TASK GROUP: Guides on Thermometry, Report to the CCT: May 2017

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Terms of reference:

To promote good thermometry practice and traceability to the SI by preparing and publishing guides on thermometry, with a focus on secondary thermometry. The guides should include techniques, thermometers, instrumentation, and uncertainty analyses for traceable temperature measurements.

Tasks:

- Revise and replace the BIPM publication *Techniques for Approximating the ITS-90* (the Bluebook).
- Maintain a list of temperatures and uncertainties for secondary fixed points.
- Revise the CCT/08-19rev, the guide on Uncertainty in the SPRT subranges of ITS-90.

1. Introduction

During this term, the attention of the task group has been focussed on the preparation of the guides on secondary thermometry, with substantial progress made on the Guide to Specialised Fixed Points and two thermocouple guides. Otherwise, the Task Group's activities have been light, especially with a major commitment of key members to other activities and working groups.

2. Membership

For the purposes of the preparation of the uncertainty guides, the working group has co-opted the following expert members:

For the guide on reference thermocouples:
Ferdouse Jahan (NMIA)
Karen Garrity (NIST)
Hideki Ogura (NMIJ)
Emile Webster (MSL).

For the guide on calibration media:
Davor Zvizdic (HMI).

For the Guide on Industrial Platinum Resistance Thermometry
Steffen Rudtsch (PTB).

3. Task Group Meeting, Zakopane, July 1 2016

Members attending: Rod White, Frank Edler, Steffen Rudtsch, Dolores del Campo, Kim YongGyoo, Stanislaw Duris, Peter Pavlachek, Edgar Mendez-Lango, Sun Jianping, Ferdouse Jahan, Hideki Ogura

Jonathan Pearce, Lugi Iacomini, Murat Kalemci, Davor Zvizdic.

This was the first meeting of the task group so the first issues discussed related to the rules of the operation of the group.

Firstly, we needed to be clear about the target audience for the guides. We concluded:

Purpose of guides: Primarily to guide the harmonisation of measurement, calibration, and uncertainty practice. The primary audience includes NMIs and secondary laboratories, and other participants in comparisons and proficiency tests. The secondary audience is the wider measurement community for the purposes of general education, but they are not why we write the guides.

Secondly, there had been questions and concerns in both the previous working groups (CCT-WG2 and CCT-WG3) about the authorship of CCT documents, and assigning authorship could be difficult when documents took time to develop and the authorship could be fluid. Named authorship was seen to be essential because it is the primary means for individuals to have their contributions recognised within their parent organisations. We agreed:

Authorship of the guides: All named authors are expected to make a significant or important contribution. Reviews and occasional corrections or additions of references is not enough, there must be a useful contribution to the content or structure of the guide. The chairman is to make any final judgement, if required, but we should make sure that the main authors' contributions are not unduly diluted or devalued.

Thirdly, given the increasing workload of all NMI staff in recent years and the need to get the guides online in a reasonable time, we agreed that we would focus most of our efforts on a maximum of three guides at one time. That is, limited time would be committed to planning future guides.

Fourthly, Rod White indicated that he would probably not be attending future CCT meetings, and therefore would not be available to chair meetings of the task group during the week of the CCT, and perhaps we should seek a new chairman to take over after CCT-2017. After some discussion at the meeting and subsequently with President of the CCT, Rod agreed to continue in the role.

4. Task 1: Preparation of the Guides on Thermometry

4.1 Guide on Thermistor Thermometry

The guide is on the BIPM website with most recent revision dated August 2014. Already, there is new material that could usefully be added.

4.2 Guide on Specialised Fixed Points above 0 °C

The guide has now been reviewed by the CCT for a second time, and Frank Edler has made the final revisions following comments, primarily from PTB and NMIJ. The guide is now with Susanne Picard for the final formatting, editing, and checking of copyrights. It should be online shortly.

