Minutes of CCT-TG-Dig meeting on 19 March 2024

12:00 – 14:00 UTC, online via Zoom

Final version

Attending:

- Jovan Bojkovski (MIRS/UL-FE/LMK Slovenia) [“JB”]
- Christof Gaiser (PTB Germany) [“CG”]
- Roberto Gavioso (INRiM Italy) [“RG”]
- Jean-Laurent Hippolyte (guest, BIPM / NPL UK) [“JLH”]
- Yasuki Kawamura (AIST / NMIJ Japan) [“YK”]
- Brenda Lam (guest, SCL Hong Kong China) [“BL”]
- Graham Machin (NPL UK) [“GM”]
- Janet Miles (guest, BIPM) [“JM”]
- Patrick Rourke (TG Chairperson, NRC Canada) [“PR”]
- Peter Saunders (MSL New Zealand) [“PS”]
- Shahin Tabandeh (MIKES Finland) [“ST”]
- Radka Veltcheva (NPL UK) [“RV”]
- Inseok Yang (KRISS South Korea) [“IY”]

Not attending:

- Ingmar Muller (PTB Germany) [“IM”]
- Mohamed Sadli (LNE-Cnam France) [“MS”]
- Howard Yoon (NIST USA) [“HY”]
- Jintao Zhang (NIM China) [“JZ”]

Action Items

1. PR to make a new draft of *MeP*-K-19D and circulate to TG members (c.f. section 1.v. below).
2. PR to look at PLTS-2000 regarding uncertainty information (c.f. section 2. below).
3. CG to discuss DCC Terms of Reference proposal with IM (c.f. section 4.iii. below).

4. PR to contact Stephane Solve to ensure online CCT-TG-Dig meetings appear on the BIPM web, and upload meeting slides and minutes there (c.f. section 4.iv. below).
5. TG members to discuss the possibility of developing temperature scale ontology data models with data modellers at their NMIs and report back at next TG meeting: GM and RV at NPL, CG at PTB (c.f. section 4.iv. below).
6. PR to make a draft of proposed Terms of Reference in the style of WGs and circulate to TG members (c.f. section 4.v. below).

1. TG status update

1.i. Welcome to new members

PR welcomed two new members to the Task Group: Howard Yoon, who will be replacing Bethany Rodman is the NIST representative; and Radka Veltcheva, who will be replacing Graham Machin as the NPL representative.

1.ii. CCT document extracted data

PR related that the ITS-90 high-temperature SPRT reference function coefficients that the TG digitized & verified have already been useful to him during creation of new software. He expressed a hope that data the TG has extracted will be similarly useful to others once the APIs have been created and made public.

PR explained that the first API has already been created and is being tested (see section 2. below). He said PLTS-2000 was done first because it is relatively simple, and ITS-90 API will be next.

1.iii. DOIs for CCT documents

PR mentioned that the BIPM expects to issue Digital Object Identifiers (DOIs) for CCT documents during 2024. JM said that it is likely to be during the second half of 2024.

1.iv. CCT document archiving, indexing and outreach recommendation

PR said that he has circulated to the TG what he expects to be the final draft of the TG's recommendation to the CCT regarding archiving, indexing and outreach for CCT documents. He explained that he intends to submit it prior to 15 April 2024 as a working document for the upcoming CCT plenary meeting.

1.v. MeP-K-19D

PR reminded the TG about the digitalized version of the *Mise en Pratique* (``*MeP*-K-19D''). He explained that the TG had been waiting for the publication of a new Johnson Noise Thermometry review article, but this has now been published. He will make a new draft version of *MeP*-K-19D as soon as possible and circulate it to the TG.

PR mentioned that CCT-WG-NCTh will be updating the relative primary radiometric thermometry annex to the *MeP*-K soon, so the new *MeP*-K-19D draft will reflect that. GM clarified that the updated annex

will add new low-uncertainty values of high-temperature fixed points that haven't been there before; the values have been accepted for publication, so will not change. GM expects to update the annex soon, perhaps this week.

PR said he intends to submit *MeP*-K-19D prior to 15 April 2024 as a working document for the upcoming CCT plenary meeting.

