Bureau International des Poids et Mesures

Consultative Committee for Thermometry (CCT)

Report of the 22nd meeting
(14–16 May 2003)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Bureau international des poids et mesures

Organisation intergouvernementale de la Convention du Mètre

Note:

Following a decision made by the International Committee for Weights and Measures at its 92nd meeting in October 2003, Reports of meetings of Consultative Committees will henceforth be published only on the BIPM website in the form presented here.

Full bilingual printed versions in French and English will no longer appear.

Working documents for the meetings are listed at the end of each Report and those which the Consultative Committee decides are for public use are available also on the website.

T.J.Quinn,
Director BIPM,
November 2003.

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR THERMOMETRY

as of 14 May 2003

President

H. Ugur, member of the International Committee for Weights and Measures, Ulusal Metroloji Enstitüsü [UME], Gebze-Kocaeli.

Executive Secretary

M. Stock, International Bureau of Weights and Measures [BIPM], Sèvres.

Members

Bureau National de Métrologie, Institut National de Métrologie [BNM-INM], Paris.

CSIR - National Measurement Laboratory [CSIR-NML], Pretoria.

D.I. Mendeleyev Institute for Metrology [VNIIM], Gosstandart of Russia, St Petersburg.

Institute for Physical, Technical and Radiotechnical Measurements [VNIIFTRI], Gosstandart of Russia, Moscow.

Istituto di Metrologia G. Colonnetti, Consiglio Nazionale delle Ricerche [IMGC-CNR], Turin.

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

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

National Institute of Metrology [NIM], Beijing.

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

National Measurement Laboratory, CSIRO [NML-CSIRO], Lindfield.

National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology [NMIJ/AIST], Tsukuba.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

NMi Van Swinden Laboratorium, Nederlands Meetinstituut [NMi VSL], Delft.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

Standards, Productivity and Innovation Board [SPRING Singapore], Singapore.

Ulusal Metroloji Enstitüsü/National Metrology Institute of Turkey [UME], Gebze-Kocaeli.

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

Observers

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

Instituto Nacional de Tecnología Industrial [INTI], Buenos Aires.

Instituto Português da Qualidade [IPQ], Caparica.

1 OPENING OF THE MEETING; APPOINTMENT OF THE RAPPORTEUR; APPROVAL OF THE AGENDA

The twenty-second meeting of the Consultative Committee for Thermometry (CCT) took place at the International Bureau of Weights and Measures (BIPM), Pavillon de Breteuil, Sèvres, on 14, 15, and 16 May 2003.

The following were present: M. Arai (NMIJ), D. Astrov (VNIIFTRI), M. Ballico (NML-CSIRO), M. Battuello (IMGC), S. Bell (NPL), G. Bonnier (BNM-INM), M. J. de Groot (NMi VSL), S. Duris (SMU), B. Fellmuth (PTB), J. Fischer (PTB), Y. Hermier (BNM-INM), K.D. Hill (NRC), C. Johnson (NIST), K.H. Kang (KRISS), H. Liedberg (CSIR-NML), G. Machin (NPL), P. Marcarino (IMGC), M. Matveyev (VNIIM), A. Pokhodun (VNIIM), T.J. Quinn (Director of the BIPM), J. Redgrove (NPL), D.C. Ripple (NIST), R. Rusby (NPL), A.G. Steele (NRC), O. Tamura (NMIJ), E. Tegeler (PTB), H. Ugur (UME, President of the CCT), S. Ugur (UME), D.R. White (MSL), Y. Yamada (NMIJ).

Invited and observers: P. Bloembergen (retired from NMi VSL, consultant of NMIJ), V. Chimenti (CEM), M. Durieux (KOL), M. E. Filipe (IPQ), E. Méndez-Lango (CENAM).

Also present: P. Giacomo (Director Emeritus of the BIPM); S. Solve (BIPM), M. Stock (Executive Secretary of the CCT, BIPM), C. Thomas (Coordinator of the BIPM key comparison database), A.J. Wallard (Deputy Director of the BIPM).

