Minutes of CCT-TG-Dig meeting on 14 May 2024

11:30 – 13:30 CEST (UTC+2h), hybrid in-person at BIPM and online via Zoom

Final version

Attending:

- Jovan Bojkovski (MIRS/UL-FE/LMK Slovenia) [“JB”]
- Kin Wah Chen (guest, SCL Hong Kong China) [“KC”]
- Xiaojuan Feng (NIM China) [“XF”]
- Christof Gaiser (PTB Germany) [“CG”]
- Roberto Gavioso (INRiM Italy) [“RG”]
- Yasuki Kawamura (AIST / NMIJ Japan) [“YK”]
- Brenda Lam (guest, SCL Hong Kong China) [“BL”]
- Graham Machin (invited expert, NPL UK) [“GM”]
- Ingmar Müller (invited expert, PTB Germany) [“IM”]
- Tohru Nakano (guest, AIST / NMIJ Japan) [“TN”]
- Patrick Rourke (TG Chairperson, NRC Canada) [“PR”]
- Peter Saunders (MSL New Zealand) [“PS”]
- Mohamed Sadli (LNE-Cnam France) [“MS”]
- Stephane Solve (executive secretary, BIPM) [“SS”]
- Shahin Tabandeh (MIKES Finland) [“ST”]
- Wes Tew (guest, NIST USA) [“WT”]
- Radka Veltcheva (NPL UK) [“RV”]
- Inseok Yang (KRISS South Korea) [“IY”]

Not attending:

- Howard Yoon (NIST USA) [“HY”]

Action Items

1. PR to update the link within *MeP*-K-19D to the 2024 version of the relative primary radiometric thermometry annex, once the annex is released (c.f. section 2.1 below).

2. CG to forward RV slides to PTB data modellers for further discussion (c.f. section 3.2 below).
3. PR to request BIPM open testing access for direct calls to the APIs (c.f. section 4.1 below).
4. PR to connect ST with BIPM digitalization staff so that ST can begin testing the APIs (c.f. section 4.1 below).
5. PR or IY to relate feedback about API returned digits to the BIPM (c.f. section 4.1 below).
6. Need volunteers from the TG to review PR's additions to the *Technical Annex to the ITS-90* extracted data; to make uncertainty propagation equations for this document's data; and to digitize and check the data from the CCT-WG-CTh T-T_{90} document (c.f. section 4.3 below).
7. PR to check if BIPM already included all of the extracted data from the PLTS-2000 supplementary information in the PLTS-2000 API (c.f. section 4.3 below).
8. PR to reach out to Janet Miles at BIPM about possible modification of the BIPM workplan for API creation (c.f. section 4.3 below).
9. MS to ask presenters from the EURAMET workshop on thermometry digitalization for permission to disseminate their presentations more widely (c.f. section 5 below).

1. Welcome and review of TG activities

PR reviewed the membership of the TG, noting that WT is representing NIST at the meeting because HY is attending a different parallel meeting. PR reminded the attendees of the TG's Terms of Reference (ToR).

2. Review of the items that the TG is bringing forward to the CCT plenary

PR reminded the TG of the three items that will be brought forward to the CCT plenary for discussion and hopefully approval. PR stated that he had already uploaded these as CCT working documents more than one month before the CCT plenary meeting, but that very few other working documents had yet appeared.

2.1 MeP-K-19D

PR said the reason that this TG revised the *MeP*-K was because Janet Miles (BIPM) had indicated that the existing version is not machine-friendly, and also because some original references were placeholders. He explained that the new version is called "*MeP*-K-19D" because it has the same core scientific content as the existing 2019 version but is better digitalized. He mentioned that the document was made more machine-friendly by embedding structure information into the document by using Microsoft Word heading styles; these are maintained through export to PDF and also make the *MeP*-K more human-friendly, including being more accessible to people using screen reader software. He said that the annexes, in-line hyperlinks and references have also been cleaned up.

