and an informal comparison with CENAM. Regional links had also been strengthened through staff placements and collaboration with other SIM NMIs.

NIMT (Thailand)

Dr Buajarern gave the presentation. NIMT, founded in 1997, had participated in the CIPM MRA since 14 October 1999 and had been a member of APMP since 31 October 2000. NIMT had 35 CMCs in the KCDB and had taken part in 29 CIPM MRA comparisons. The structure of the Dimensional Metrology Department was shown. Activities included: primary length standards, precision engineering metrology, nanometrology, wavelength standards, angle standards, surface texture, length measurements, coordinate metrology, form, line scales, diameter standards, nanotechnology, and hand tools. The laboratories had taken part in relevant CIPM MRA comparisons. NIMT maintained a primary standard iodine-stabilized 633 nm He-Ne laser and an iodine stabilized 532 nm Nd:YAG laser; the services based on the lasers were compliant with ISO 17025:2017. The length laboratory operated a modified Twyman-Green interferometer for gauge block pairwise length difference measurements; several improvements were being developed. NIMT had built an interferometric line scale calibration interferometer covering the 0 mm – 400 mm range and had transferred the relevant technology to other laboratories. A new laboratory to support the calibration of basic dimensional measuring instruments had been established. The angle laboratory takes traceability from a self-calibrating angle measuring system, and also offers measurement of straightness and squareness.

The coordinate metrology laboratory covered the use of CMMs and services to support laser trackers were under development. In the diameter standard laboratory, on-going research was being conducted into a 2D scanning method for thread measurement. The surface texture laboratory had taken part in the EURAMET.L-K8.2013 comparison and the form laboratory was taking part in the APMP.L-K4.2021 comparison. The nanometrology lab uses a SIOS NMM-1 with sub-nm accuracy and operates a pulsed laser system. A new project was underway on robot calibration in the METROLOG environment.

NSC IM (Ukraine)

Dr Kostrikov gave the presentation. The institute’s history began on 8 October 1901 under an initiative of Mendeleyev. NSC IM had contributed measurements on the speed of light in 1967. NSC IM covers four thematic areas: metrology for society, metrology for economy, fundamentals of metrology, and international relations. The national measurement standards of NSC IM included those in: time and frequency, electricity and magnetism, photometry and radiometry, ionizing radiation, thermometry, mass and related quantities, and length metrology.

NSC IM has national standards for: involute surfaces and tilt angle of tooth trace; measurement of deflections from linearity and planarity; lengths from 0.01 mm to 1000 mm; and measurements of roughness parameters. NSC IM also operates secondary length standards for: involute surfaces of

fine-module toothed wheels; spectroscopy; long lengths from 24 m to 1000 m (one of very few such facilities with CMCs); acoustic measuring instruments; length units in the range from 1 m to 50 m; measurement of plane-parallel and measures of length in the range from 0.1 mm to 100 mm; verification of measuring rings in the range from 1 mm to 100 mm; verification of grating length measures in the range from 0.001 mm to 200 mm.

NSC IM had participated in the CIPM MRA since 2003. It had taken part in two key comparisons and 21 supplementary comparisons and had 28 CMCs in the KCDB. Images of several items and facilities were shown including an outdoor range running up to 1 km.

NSC IM had been active in several EURAMET EMPIR research projects, including projects SIB60 and *GeoMetre* on surveying and long-distance metrology. NSC IM had many years of publishing experience. The *Ukrainian Metrological Journal* (UMJ) was a specialized scientific and technical edition, founded by NSC IM in 1995, first as the *Ukrainskyi Metrolohichnyi Zhurnal* (‘*Ukrainian Metrological Journal*’), and in 2017, in order to expand the geographic spread of publications and readers, an English translation was added to the title. The journal was available on the web at http://www.umj.metrology.kharkov.ua. The journal had been included in Web of Science Core Collection since July 2019. Additionally, since 2014, NSC IM has been publishing the ‘*Information Bulletin on International Metrology*’, which is published twice a year.

Under the guidance of COOMET, NSC IM has operated the biennial International Scientific and Technical Conference ‘*Metrology and measurement techniques*’, the purpose of the conference being to promote the development of metrology and to implement its achievements in research, practice and study. 138 reports had been submitted from ten countries. In terms of international activity, NSC IM had taken part in several activities in 2021: CIPM workshop on the SI units in FAIR digital data, SMSI 2021, Measurement 2021, NEWRAD 2021, IMEKO 2021; it had also taken part in meetings of the CCPR, CCT, CCTF, CCM, and CCRI.