Absent: the INTI, SPRING Singapore and the NIM sent apologies. (The NIM noted their absence was due to the SARS quarantine.)

The President opened the meeting. The start time was slightly delayed due to the transit strike in Paris and the general unavailability of taxis.

Dr Steele (NRC) was appointed rapporteur.

The agenda was approved.

2 DOCUMENTS PRESENTED TO THE 22ND MEETING OF THE CCT

Thirty-three working documents were submitted for consideration at the meeting. The titles and authors are listed in the appendix to these minutes, and the full text can be found on the BIPM website (http://www.bipm.org). Not all documents were considered explicitly during the meeting, in accordance with the decision taken at the last CCT meeting; only those items specifically mentioned under the relevant agenda items (namely the working group and key comparison reports, and documents related to the discussions concerning ITS-20XX) were discussed by the committee at this session. Other submitted documents not related to a specific agenda item will be discussed only within the appropriate working groups.

There was some discussion on mechanisms for handling the submitted documents, which are made available to the public via the website at the conclusion of the CCT meeting. Authors of future documents are reminded that they should indicate whether the material is relevant to a specific agenda item or whether it is submitted for general consideration and as archival information; in either case, a statement requesting that the document remain confidential after the CCT meeting should be added if so desired. It was generally agreed that a list of suggested scientific topics for consideration at the CCT, to be included as an item on the proposed agenda, would simplify the task of categorizing submitted documents, and would further allow some latitude for handling novel contributions.

3 REPORTS OF THE WORKING GROUPS

3.1 Working Group 1: defining fixed points and interpolating instruments

Dr Ripple presented the report of the chairman of Working Group 1 (CCT/03-23), which discusses progress towards producing updated *Supplementary Information for the ITS-90*, including efforts to address uncertainties in fixed-point cells due to impurities.

Working Group 1 believes that the *Supplementary Information* should specify: i) that the reference temperatures are for chemically pure substances; and ii) that the isotopic concentrations corresponding to the assigned temperature should in general be specified. In the absence of other information, the isotopic concentration would be the naturally occurring composition. When sufficient knowledge of isotopic effects is known, procedures for correction to an isotopic composition specified in the *Supplementary Information* would be made. A procedure to incorporate such a correction for the triple points of water and for equilibrium hydrogen is under development.

Draft recommendations are in progress on:

i) Revision of the Working Group 1 document on the estimation of fixed-point cell uncertainty due to impurities.

Methods based on chemical assays are recommended as the primary method, supplemented by thermal analysis (such as the slope of a melting curve) and comparisons between cells. Estimates of uncertainties based on representative comparisons are mainly useful as a validation tool to check for contamination during preparation. Sole reliance on thermal analysis should be avoided as a means of determining the cell uncertainty.

ii) Proposed methods for correction of the experimentally determined liquidus point for impurity concentrations.

Working Group 1 agrees that such a correction is in principle desirable, but only if the uncertainty of the chemical analysis is at a level of 100 % ($k = 2$) or better. Present evidence is that chemical assay results have variable utility, with uncertainties in the range from 20 % to 300 %. The working group requests information on other chemical analysis techniques available or in use by NMIs, and may

seek the advice of the CCQM, which has recently discussed the analysis of trace impurities and concluded that reliance on a single method is generally insufficient.

iii) Proposed methods of experimentally determining the liquidus point.

There was some discussion on the task of compiling a bibliography of recent publications, which is still active. NMIs are reminded that URLs for their publication lists can be submitted to the BIPM for inclusion on the website. NRC thanked Dr Köhler for his assistance in making their website available via the BIPM search engine.

3.2 Working Group 2: secondary fixed points and techniques for approximating the ITS-90

Mr Hill presented the report of the chairman of Working Group 2 (CCT/03-14), which discusses progress towards producing a revised version of the *Techniques for Approximating the ITS-90*. The revisions to the document extend well beyond a simple updating of the references. In spite of the fact that there are concerns about the availability of time for working group members to make progress on their tasks, there is hope that a substantial amount of the work will be completed and ready for wider circulation to the CCT during the TempMeko 2004 conference.