PR reminded the TG of the particular *MeP*-K references that were updated. He noted that the 2024 version of the *MeP*-K relative primary radiometric thermometry annex prepared by CCT-WG-NCTh is not quite ready, but should be soon; the *MeP*-K-19D link to this annex will need to be updated once the annex is released, before the new *MeP*-K becomes publicly accessible. GM replied that CCT-WG-NCTh will bring that annex forward to the CCT plenary meeting. PR also mentioned new references added relating to gas thermophysical properties, Johnson noise thermometry, and the overlap between ITS-90 and PLTS-2000.

2.2 Indexing & archiving recommendation

PR said the reason that making this recommendation was put into the TG's ToR was because the CCT has many important documents hosted on the BIPM web that should be widely and consistently used by the community, but presently it is hard for users to know when & how any given document has been changed. PR also highlighted the problem of scientific papers citing CCT documents, but the cited version of the document disappears when a new version is released. PR gave the example of the *Guide to the Realization of the ITS-90* chapter 5 (SPRTs).

GM mentioned that EURAMET publishes guides as well, and they have to deal with the same archiving issues, but may be ahead of CCT in this regard. PR invited those who are familiar with the EURAMET document approach to bring it forward to the TG. GM explained that the CCT President may be the one most familiar with what EURAMET is doing in this area.

PR recapped the archiving part of the recommendation, including the proposal for changelog entries and keeping previous document versions accessible in archival form. GM noted that the new relative primary radiometric thermometry annex does not have a changelog, but does indicate where changes were made. PR agreed, since the recommendation has not yet been adopted by the CCT, and would not be retroactive. He expressed that the Preamble of *MeP*-K-19D is essentially the same as a changelog entry for that document.

PR explained that he changed the wording of the recommendation to be less prescriptive regarding how the BIPM should host the documents. PR clarified that the TG cannot tell the BIPM what to do, but can request their support.

PR recapped the indexing part of the recommendation, highlighting that Digital Object Identifiers (DOIs) issued for CCT documents should be compatible with the archiving recommendation, and remain attached to a particular document version even as that version becomes archived.

PR also recapped the outreach part of the recommendation, which proposes a mailing list to apprise stakeholders when new or updated CCT documents have been issued. PR mentioned that mailing list messages should only be sent out once the documents have received final DOIs, and should not be sent too frequently. GM noted the strong EU GDPR regulations that prohibit sending e-mails to people unless they sign up for them. GM expressed strong support for a mailing list like this to get CCT information out to people, but said that we need to get each person's permission in order to add them to the list. PR agreed, and explained that the TG would reach out to CCT delegates, WG/TG members and RMO TCT chairs to get their approval to be added to the list. MS said this should be fine, but could be a problem if it goes further and we start adding e-mail addresses from other organizations.

PR also mentioned that it is not clear who would administer the list. If the CCT adopted the recommendation, they could request the BIPM's support for this.

GM said that the mailing list might be important also to high-level calibration labs. PR replied that the list could start with CCT people, but then on a case-by-case basis it could be brought to the attention of other organizations who could opt in if they so choose.

2.3 New Terms of Reference and possible TG-to-WG conversion

PR explained that the current CCT-TG-Dig ToR are mostly complete, except that beta testing is just beginning. He said that since there is still more to do in thermometry digitalization, the TG has drafted new proposed ToR. He listed the proposed tasks, and said that since they are more focused on advising and supporting the CCT and BIPM on an on-going basis, the TG had previously suggested that conversion to a WG would be appropriate.

PR clarified that he intended the proposed task to "advise BIPM staff during the development and testing of digital functions and documents relevant to the CCT" to cover both functions that CCT asks the BIPM to make for the CCT, and functions the BIPM makes on their own that relate to CCT subject areas.

PR also clarified that the "identify" wording in the proposed task "identify digital functions, data and guidance that would benefit the CCT and broader thermometry community" was carefully chosen to be non-directive to the BIPM. He explained that the TG's job would be to identify useful functions (such as further APIs, ontologies / data models, etc.), but not prescribe who implements them; for example, the CCT could request the BIPM's support on a case-by-case basis.

PR mentioned that some other CCs do not have specific digitalization groups, but those that do are all TGs, not WGs.