2. Report on testing of 1st CCT API made by BIPM

IY reported on testing the first Application Programming Interface (API) created by the BIPM for the CCT, which is for the PLTS-2000. He explained that the API has two functions: calculating the temperature to pressure conversion, and giving the list of equation coefficients. He noted that it can be accessed via a web user interface (for humans) and also directly called via the URL to return results in XML format (for machines), for now only by a few IP addresses for testing purposes. He concluded that the API mostly works, the numbers returned are correct, but there are some issues.

IY mentioned that the order of coefficients was incorrect in the XML file and the XML file did not have any style information associated with it. JM said she would look into how to fix the coefficient order.

IY also said that he created Python code to connect to the API but it did not work. JM explained that such functionality was not yet opened.

IY said that the API may work as an authoritative guide to verify individual users' codes, but is probably not suitable for real-time, in-line applications to calculate temperature, because users might be measuring & converting to temperature every 10 seconds and also may be disrupted if the BIPM API server goes down for maintenance. PR mentioned that NPL has a new "*MeP* laser" for realizing the metre, that connects to BIPM APIs, but the NPL code does not check every time; rather, it has a button to click to check and download coefficients to be then used locally. ST agreed that periodic downloading coefficients rather than using API conversion directly is best.

IY showed that there is some text in the API about uncertainties, but nothing further, and uncertainty information could be helpful to the user. JM said the API could be updated to calculate uncertainties if CCT-TG-Dig provided this information to the BIPM. IY mentioned that the API returns results to a number of decimal digits, but without uncertainty information, it is hard to know if the digits are good.

PR agreed that uncertainties would be useful, but worried that it might get complicated, especially for the ITS-90, and that it would be worse to give partial uncertainty information than none at all. PR understood the role of CCT-TG-Dig as extracting existing information from documents. CG agreed that new uncertainty information is beyond the scope of this TG, and that uncertainties are very complicated for the ITS-90. PR will look back at the PLTS-2000 to see what uncertainty information might be in the scale definition document.

PR asked why the API returned 5 decimal digits and whether that is the right precision. JM replied that this is how the API currently works and agreed that we should pay attention to it. IY proposed that if the API does not deal with uncertainty, then the API should give as many digits as possible and let users round or truncate however they want. PR and PS agreed with IY. PS said it should be up to the user to

propagate uncertainties through the equation. JM mentioned that the numbers are coded as simple floats, and PR said that this might guide on how many digits are returned.

IY thought about what "digitalization of SI" or "digitalization of ITS-90" should mean, and concluded that it would be more useful to produce a CCT-approved or CIPM-approved Python library that could be downloaded and run locally by users. PR agreed that would be useful, and asked who would make it.

JM mentioned that BIPM staff were recently told not to make APIs for the CCs, so if the CCT wants a Python library created it will be up to the CCT to make that happen. JM said they will still try to get APIs created for the already-extracted CCT-TG-Dig data, because that was already understood to be the project, but they cannot take on other coding. JM does consider extraction of digital data to still be an important part of digitalization.

3. Highlights of CIPM digital workshop & FORUM-MD

3.i. CIPM "Towards Digital Quality Infrastructure" workshop

PR reported on the CIPM workshop.

PR mentioned that the SI Digital Framework at https://si-digital-framework.org has moved into open beta testing and that the BIPM encourages everyone to test it; PR is happy to compile feedback from TG members. He related common themes from the workshop panel discussions: what value does digitalization add for stakeholders? Resources to work on digitalization are not free, so need to focus; and different formats are a challenge.

PR described predictions made at the workshop that Digital Calibration Certificates (DCCs) will change metrology like MP3s changed the music business and that in 3 years discussions will focus on the equivalent of music streaming. PR also related elements from workshop presentations: the NCSLI MII committee is mapping taxons to KCDB entries, and Fluke is trying to make a database of all models of measurement instruments in the world.

3.ii. CIPM Forum on Metrology and Digitalization (FORUM-MD) plenary meeting

PR reported on the first plenary meeting of FORUM-MD, focusing on what other CCs are doing in digitalization:

- CCTF: automation & machine-readable generation of data in continuous CCTF-K001.UTC, API access, metrological logic for SIRP.
- CCPR: harmonize KCDB quantities, bring digital SI to stakeholder data formats, digital twins for virtual NMI in space.
- CCU: support digitalization of SI Brochure, develop axiomatic system for Core Metrological Terms.
- CCQM: enable machine interaction with data sources.