NIS (Egypt)

Dr Terra, head of the primary length laboratory gave the presentation. He mentioned the presentation was available for viewing as a video from the CCL website. It was noted that Egypt’s history in metrology went back several thousand years, with the cubit being one of the earliest defined length units. NIS is located in Giza, approximately 3 km from the Pyramids. The length area is one of six divisions in the organization and has three departments, covering primary length standards and laser technology, secondary line and end standards, and engineering and surface metrology. An overview of the length facilities at NIS was presented. The primary length standards section included iodine stabilized He-Ne lasers, a femtosecond frequency comb system, a NIS developed laser stabilized to the two-photon transition in rubidium (Rb), systems for characterizing laser sources, and for optical fibre metrology. Also shown were a system for the calibration of laser doppler velocimeters developed at NIS, and details of geodesic baselines for EDMs and GNSS receivers. The secondary standards laboratory included systems for short and long gauge block metrology, refractometry calibrations and calibrations of polarimeters and quartz plates. The engineering and surface metrology section included equipment for the calibration of gauge blocks by comparison, a 2 m tape calibration facility, systems for 2D and 3D co-ordinate metrology, roundness, surface and angle measurement and an atomic force microscope for nanometrology. Published research highlights were shown; there had been 35 publications since the 2018 CCL meeting and over 100 publications in the last two years.

NIS reported that they had 18 CMCs in the KCDB and had participated in five length intercomparisons including: BIPM.L-K11, CCL-K11, AFRIMETS.L-S3 (NIS piloted this comparison), EURAMET L-K8, and APMP.L-K8. Further participation in AFRIMETS comparisons on gauge blocks by interferometry, hand instrument calibration and EDM calibration was planned, with NIS piloting the last two. Participation in other comparisons under CCPR but with a length-related theme on optical fibre metrology was also reported.

Dr Castelazo thanked the applicants for their presentations and mentioned that the presentations and reports were available in the meeting documents on the CCL website. He asked the CCL attendees if there were any comments or objections – there were none. He would be open to any private comments in the Zoom meeting chat. He added that a short meeting of the CCL WG-S would take place shortly after the CCL meeting ended to give their opinion on the applications.

III-4 PUBLICATIONS – METROLOGIA FOCUS ISSUE ON LENGTH METROLOGY

On behalf of the joint co-editors, Dr Lewis presented the current status of the *Metrologia* Focus Issue on Length Metrology. He and Dr Yacoot had been asked by Dr Castelazo to co-edit this special issue. The journal was applying the normal review process to papers received for this issue, and the papers were being published online immediately after completing the review. The papers would be collated into a virtual issue after the last paper had been published.

So far eight articles had been fully published:

The new mise en pratique for the metre – a review of approaches for the practical realization of traceable length metrology from 10^{-11} m to 10^{13} m
DOI : 10.1088/1681-7575/ac1456

Algorithms for using silicon steps for scanning probe microscope evaluation
DOI : 10.1088/1681-7575/ab9ad3

Uncertainty in the mutual calibration method for the traceable thickness measurement of ultra-thin oxide films
DOI : 10.1088/1681-7575/abe8c2

A novel method for simultaneous measurement of thickness, refractive index, bow, and warp of a large silicon wafer using a spectral-domain interferometer

DOI : 10.1088/1681-7575/aba16b

Choosing wavelengths and assessing blunder risk for the method of exact fractions

DOI : 10.1088/1681-7575/abd0cf

Measurement of the miscut angle in the determination of the Si lattice parameter

DOI : 10.1088/1681-7575/abef23

Precise measurement of the thickness of silicon wafers by double-sided interferometer and bilateral comparison

DOI : 10.1088/1681-7575/ac1e36

Exploring uncertainty contributions of the alignment of PTB's double ended interferometer by virtual experiments
DOI : 10.1088/1681-7575/ac2724

The editorial for the issue was in preparation and would follow after all other articles and when the issue had been closed. There were three articles which were in the review process and would likely be published. Two additional articles had just been submitted and were entering the review stage. There were three articles known to the editors as being likely to be submitted – it had been hoped they would be submitted prior to the CCL meeting in order to be able to close the issue, but they were still outstanding. As there was no hard deadline for closing the issue, the issue could be left open for a while.

Dr Yacoot and Dr Lewis would contact the authors of the outstanding articles for the *Metrologia* Focus issue to see how soon they can be submitted, or otherwise take a decision on closing the issue **[Action A.6]**.

III-5 CHAIRS AND MEMBERS OF WORKING GROUPS

Dr Castelazo showed a table of current chairs of the CCL Working Groups and the starting date of their period of office.