3. Reports on discussions with data modellers

3.1. NPL (R. Veltcheva & G. Machin)

RV related her discussions with the NPL data science team about the existing SI Digital Framework and eventual data model of the ITS-90. She explained that the SI Digital Framework has the SI Reference Point and KCDB CMCs that can be retrieved in XML format and included in Digital Calibration Certificates (DCCs). She also mentioned that this could be used to make DOIs for Key Comparisons, and from there DOIs for ITS-90 fixed points, which can feed into DCCs for SPRT calibrations at those fixed points, and eventually into DCCs for industrial thermometer calibrations. RV explained that the main action for thermometrists is to explain how the ITS-90 works to the data modellers, then the data modellers can create the ontology.

PR asked how willing the data modellers are to undertake this work, and on what time scale. RV replied that the NPL data modellers, including the head of the data science team, are very interested to do this work. On topic of time scale, RV mentioned that the best person to do this would be Jean-Laurent Hippolyte, who is currently on secondment from NPL to BIPM; and the NPL data science team cannot

take on anything new this year, but that next year they expect to have a digital-related project within which they could do the work.

PR thanked RV for making initial contact with the NPL data science team, and suggested getting back in touch with them a year later, once they have the new project running.

3.2. PTB (I. Müller & C. Gaiser)

CG related that the discussions at PTB were not as optimistic as those at NPL. He explained that the data modellers at PTB are also interested in ontologies, but were not able explain what a temperature scale ontology would mean. CG suggested he could send RV's slides (section 3.1) to the head PTB data modeller. CG expressed his opinion that he is not really convinced about the usefulness of such ontologies.

PR asked what would be the benefit of an ontology (machine understanding) if the mechanistic digital traceability chain linkages (DOIs, as per RV's presentation in section 3.1) are already sufficient to make DCCs without computers needing to understand why and how the ITS-90 works. CG replied that a more logical approach might be to start with DCCs and see if there is a need for an ontology.

ST mentioned that ontologies are needed for thermometry applications in other fields, like sensor networks. ST defined ontologies as enchaining the relationships into a common language that can interoperate with other things, so that machines can understand temperature as we understand temperature (beyond the metrology community).

CG said that it is very hard to explain temperature to people, especially the difference between thermodynamic temperature and ITS-90 temperature, so would be even more difficult to explain to a machine. CG suggested to start first with small parts, as RV showed for SPRT calibrations in her presentation (section 3.1). RV reiterated that her presentation was just a simple example of traceability, and there is more to thermometry. ST emphasized the importance of interoperability, including outside the lab.

XF agreed with CG, and related the demand in China for a digital registry of all thermometers, which includes all history of their calibrations (including by various labs). XF reiterated that explaining temperature to a machine would be very difficult, and the TG should focus on things that would be practically helpful to humans, not machines. XF raised the idea that these developments should come in collaboration between CCT, BIPM, IEC, ISO, etc.

PR expressed that the key thing is time scale, and that there are near-term needs like those mentioned by XF. He also said that eventually there will be a world of autonomous sensor networks that will need to interpret temperature without the help of a human metrologist, but the time scale of that need is different.

PR requested that RV remain connected to the data modellers at NPL, and to undertake further conversations with that team once they have the new digital project in place. CG will also bring RV's slides to the PTB data modellers for further discussion. ST gave CG contacts at PTB who are already working in the area of ontologies.

PR observed that ST is knowledgeable about ontologies and encouraged him to be further involved. ST mentioned that he is representing CCT-WG-Hu on CCT-TG-Dig; but PR encouraged all TG members to

share any relevant expertise with the group. ST related that there is a European project on sensor networks, so he may be able to bring information back to the TG from that.

4. CCT APIs

4.1. Report on testing of PLTS-2000 API (I. Yang)

IY gave a report on his testing of the PLTS-2000 API created by the BIPM, updated since his report at the last CCT-TG-Dig meeting. He related that the returned coefficients are now in the correct order and also include the coefficient names. He also mentioned that the API now also gives new arrays: Table 1 from the PLTS-2000 Supplementary Information; and tables of T_{2000}, p, and $\mathrm{d}p/\mathrm{d}T_{2000}$ over different temperature ranges in various intervals. He explained that these seem to be working properly.