- CCM: pilot study of mass comparison using DCCs to transfer & analyze results, machine-actionable comparison infrastructure, NMI digital workflow, digital seal on DCCs, digital twins for Kibble balances. PR wondered whether the CCT would want to incorporate digital elements in its future comparisons.
- CCRI: advise on SI Digital Framework, benefits & challenges of automation, reference data & semantics, digital traceability chain, benefits of AI and other new metrology.
- CCL/CCTF/BIPM: digitalized SI metre with API access to *MeP* data, NPL digital-ready *MeP* laser, resolve ambiguous CMC measurands, CMC interoperability in KCDB.

PR also mentioned the CODATA Digital Representations of Units of Measurements (DRUM) task group.

PR stated the formal decisions taken at the FORUM-MD plenary meeting: creation of WGs/TGs (coordination between CCs; coordination between RMOs; SI digital framework; metrological semantics; harmonizing DCC & DRMC; FAIR for metrology; data quality in metrology; secure & trustworthy AI) and organization of workshops (metrological traceability; complex sensor networks). PR clarified that CC digitalization representatives are guests to the FORUM-MD, not members, because they do not represent a give member NMI. PR will take part in the "coordination between CCs" FORUM-MD TG.

PR related that the FORUM-MD TG meetings are expected to take place at the end of June 2024 and the next FORUM-MD plenary meeting in March 2025 (pending BIPM availability).

4. Suggestions for new CCT-TG-Dig Terms of Reference

PR considers that the current CCT-TG-Dig objective and task related to indexing and archiving will be complete by the May 2024 CCT meeting, and that the objectives and tasks related to data extraction will be mostly complete by then. He noted that beta testing of BIPM APIs is just beginning.

PR mentioned that the TG had a few other documents that data might be extracted from, but had planned to wait until the BIPM had finished making APIs from the current documents before deciding to go further. PR commented that if the BIPM does not have resources to make further APIs for CCs, then the TG may decide not to extract any further data.

4.i. Carry-over from present ToR / philosophy

PR stated that he understands CCT-TG-Dig was created to advise and support both the BIPM and the CCT on digitalization. He mentioned his belief that the TG objective to extract data from *MeP*-K-related documents came directly from the BIPM's priorities when the TG was created 2 years ago, but that since then the BIPM's digital focus has shifted. However, PR said he still believes that it is important to support the BIPM digitalization efforts from a thermometry perspective.

PR proposed a new TG objective: "advise and support the CCT, and its Working Groups and Task Groups, on digitalization."

PR proposed a new TG objective: "advise and support the BIPM on thermometry-related aspects of the Digital SI."

PR proposed a new TG objective: “establish digital functions and guidance to ease the digital transformation of the thermometry community.” PR said that continued API work can fall under this objective, and it can cover other work as well.

PR proposed a new TG task: “provide thermometry-related digitalization guidance to the BIPM, CCT and other CCT Working Groups and Task Groups.”

PR proposed a new TG task: “identify thermometry, humidity and/or thermophysical properties data, equations, etc. to be developed into machine-accessible online functions by BIPM staff.”

JM mentioned that it has been difficult to get BIPM developer time to work on CCT-TG-Dig APIs, but that there may be resources in the NMIs to do further work on, for example, Python libraries. PR acknowledged the difficult situation of scarce BIPM resources and scarce NMI resources. JM suggested that the proposed task not be so specific, but rather that the TG can identify online functions that are needed, suggest these to the CCT and the CCT can decide how to get the work done. JM noted that the BIPM Director attends CCT meetings, so there is the possibility for the CCT to persuade the BIPM Director that the BIPM should undertake the work.

CG expressed that the TG should focus on what APIs are needed most. He noted that there are not many PLTS-2000 users, and therefore it is not a good API test case, but that an ITS-90 API will really show how useful APIs are. He suggested that if it is shown to be useful, more time can then be invested. PR agreed that the ITS-90 API is next to be made, and that it is the biggest in terms of both work and importance.

ST mentioned that he is developing new equations for non-ideality of gas mixtures and digital numerical tools for CCT-WG-Hu; they are thinking about web applications and APIs. He expressed interest in new APIs for humidity conversions. PR suggested that ST bring the new equations to CCT-TG-Dig when they are finished, and that the TG could consider whether they should be made into APIs by the BIPM in place of other data already extracted (since the BIPM does not want to take on additional API work). ST said he may be able to provide some code, and it can be discussed when it is ready, after the new equations are agreed by CCT-WG-Hu.