4.3 Guides on Thermocouples

The guide on thermocouple thermometry inherited from the old CCT Working Group 2 was already in an advanced state, but completion was interrupted by urgent requests for a guide covering reference

thermocouples to support international comparisons and accreditation of thermocouple calibration capabilities. The issue was a lack of harmonisation in the calibration states of thermocouples and the conditions of calibrations. The differences can lead to errors in use comparable with reported uncertainties, and few calibration laboratories and users seem to be aware of the problems. After some discussion, the decision was made to continue with two separate guides:

- General thermocouple thermometry, based very much on the most recent draft of the WG2 Guide providing guidance on the operating principles, sources of error, construction, installation, and use of all types of thermocouples. This guide will discuss the utility of calibrations in different situations, but would not include detailed description of calibration procedures and uncertainty analyses.
- Reference thermocouple thermometry, providing additional detail for the sources of error, construction, and calibration of thermocouples used as reference thermometers (primarily Types R, S, B, Au/Pt, Pt/Pd, other noble-metal couples). This document will describe calibration procedures in detail and give examples of uncertainty analyses.

The first of the guides is substantially complete, but further work needs to be done on the second guide to ensure that the separation of tutorial material (general guide) and expert material (reference thermocouples) between the two guides is both complete and appropriate. It is hoped that the general guide will be circulated to the CCT before the end of 2017, and the reference thermocouple guide will follow soon afterwards.

4.4 Guide on Industrial Platinum Resistance Thermometry

This is another guide commenced under CCT-WG 2. Dr Yamazawa (NMIJ) had collated material to be incorporated into the guide, but has changed jobs and is no longer available to contribute. Jonathon Pearce (NPL) has volunteered to be lead author and take over where Dr Yamazawa finished. Now that the guide on specialised fixed points is nearing publication, preparation of this guide will become a priority for the task group.

4.5 Guide on Calibration media

Calibration media is another area where guidance on the measurement and evaluation of the various performance measures for calibration media would be very helpful. Possible topics (not necessarily in this order) include design principles, temperature control, fluid baths, furnaces, cryostats, heatpipes, multi-entry fixed points, dry blocks, fluidised beds, air baths, surfaces, and performance measures (primarily uniformity, stability, immersion profiles). This guide will become a priority once the first of the thermocouple guides is complete.

4.6 Radiation thermometry

There have also been requests for a guide on radiation thermometry that gives firm guidance for the calibration of non-primary radiometers. We envisage that the guide would be based on the CCT-WG5 uncertainty guide prepared several years ago, but provide more tutorial material on operating principles and the nature of the sources of error, as well as giving calibration examples. At present the task group has does not have the manpower or the expertise, and we plan to wait until CCT-WG-NCT completes their uncertainty guide, *Uncertainty estimation in primary radiometric temperature measurement*, before we co-opt appropriate experts. Following the task group meeting at Zakopane, CCT-WG-NCT asked about our intentions, and were happy with this approach.

5. Task 2: Maintain a list of temperatures and uncertainties for secondary fixed points

The BIPM has approved in principle the placing of a database on the CCT web pages close to the Guide on Specialised Fixed Points. Susanne Picard has also completed converting the Bedford paper to Excel spreadsheet entries. Now that the Guide to Specialised Fixed Points has been completed we can consider the adding entries to the Excel spreadsheet.

The final form of the data base has yet to be determined. The minimal solution is a simple excel file with filter and sort features. The ideal solution is a searchable database that returns a list of suitable fixed points meeting the users' criteria, and citations to papers describing the realisation of the fixed points. Rod and Davor will now prepare definition of database structure in so-called Third Normal Form, then we will discuss with Susanne what BIPM can do within their limited resources and capability.

Later, we will need to (i) establish protocol for inclusion of papers/data, (ii) update the database with all relevant papers published since Bedford. Also, we may need to add thermodynamic temperatures for some of the fixed points. Once we know what is possible/practical, we can allocate effort to review Metrologia, Tempmeko proceedings, and other journals, for relevant papers.