An electronic copy (in PDF format) of the existing *Techniques for Approximating the ITS-90* has been prepared. This document and the most recent list of secondary reference points (*Metrologia*, 1996, **33**, 133-154) are to be hosted on the BIPM website. It is envisioned that the addenda produced by Working Group 2 will be published electronically as they become available, and that the final text of the new documents will be made available on the BIPM website, thus allowing rapid updates and easy access.

Working Group 2 has also examined the reference functions for Au/Pt (NIST) and Pt/Pd (NIST/IMGC) thermocouples, and recommends that the NIST Au/Pt and NIST/IMGC reference functions be endorsed by the CCT for general use as an aid to the IEC process of defining international standards for these important thermocouple types.

3.3 Working Group 3: uncertainties

Dr Bonnier presented the report of the chairman of Working Group 3 (CCT/03-22), which includes a discussion on the draft of the working document for harmonizing the presentation of uncertainty budgets for SPRT calibrations at the defining fixed points. The working group will incorporate the recommendations of Working Group 1 on impurity-related uncertainties, as and when they become available.

There was some discussion related to the draft document, including such topics as i) the notion that the range of melted fraction used in the determination of the fixed point value has a direct impact on the calculation of the melting range; ii) the introduction of a scheme which distinguishes between the experimental determination of the liquidus point and the subsequent correction for systematic effects, including corrections for impurity and isotopic composition (based on information from Working Group 1) as separate steps in the procedure for creating the uncertainty budget.

It is expected that the Working Group 1 document will be prepared for circulation within one year, although some technical refinements (such as the notion of using the maximum value of a freezing

curve as the fixed point temperature) are yet to be determined. This Working Group 1 document will specify recommended values for the uncertainty components related to impurity effects, to be used within the process document on the construction of uncertainty budgets currently in preparation by Working Group 3.

There was some discussion concerning the creation of a satellite workshop or a special session on the topic of uncertainty in thermometry to be held in conjunction with TempMeko 2004, along with general agreement that this would be a useful addition to the conference. It was observed that both NMIs and their clients could be served by such a session, particularly if the results of the on-going CMC evaluations for Appendix C to the MRA could be disseminated.

Working Group 3 has determined that its scope should be limited exclusively to uncertainty in contact thermometry, and recommends that the remit for Working Group 5 be expanded to include uncertainty in radiation thermometry. These changes are reflected in the minutes for agenda item 7.

3.4 Working Group 4: thermodynamic temperature determinations and extension of the ITS-90 to lower temperatures

Dr Rusby presented the report of the chairman of Working Group 4 (CCT/03-26), which includes a short résumé of work in progress that will lead to new thermodynamic temperature values above 1 K, along with some observations on the preparation of a first draft of the *Supplementary Information for the Realization of the PLTS-2000*.

There was some discussion of ongoing work related to PLTS-2000. At the PTB, a project is under way to compare ITS-90 and PLTS-2000 in a single cryostat; results on the size and uncertainty of corrections are anticipated by the time of the next CCT meeting. An ongoing EU project is being coordinated by the NPL, with the expectation of a paper summarizing the work involving a variety of sensors at TempMeko 2004.

Working Group 4 will keep a watching brief on new developments in both thermodynamic and ultra-low-temperature thermometry, and noted with interest the recent development of a tunnel-junction noise thermometer by Spietz *et al*. of Yale University that is potentially useful as a thermodynamic probe over a very wide range of temperatures. It may initially find application at very low temperatures where the relative uncertainty, currently 0.1 % of T, is of interest.

3.5 Working Group 5: radiation thermometry

Dr Fischer presented the report of the chairman of Working Group 5 (CCT/03-03), which includes an analysis of the base-line parameters underlying the scale realization with respect to their contribution to the uncertainty budget.