PR proposed a new TG task: “advise BIPM staff during the development of relevant digital functions and documents, including testing and feedback on beta versions.” PR said he intends this to apply not only to the functions that the BIPM creates for the TG, but also the general digital functions being developed by the BIPM, where these are relevant to thermometry.

GM noted that previous ToR were time-limited and specific, but new ones are broader and support all of the objectives of the CCT. GM suggested that there should be a discussion at the CCT of whether to transform this TG into a WG, since the work is too important to keep nestled within a smaller group.

4.ii. Links to other thermometry digitalization bodies

PR proposed a new TG task: “strengthen links to other thermometry digitalization bodies, for example within the RMOs.” JB & GM mentioned that EURAMET has a thermometry digitalization group, and that they are part of it.

PR said he believes that a useful role for CCT may be harmonizing and mediating between thermometry digitalization work that may be going on in pockets in different RMOs.

JM said that all RMOs have digitalization bodies, but not necessarily thermometry digitalization bodies. PR mentioned that he is unsure whether RMOs other than EURAMET have thermometry digitalization groups at the moment. PR said that CCT-TG-Dig should not connect with general RMO digitalization groups, since FORUM-MD is more natural place for that.

4.iii. Digital Calibration Certificates

RV summarized work related to DCCs taking place within RMOs such as EURAMET and SIM, and at NMIs such as PTB, NPL and CENAM, often in collaboration with large corporations.

RV proposed a new TG objective / task: "monitor recent developments of DCC in temperature area and connect them in harmonised approach." RV gave the examples of developing good practice guides for DCCs in thermometry, organized according to the classification of services in thermometry, and making instructions on how the thermometry community could use DCC schema to create DCCs.

RV proposed a new TG objective / task: "work together." RV explained that CCT-TG-Dig can have a role helping RMO TCTs work together to prevent unnecessary parallel work and develop a globally harmonized approach to thermometry DCCs. RV also suggested to work with NMI colleagues from data science teams to help develop software.

RV said that these activities can have a big impact to facilitate global participation and harmonization of DCCs, and that CCT-TG-Dig can distribute documents to the RMOs and then to NMIs.

PR agreed that the proposed tasks are important and asked who in the TG would work on them, since it could be a big job. PR said he does not have experience in this area. PR proposed that RV lead the activity. CG said that although IM is not at the meeting, IM was mainly motivated to join CCT-TG-Dig because of DCCs and would probably be happy with what RV proposed. CG agreed to talk to IM about this proposal. RV said she is happy to contribute to this activity, including working with those from PTB who have been active on DCCs.

PR expressed the desire to also have contributions to the activity from other regions, for example from APMP. IY said that he would be interested in following the progress for DCCs. PR said that he could participate, not necessarily as a representative of SIM, but just to learn more about DCCs.

4.iv. Items arising from BIPM digitalization priorities, e.g. ontological diagram(s)

JM suggested that PR upload the meeting slides, minutes, etc. to the CCT-TG-Dig meetings part of the BIPM web. PR agreed and stated that he would contact Stephane Solve to ensure that the TG meetings that have taken place online are listed on the BIPM web.

JM presented the BIPM's digitalization work to the TG, focusing on the SI Digital Framework: machine-interpretable references underpinning measurement data. She gave an example Au/Pt thermocouple CMC from PTB as handled in the SI Digital Framework, including permanent identifiers and temperatures underpinned by the SI Reference Point. She mentioned that the JCRB will discuss whether to also list which comparison underpins a given CMC.

JM demonstrated the SI Reference Point, and explained that people can link their temperature data to the permanent identifier https://si-digital-framework.org/SI/units/kelvin in order to express the units as kelvin in a machine-understandable way. She showed that the SI Reference Point knowledge base is encoded in knowledge graphs, in "TTL" file format.

JM explained the Resource Description Framework data modeling behind the knowledge graphs as sets of triples (subject, verb, object) used to build up relationships between ideas. She said that all nodes (subjects/objects) and connectors (verbs) on the knowledge graphs need permanent identifiers to be Findable, Accessible, Interoperable, and Reusable (FAIR).

JM said it would be very important to soon have a data model for the temperature scales, where, for example, the fixed points could be defined in a machine-understandable way. She suggested that it would be an interesting project for CCT-TG-Dig to develop such a data model and link to the CCT API data sets already being created. She suggested that such a project could result in combined web UI for human users, APIs for programmers, and SPARQL end point for machine-to-machine communication.