CCL WG-MRA	A. Balsamo	2017
CCL WG-N	A. Yacoot	2018
CCL WGFS	M. Matus	2018
CCL WGFS (CCTF side)	S. Bize	
CCL WG-MRA sWG-CMC	B. Eves	
CCL WG-MRA sWG-KC	A. Lewis	
CCL WG-MRA TG-L	F. Meli	

According to the rules, WG chairs serve a maximum of 4-year terms but can be re-elected. He welcomed the possibility to re-elect chairs as it was difficult to find people willing to undertake these appointments. The re-appointment of Dr Balsamo, nominated at WG-MRA 2021, was confirmed. Dr Balsamo confirmed that he would be happy to shorten his second term if necessary, to avoid all the WG chairs having to step down at the same time. With the ability to make decisions by email correspondence, Dr Castelazo thought it may no longer be necessary to make final decisions on end of terms at this point, as this could be discussed and agreed offline within a meeting of WG-S.

For the sWG chairs, there was no formal rule on their periods of office – this was an internal matter for the CCL. Dr Lewis added that he had performed both the WG-MRA and sWG-KC roles at the same time, as well as continuing as sWG-KC chair since Dr Balsamo took office, so he had been in this post for at least 8 years but was happy to continue.

Dr Castelazo listed the Moderators of the Discussion Groups.

DG1 – A. Lewis
DG2 – A. Hirai
DG3 – O. Kruger
DG4 – M. Viliesid

DG5 – E Prieto
DG6 – A. Balsamo
DG7 – H. Bosse
DG8 – A. Baker
DG11 – M. Matus

Dr Prieto would be retiring in 2022, so Mr Coveney had been nominated to take over as DG5 Moderator. Dr Prieto added his support for Mr Coveney, especially in light of his work on the recent K5 comparison.

Dr Prieto then thanked all of his colleagues in CCL and its Working Groups for his pleasant and productive time within the committee. He asked that CCL would welcome his colleague Mar Perez in the future.

Dr Castelazo added his gratitude to Dr Prieto and mentioned that it was time for the younger members to step up to replace the longer serving members as they retired.

Dr Castelazo added that discussion on periods for chairing would continue in WG-S **[Action A.7]**.

III-6 RECOMMENDATIONS TO THE INTERNATIONAL COMMITTEE FOR WEIGHTS AND MEASURES (CIPM)

Dr Castelazo asked Dr Lewis to show a draft recommendation that had been discussed with him overnight. The draft text was shown and discussed. Dr Castelazo recommended that early contact be made with the CCTF President; Dr Bize responded that he would make contact with Dr Dimarcq **[Action A.8]**.

RECOMMENDATION CCL 1 (2021):
On the formation of a task group on digital MEP data formats in time and length metrology

The Consultative Committee for Length (CCL),

considering that:

- there is a continuing need to develop practical sources for use in the realization of the definition of the metre;
- there is a need to compare multiple sets of data in a common format for each such source;
- no such common format exists;
- the CCL-K11 key comparison is not intended to provide such data;
- the necessary frequency measurements can now be carried out routinely using optical frequency combs;
- routine measurements of sources using combs are rarely submitted for peer-reviewed publication;
- data on the characteristics of radiation sources will form a key part of efforts to digitise the metre;

and **noting** that:

- information on new sources will be published in the List of Recommended Frequencies (LoR);

- the LoR is a joint undertaking of the CCL and the Consultative Committee for Time and Frequency (CCTF);

recommends that:

- CCL and CCTF set up a joint Task Group;
- this task group shall formulate digital-ready common formats for recording the characteristics of sources to be included in the List of Recommended Frequencies;
- this task group shall include representation from the wider CCL and CCTF membership with related interests;
- this task group shall work with the BIPM on storing this data within the BIPM website in a way that supports the forthcoming API access method;
- the group shall gather together the existing data which is not yet stored;
- this task group shall report periodically, at least annually, to CCL and CCTF, via the joint CCL CCTF Working Group on Frequency Standards (CCL-CCTF-WGFS).

The revised recommendation was approved with no objections.

III-7 ACTIONS ARISING FROM THE 18TH CCL MEETING

Dr Lewis showed the list of actions arising that was compiled during the meeting. Some corrections were proposed and duly made. The actions arising from the meeting, including these corrections are recorded in appendix L 2 of these minutes.

III-8 ANY OTHER BUSINESS

None was tabled.