6. Task 3: Revision of CCT/08-19rev

The decision to revise the SPRT uncertainty guide was prompted by a letter from Ms Sonia Gaiță (Romania, received 6 Jan. 2014) advising Dr Duan of 'problems' with the Guide. The letter was accompanied by two supporting documents. The first document discussed the method by which uncertainty is propagated in the guide, while the second listed errors in the guide.

The first document displays a commonly-experienced conceptual difficulty accepting that there are many different but equivalent ways of writing the ITS-90 interpolations. In fact, there are an infinite number of equivalent approaches, and three with particular advantages in different situations. Her preference most closely reflects the original formulation of the ITS-90 equations in terms of deviations. In contrast, the approach adopted in the guide is simpler and most like the algebra in mathematical texts on interpolation, so aids in the understanding of interpolation and in the origin of interpolation errors (the various forms of non-uniqueness). The conceptual difficulty is probably best resolved by ensuring the equivalence of different interpolations is discussed in future revisions, the Supplementary Information, and in any further publications on ITS-90 mathematics.

The errors identified in Ms Gaiță's second document can be classified into three main groups (i) typographical errors in equations (some repeated several times due to the different variations in the equations), (ii) errors of omission where definitions are incomplete or imprecise, and (iii) our failure to give an explicit measurement model. The first two groups of errors are minor and simple to correct, but correcting the third problem is far from simple. While it is obvious where a statement of the measurement model should be included in the guide, it is not obvious how to include it. The complexity arising from several layers of calculation (SPRT and standard-resistor resistance models, bridge ratios, self-heating correction, temperature related corrections, then interpolation), the variations due to different calibration methods, variations between different fixed points, and variations in the choice of interpolating equation, was the very reason such as statement was not included in the first place. However, we concluded there should be some sort of summary giving an overview of the measurement model and the mathematical contributions to it.

Following the receipt of the letter from Ms Gaiță, a detailed scientific review of CCT/08-19rev was also carried out and identified several areas requiring major revisions or additions:

- A more complete and definitive statement on the uncertainties associated with sealed metal fixed-point cells. (This topic has now been dealt with by a new CCT Task Group on Sealed Metal Fixed Point Cells.)
- Expansion of the discussion on impurities in fixed points

    - Emphasise that the number of impurity particles dissolved in the solid/liquid determines the temperature elevation/depression. Account must be made of chemical reactions causing precipitation of impurities, or changes to different species.
    - Methods for correcting for impurities and their limitations.
    - Tabulation of the distribution coefficients
    - Where distribution coefficients with $k > 1$are known to be rare (e.g., with tin), use a single-sided OME method
- Isotope effects for neon
- New section on interface curvature and initiation effects in metal fixed points (Gibbs-Thomson effect) and conclusions from numerical models
- Update isotopic correction constants for water triple point
- New data on drift rates of TPW cells, and dilution effects
- Update information on use of bushings in fixed points
- Update information on impurity and drift effects in SPRTs
- Update information on non-uniqueness, including the discontinuity at TPW
- Optimal measurement strategies for self-heating correction in SPRTs
- Anomalous self-heating in C-SPRTs
- Use of Alan variance to investigate resistance bridge performance

After some discussion, the working group decided that we should make a minimal and quick revision to CCT/08-19rev addressing as many of Ms Gaiță's concerns as is practical. The revised document should retain the Working Document number CCT/08-19rev so it is clear to users that it represents a snapshot of the science circa 2008. However, the revision could not take place immediately because of members' commitments to other projects, and is probably best left until sometime well after the revised *Supplementary Information* has been published. With two documents published together, there is potential for confusion amongst users if the documents work at different levels of detail and make slightly different recommendations. At some time in the future, a full revision could be considered.

One complication with this proposal is that the terms of reference for CCT-TG-GoTH relate to secondary thermometry. It seems more appropriate for CCT-WG-CT to consider the revision.