JM suggested that such work could be taken on by an NMI that has both a thermometry department and data scientists, such as PTB or NPL. CG said that this was still too abstract, and he didn't have a clear picture of the benefit, but that it could be discussed at the next TG meeting immediately preceding the CCT meeting. GM said that he wants to discuss it with Louise Wright at NPL, who is very involved in such matters.

GM asked why BIPM focused only on temperature, and not also humidity. JM replied that humidity will be there too, and asked how relative humidity is measured and expressed. ST replied that it depends on the range and technique, but the key is how to convert from one parameter to another. ST expressed a vision of the future of humidity in which an API does the work, and people could use it in connection with their own software codes. JM reiterated that humidity has not yet been listed as a quantity in the SI Reference Point, but that it will be, and she needs to talk to a humidity expert to do it. ST discussed unit expressions and how these could be made more practical. JM said she will get in touch with ST when she has questions. ST agreed and can coordinate with CCT-WG-Hu.

PR asked who will do the work to develop the suggested temperature scale ontology data models. He expressed that CCT-TG-Dig could give good feedback to whoever develops the data models, but perhaps not take on the work itself. He said that a thermometrist – data modeller pairing would need to be available to do the core work of model building, perhaps at NPL or PTB.

PR also asked about the urgency of this task, since he sees a clear present use case for the APIs but less so for the ontologies, at least for current thermometry NMIs and calibration labs. GM agreed that it is hard to see how ontologies would be used by the thermometry community at the moment. GM remarked that he may learn more when he talks to Louise Wright.

JM explained that without an ontology, we cannot currently have a machine understand what an ITS-90 temperature is, because it is not linked to anything else. But JM acknowledged that if there is not currently a use case for it, it could be done later. PR agreed that the global thermometry system is currently running alright without computers having this understanding. PR asked RV if NPL thermometry calibration clients are able to use their current DCCs without needing ontologies. RV agreed that NPL clients are able to use the DCCs, and reiterated that details and standardization of thermometry DCCs

are important for this TG to address. RV mentioned PTB's GEMIMEG-Tool. RV agreed with GM about deferring to data science colleagues.

PR asked GM and RV to discuss with an NPL data modeller and CG to discuss with a PTB data modeller and report back at the next TG meeting. PR said that his proposed general objective about digital functions (section 4.i. above) could cover this activity, so no new specific task is needed. However, he said if no specific data modeller can take it on, then it would not be a priority for the TG over the next two years. PR suggested that a better near-term focus would be establishing the ITS-90 API using existing data, since it could then form the starting point for an ontology. JM agreed that the activity may be better suited to an NMI with data modellers than as a TG task.

4.v. Open discussion about the future of the TG

PR raised the idea to ask for representatives from all other CCT WGs/TGs, since most but not all are covered in CCT-TG-Dig. He said this can be discussed at the CCT meeting.

PR returned to the idea of converting the TG into a WG, since the proposed continuing / advisory roles may be more suited to a WG. GM replied that a WG may be better than a TG, but that doesn't mean it needs to be a WG that exists for decades: perhaps address digitalization over the next 5-10 years and then the job could be finished and the WG dissolved. GM said that the TG is evolving into doing higher level work than what it was initially set up for, and that he would support it being a WG. GM remarked that he defers to what the CCT and CIPM think about this. PR agreed. PR stated that he will draft new ToR in the style of WGs and circulate to the TG members.

PR expressed that he welcomes feedback on the operation of the TG.

5. Discussion of the need for further meetings

PR explained that he had originally planned the 19 March 2024 online meeting, 22 April 2024 online meeting, then 14 May 2024 hybrid meeting to come to consensus on new proposed Terms of Reference, but that those others may not be needed, since TG members are in agreement. PR asked TG members if they still want the other meetings. CG & GM agreed to drop the April 2024 meeting, but stated that it is important to keep the May 2024 meeting since it is valuable to meet face to face in person. PR agreed.

PR queried the TG members on preferred methods of meeting. PR mentioned that some other digitalization groups meet very frequently, as much as once per month with presentations, but expressed his belief that approximately annual meetings, with most business conducted via e-mail, is more appropriate for CCT-TG-Dig. GM agreed, and suggested that in the future smaller groups within the TG may move certain tasks forward then report back to the TG, since this is done in other CCT WGs. PR agreed.

6. Any other business

No other business.