III-9 DATE OF NEXT MEETING

Dr Castelazo expected that the next time the CCL would meet in-person. The next meeting will be in 2024, at the BIPM, probably in the third quarter. The exact date would be confirmed in due course.

III-10 CLOSING THE MEETING

Dr Castelazo thanked everyone for their participation. Ms Tan expressed her thanks to Dr Prieto and wished him the best for the future. She also expressed gratitude to the rapporteurs, especially Dr Lewis for having delivered this role extremely well for so long.

The CCL President closed the meeting at 13:00.

Appendix L 1.

Working documents submitted to the CCL at its 18th meeting

Open working documents of the CCL can be obtained from the BIPM website (after logging in):
https://www.bipm.org/en/committees/cc/ccl/

Documents

CCL-21-I-04	Agenda for 18th CCL meeting
CCL-21-I-05a	Report from the 2018 CCL meeting
CCL-21-I-06	Report on the 110th CIPM meeting
CCL-21-I-07.01	Digitalizing the SI metre
CCL-21-I-07.02	Digitalization survey report
CCL-21-I-08	Report from WG-N
CCL-21-I-09	Report from WG-MRA
CCL-21-II-02	Report from WG-S
CCL-21-II-03	Report from WGFS
CCL-21-II-03a	WGFS recommendations to the CCL
CCL-21-II-03b	CCL-K11 technical protocol v3.2
CCL-21-II-03c	CCL-GD-08 v1.0
CCL-21-II-06.01	Report from TC-L AFRIMETS
CCL-21-II-06.02	Report from TC-L APMP
CCL-21-II-06.03	Report from TC-L COOMET
CCL-21-II-06.05	Report from TC-L EURAMET
CCL-21-II-06.06	Report from TC-L SIM
CCL-21-II-07.01	Report from DG1
CCL-21-II-07.02	Report from DG2
CCL-21-II-07.03	Report from DG3
CCL-21-II-07.04	Report from DG4
CCL-21-II-07.05	Report from DG5
CCL-21-II-07.06	Report from DG6
CCL-21-II-07.07	Report from DG7
CCL-21-II-07.08	Report from DG8
CCL-21-II-07.11	Report from DG11
CCL-21-III-02	Liaison of CCL to ISO-TC213
CCL-21-III-03.01	CCL membership and requests to join
CCL-21-III-03.02	NIMT report to CCL (application to join CCL)
CCL-21-III-03.02a	NIMT presentation
CCL-21-III-03.03	NIS length activities
CCL-21-III-03.03a	NIS report to CCL (application to join CCL)
CCL-21-III-03.03b	Publications of NIS, Egypt
CCL-21-III-03.03c	Video copy of NIS presentation
CCL-21-III-03.04	NSC IM report to CCL (application to join CCL)
CCL-21-III-03.04a	Publications of NSC IM, Ukraine
CCL-21-III-03.05	Report of INTI to CCL (application to join CCL)
CCL-21-III-03.05a	INTI presentation
CCL-21-III-05	Report on the *Metrologia* Focus Issue
CCL-21-III-06.01	Draft recommendation from CCL

Appendix L 2.
List of actions resulting from the CCL 18th meeting

This is a list of the actions decided upon during the 18th meeting of the CCL.

No	Action	Status
A.1	All presenters to ensure that up to date versions of their presentations or working documents are supplied to Dr Panfilo for inclusion with the meeting documents online.	
A.2	Dr Lewis to discuss critical and practical aspects of digitalizing the metre realization with the WG-N (through Dr Yacoot), DG11 and CCTF colleagues, and to report to CCL within one year.	
A.3	Dr Lewis to supply a copy of the working draft of the NPL good practice guide on angle measurement to Dr Prieto.	
A.4	Dr Castelazo to contact Dr Lewis, Dr Matus, Dr Leroux, Dr Bosse, and Dr Panfilo to form a Task Group to discuss the format of laser frequency data for submission to the CCL-CCTF-WGFS, taking into account the needs of the digitalized SI metre initiative.	
A.5	Dr Prieto to share the EURAMET guidance information on converting CMCs to quantity equation (specifically the significant digits conversion rules) with Dr Xue.	
A.6	Dr Yacoot and Dr Lewis to contact the authors of the outstanding articles for the *Metrologia* Focus issue to see how soon they can be submitted, or otherwise take a decision on closing the issue.	
A.7	WG-S to continue discussions on the periodicity of sWG chair positions, and alignment of periods of office with CCL meetings or otherwise.	
A.8	Dr Bize to communicate with Dr Dimarcq regarding the recommendation to set up a task group on digital MEP data formats in time and length metrology.	