IY said that testing of the real API calls (via, e.g., Python, rather than only the web application) is important, but is currently blocked by the BIPM.

PR expressed his surprise that BIPM has starting building the PLTS-2000 Supplementary Information into the API. PR asked if the new tables are in the PLTS-2000 and who decided to put them into the API. IY said they are not explicitly in the scale, but can be generated from the function. IY guessed that the BIPM programmer might have been trying to show what is possible. PR mentioned that he had asked the BIPM to stop adding new API functionality until after this CCT-TG-Dig meeting, since the TG will discuss next priority order, and that he had planned to suggest de-emphasizing the PLTS-2000 Supplementary Information.

ST asked how the testing was performed. IY explained that he entered numbers into the web calculator, and compared it to his Excel version. ST suggested putting in complex numbers, or other non-expected inputs, to see what the algorithm will do. PR suggested that ST could get involved in the API testing. ST agreed, and PR said he would connect ST to the BIPM staff for this. PR said that more volunteers for API testing would be welcome.

PR asked IY about the number returned digits from the API, because at the previous CCT-TG-Dig meeting it was decided that more digits should be returned from the function. IY said this has not changed. PR said that would be useful feedback to the BIPM. CG noted that the coefficients are returned with the complete number of digits, it is only the function output that is given with few digits.

4.2. Report on testing of ITS-90 API (P. Saunders & Y. Kawamura)

PS expressed his regret at not being able attend in person at the BIPM. PR said he was grateful that there was at least a hybrid option.

PS gave a report on the initial testing of the ITS-90 API performed by himself and YK. He related that all API calls except for one passed the test in terms of correct numbers, but that almost all of them had small details that should be fixed. He described that the BIPM had combined numerous requested functions into a smaller number of API functions. He suggested some should be further combined (W_r above and below TPW could be combined; and A_i, B_i, C_i and D_i coefficient calls could be combined) and some should be uncombined (T_{90}, $\mathrm{d}T/\mathrm{d}p$ and $\mathrm{d}T/\mathrm{d}I$ at the fixed points).

PS reviewed the API functions individually:

1. "SPRT requirements" is straightforward, but description could be written more clearly, and decimal points should be used instead of commas in the description. YK suggested some logic to check if multiple criteria are satisfied, but PS pointed out that this is not needed because ITS-90 only needs one to be satisfied. PR said the API title is not obvious. PS agreed, and said many API functions similarly need better titles and descriptions.

2. "Fixed point relative temperature" is confusing because it does three different things, and also the name is confusing (why "relative"). There are typographical errors in the title, description, and json file. The json file doesn't specify which of the three possibilities were returned, but this would not be a problem if it was split into three separate functions.

3. "$p - T$ relation of e-H_2" numbers are correct but pressure limits are incorrect (these were incorrect in CCT-TG-Dig file sent to BIPM staff), so the function could return values that are out of range. Having the equation number as a function call argument is strange – PS suggests it could be changed to "low" or "high". Numbers in the description also always need units.

4. "$T_{90} - W_r$ relation (above 273.15 K)" returning W_r was initially incorrect, but YK provided feedback to BIPM staff and it has since been fixed. Title and description are also unclear.

5. "Returns the list of C or D coefficients" title could be improved. "C" and "D" input strings are case sensitive here, but not in other functions. PR expressed that this is one of the more useful functions, so that people don't need to query the BIPM server for every ITS-90 temperature evaluation but can get the coefficients to do it locally.

6. "$T_{90} - W_r$ relation (below 273.16 K)" has same feedback as 4. above. PS suggests that 4. and 6. should be combined into a single function, with slight problem of the overlap between the low and high ranges of the reference function. PS suggests switching to the high-temperature range at TPW, not 0 degrees C. PR asked how close the two functions are in the overlap range. PS answered that he checked and they are very close.

7. "Returns the list of A or B coefficients" PS suggests to combine with 5.

8. "Vapour pressure calculate" has description typographical errors. More seriously, need to define allowed pressure ranges on the input values because the function is not monotonic.