The analysis completed to date considers realizations above the silver point, and includes the following key features: i) sensitivity coefficients in an uncertainty model; ii) “normal” and “best practice” uncertainty values characterized for three different realization schemes (two are lamp-based, one is thermometer-based); iii) links to the requirements of Appendix C, where services “normally offered” by the NMIs are listed; iv) some technical limitations on implementation (such as determination of the wavelength, filter stability, and the non-linearity of the thermometer). The current work plan includes the task of considering uncertainty budgets for radiation thermometry

below the silver point, as well as identifying initial values for the metal carbon eutectics to be supplied as input to Working Group 2 for consideration as secondary reference points. Document CCT/03-03 has been transferred to Working Group 1, which has accepted its inclusion in the new revision of the *Supplementary Information*.

Good relations with the CCPR have been maintained, with Dr Fox acting as a direct liaison between the relevant working groups of the two Consultative Committees.

3.6 Working Group 6: humidity

Dr Bell presented the report of the chairman of Working Group 6 (CCT/03-11) on behalf of Dr Huang (who sent apologies to the President). The report includes a summary of a recent Working Group 6 meeting, status of CCT-K6, the results from the draft B report of the APMP key comparison on humidity, a list of contributions by the working group members to the 4th International Symposium on Humidity and Moisture, information concerning two planned EUROMET key comparisons, one on high temperature dew-points and one identical to CCT-K6, as well as a planned SIM comparison between the NIST and the INMETRO (Brazil).

No formal joint effort has yet been undertaken to produce the document on uncertainty components and budgets in humidity for use by Working Group 3 and others. A preliminary summary prepared by an ad hoc subcommittee (NMi VSL, MSL, and NPL) has been made available in the CCT working documents as CCT/03-20. There was some discussion on consistency of presentation in documents related to uncertainty in the various areas of temperature and humidity, and general agreement that the appropriate working groups can work together to ensure consistency of approach and notation to avoid unnecessary confusion.

3.7 Working Group 7: key comparisons

Mr Hill presented the report of the chairman of Working Group 7 (CCT/03-33) in the absence of Dr Pavese (who sent apologies to the President), noting that the report was a revised version of the chairman's draft that had been reworked and approved by the working group membership prior to the CCT meeting. The report includes a summary of ongoing comparisons under the administrative care of the working group; there are no outstanding action items requiring the attention of the CCT at this time.

The importance of making the results of key comparisons available on the MRA Appendix B database was noted, and Dr Thomas was commended for her experience and efforts to streamline the process and formatting on the website. Pilots of key comparisons were reminded that the BIPM could be used as a resource when preparing their database entries.

In order to avoid unnecessary delays, the RMO key comparison representatives were reminded that it is in their best interests to take an active role in the passage of their comparison through the Working Group 7 process, starting with the Protocol if practicable, and working together to complete the Appendix B entry for approval on behalf of the President.

There has been some discussion on the interpretation of the phrases "significant unresolved deviations" (SUDs), which appears in the MRA in the context of the compatibility of entries in Appendix B and Appendix C, and "significant deviations", which can be identified by the pilot

laboratory during the key comparison. The working group proposes to develop a report discussing general methods for identifying these deviations for discussion at the CCT, and will assist the pilots of key comparisons to apply them as required; such a document would be potentially useful to RMOs in identifying SUDs.

3.8 Working Group 8: calibration and measurement capabilities

Mr de Groot presented the report of the chairman of Working Group 8 (CCT/03-32), which includes a complete listing of CMC service categories for temperature (to be available on the BIPM website after the approval of the CMC entries in thermometry), and a summary of recent work done by the Inter-RMO CMC Review Committee relating to service category 1.3.2 (SPRTs at fixed points of the ITS-90).

The President thanked the working group for its work on establishing the service categories for use in Appendix C.

3.9 Working Group 9: thermophysical properties

Mr Redgrove presented the report of the chairman of Working Group 9 (CCT/03-30), which includes a proposed list of CMC service categories for thermophysical properties, and a survey of major techniques in the field that may prove suitable candidates for CCT key comparisons. It was agreed that overlap with other service categories, e.g. with CCPR regarding reflectance and emissivity, should be avoided.