9. "Vapour pressure coefficients" are fine.

PS summarized that the API covers most of what is in the *Metrologia* ITS-90 paper.

PS related YK's query about how to represent units in the output file, since currently no units are provided in the digital data. PS said that the output can be unambiguous even without units if each function only returns one thing, but that we should think about the issue of units in general for all APIs. PR mentioned the BIPM's Digital SI Reference Point, and raised the idea of the APIs linking into that to ensure units are digitally defined. IY said that the PLTS-2000 API outputs have the units in the name (separated by underscore), but this is not consistent in ITS-90 API. IY said it should be consistent across all APIs. GM said that metrologists are the ones who care about units, so we should make sure they are included in order to be completely unambiguous. PS and PR agreed.

PS reiterated that the English writing in the APIs should be tidied up, and the logic of the API calls could be improved.

PS also suggested additional API calls related to the ITS-90 that might be useful: calculating deviation function coefficients from input calibration data; and propagating uncertainties through the calibration equations, which would be done automatically done if GTC was included in the code. PR recalled that Janet Miles was not too interested in GTC in earlier conversations, but it could be raised again. PR also noted that there would need to be a disclaimer that such uncertainties propagated through the equations were not a complete uncertainty budget, because there are other complicated uncertainty components too. PS agreed. PR recalled that the TG previously decided to not derive uncertainty propagation for everything, but it could be useful if GTC did it automatically.

PR thanked IY, PS, and YK for their detailed testing, emphasizing that this testing is extremely important, and that the TG will need to be very certain that the APIs are correct before they go live to the public.

4.3. Discuss API creation priorities and possibility to swap in other documents

PR reminded that, as described in the Report of the 30th CCT plenary meeting, the main reason CCT-TG-Dig was created was to identify data from CCT documents for digital API creation. He explained that the push for this came from the BIPM Director and BIPM staff, but that at the March 2024 CCT-TG-Dig meeting, Janet Miles of the BIPM apprised the TG that BIPM staff have received new direction to no longer make APIs for the CCs. He recalled, however, that Janet Miles said the BIPM would finish API creation for the data that CCT-TG-Dig has already extracted.

PR proposed that the TG consider the priority order for API creation, including possibly swapping out some data that was already extracted so the BIPM could make APIs for more important CCT data. PR expressed that an API for T-T_{90} and conversions between T and T_{90} would be very useful, and that the reason this data was not extracted in the first batch was that CCT-WG-CTh had not yet finished revising the T-T_{90} consensus estimate when the TG began its work. PR recalled the suggestion of ST that an API for humidity functions would also be useful.

PR suggested that the *Technical Annex to the ITS-90* could be a high priority, but he requested a volunteer from the TG to review the edits PR made to this document after IY and CG had already finished their work (for example, PR's uncertainty interpretation). PR said he would like this review to take place before the BIPM makes the API for the *Technical Annex*. He expressed that the *Technical Annex* equations would benefit from a TG member making explicit uncertainty propagation equations (if BIPM cannot use GTC), since in this particular case the API would not be very useful without them.

PR suggested that the next immediate BIPM API creation priority should be the data from the *Uncertainty estimation in primary radiometric temperature measurement* annex, since that extracted data is already final. He stated that the BIPM should not make APIs from the *Technical Annex to the ITS-90* data or *Relative primary radiometry thermometry* annex data until those have been updated.

PR expressed a desire to swap out the previously-extracted acoustic gas thermometry data and PLTS-2000 supplementary information, so that the BIPM could make an API for the T-T_{90} consensus estimate (and conversions between T and T_{90} etc.) and an API for humidity functions instead, as these should be more immediately useful to the thermometry community. But PR noted that, as per IY's report, the PLTS-2000 supplementary information data has already been added to the PLTS-2000 API. IY clarified

that it was only one table. PR replied that the TG should check how much of the PLTS-2000 supplementary information has not yet been added to the API; if a significant amount remains, the TG could ask the BIPM to stop adding that and swap other document data into the API work plan instead.

GM commented that the T-T_{90} consensus estimates and conversions from T_{90} to T are very important, including for climate-related applications. PR agreed and replied that the T-T_{90} consensus estimate document would have surely been included by the TG in the original data extraction exercise if it had not been under revision by CCT-WG-CTh at that time. CG noted that above 335 K there is no function for $u(T\text{-}T_{90})$, only values at specific points, so this should be discussed.

GM asked what RG & PR think of swapping out the AGT data, since work was already done to extract and validate that data. RG said he is fine with this, the extracted data being mostly related to sensitivities to gas impurities. PR explained that while he is upset about the wasted effort, he believes it is more important to make an API from the T-T_{90} document; the AGT data files will remain and could possibly be used in the future. GM suggested that the TG first ask BIPM if they could do one extra API, with a swap out as a backup option.

PR asked ST about the time frame for humidity equations. ST replied that the equations (and 200 pages of documentation) are finished, and will be discussed at the CCT-WG-Hu meeting on 15 May 2024. ST suggested that he could help the BIPM with programming. PR agreed that the humidity functions would be useful.

PR said that he will reach out to Janet Miles at BIPM about possible modifications to the BIPM work plan for CCT APIs. PR encouraged new members of the TG who did not participate in the first round of data extraction & validation to take the lead for the new data tasks.

ST raised the possibility of APIs giving derivatives of functions, or even server-side Monte Carlo simulations, in order to give users uncertainty information. PR suggested that ST bring this up with BIPM staff during the testing process, and reminded about GUM Tree Calculator (GTC) that was mentioned by PS.

5. Discussion on next steps for CCT-TG-Dig

PR looked ahead to the new TG Terms of Reference, and asked for volunteers to liaise with other bodies active in thermometry digitalization. ST, IM and RV are also members of the EURAMET thermometry digitalization TG; PR asked them to act as more formal ambassadors from CCT-TG-Dig to that TG. PR would like them to give a short report on this at every CCT-TG-Dig meeting. PS noted that APMP has a digitalization focus group led by Blair Hall of MSL, so PS can communicate with him and relay relevant information back to CCT-TG-Dig.

PR asked RV and IM to lead the DCC monitoring activity within the TG, and give a short report on this at every CCT-TG-Dig meeting. RV agreed.

IM relayed to the TG that in the CCT-K11 key comparison on body temperature, the European participants decided to use DCCs for data exchange, and use the PTB Digital Metrological Expert software to do the KC data evaluation. He said this will be presented at the IMEKO congress this year. He

also related that the German accreditation body has technical committees that write reports with “ref types” and an additional technical committee that harmonizes the “ref types” across metrology areas; these will be used in the CCT-K11 comparison DCC templates. PR related that CCM is now doing a comparison that completely uses DCCs to exchange data, and he was interested to learn that CCT is starting to go in this direction too.

IM mentioned that the EURAMET thermometry digitalization group had held a workshop on DCCs, with presentations from NPL, PTB and SMD. MS said that every year EURAMET has a workshop, with topic chosen based on current interest; this workshop was focused on practical aspects of digital workflows. He said that the presentations will be available for EURAMET people, but he can ask the presenters if they could be more widely disseminated.

PR recalled that CCT-WG-CTh will meet next in October 2025 at TEMPMEKO 2025, and suggested that CCT-TG-Dig can similarly set its next formal meeting at that same time. He said that in the meantime the TG can conduct its business primarily by e-mail, but that he was not opposed to scheduling additional virtual meetings about particular topics if warranted. MS noted that TEMPMEKO 2025 will have one day set aside for WG/TG meetings.

PR reminded that he is the CCT representative to the CIPM Forum on Metrology and Digitalization (FORUM-MD) and that he intends to bring useful information from FORUM-MD back to CCT-TG-Dig, rather than directly to the CCT (at least between CCT plenary meetings).

GM suggested PR apprise the CCT President ahead of the CCT plenary meeting about the request to convert the TG into a WG. PR replied that he has been in touch with the CCT president about all of the things CCT-TG-Dig will bring forward to the CCT plenary, but will draw her attention specifically to the TG-to-WG conversion at the CCT-WG-SP meeting on 15 May 2024.

6. Any other business

No other business.