There was some discussion regarding the initiation of key comparisons in this area, particularly since the community as a whole has little experience with measurement comparisons at this level. The strategy of the working group to pursue topics one capability at a time, and to conduct pilot studies (as is done routinely in the CCQM) to establish the state of measurement and maturity of the field received the general support of the CCT, and the services of Working Group 7 to help in drafting comparison protocols were offered.

4 REPORTS OF CCT KEY COMPARISONS

4.1 CCT-K1: Realizations of the ITS-90 from 0.65 K to 24.5561 K using rhodium-iron resistance thermometers

Dr Rusby summarized the status of CCT-K1, for which all measurements are now complete and data reduction is in process. The intention is to compile the matrix of laboratory temperatures for all twelve thermometers at some fifty or sixty comparison temperatures, to look for discrepant values that may require discussion with the individual participants, and to write and circulate the first draft A report by the end of the summer. It is hoped that the process can be completed, and that a final agreed-upon draft B report and the associated Appendix B entries can be obtained in the

timeframe of TempMeko 2004. The pilot laboratory was offered the services of the CCT working groups and BIPM staff to help in any way that would be useful in bringing the key comparison to a successful conclusion.

4.2 CCT-K5: Realizations of the ITS-90 between the silver point and 1700 °C using vacuum strip lamps as transfer standards

Mr de Groot summarized the status of CCT-K5, for which all measurements are complete and the first version of the draft A report has been circulated among the participants. There have been extensive discussions related to the analysis, and several revised calculation schemes have been considered. A meeting was held with most key comparison participants attending at TS8. The latest calculations are expected forthwith, and the second revised draft A report incorporating all of this new information is anticipated during the summer.

There was some discussion regarding the quality of the comparison results, shown in an anonymous graph during the presentation, particularly considering the small uncertainties anticipated at the highest levels of measurement as summarized in the document prepared by Working Group 5. It was generally agreed that the pilot laboratory should attempt to capture the experience gained during this comparison in the draft A report, and to make recommendations for improvements to the measurement protocol for future comparisons in this field. These recommendations would be particularly useful for Working Group 7 when considering the equivalence of future key comparisons (whether bilateral, regional, or otherwise) to CCT-K5. Pilots of ongoing regional key comparisons equivalent to CCT-K5 were encouraged to follow the progress of this report and analysis carefully.

4.3 CCT-K6: Comparison of humidity standards

Dr Bell reported that Working Group 6 has resolved the preparatory issues related to the protocol and the definition of the measurand for CCT-K6, and stated that measurements will begin as soon as clearance is received from Working Group 7.

4.4 CCT-K7: Comparison of water triple point cells

Dr Stock summarized the status of CCT-K7, which will be in the form of an inverted star comparison with individual travelling standards coming to the BIPM for measurement from the participants' laboratories. Recent improvements to the BIPM facilities, including the acquisition of a stable oil bath for the reference resistors and a new high-precision automatic resistance bridge were also described. Measurements are now underway, and completion is expected during the summer. The first draft A report is anticipated early in 2004.

There was some discussion related to the technical details of the comparison uncertainty budget, including the impurity effects in the individual triple point cells and the repeatability measurements performed on the BIPM family of cells, and the pilot expressed great willingness to include all participants in the discussions related to the analysis.

Further discussion took place concerning the implications of changing laboratory reference cells after successful completion of the key comparison, including the entry of measurement results into Appendix B and of calibration and measurement capabilities based on this information into Appendix C. This was considered to be particularly essential for the case of the triple point of water, but the implications were deemed important for all aspects of scale realization and dissemination. Emphasis was placed on the importance of the laboratory quality procedures, and on the fact that updating laboratory values is intended to be an open and trusted process that relies on publication of new information for use by interested parties. The President was urged to make the case for openness with scientific justification when this matter is discussed at the JCRB meeting, and to argue against any scheme that would require an extensive number of subsequent bilateral key comparisons to permit changes after the MRA transition period comes to an end. It was pointed out that the implementation of working quality systems ensures continuity of service without excessive reliance on outside evaluation of individual values. The JCRB is aware of the financial consequences of these decisions to make changes, although acceptable justification will always be required in one form or another.

More detailed scientific discussion took place concerning the nature and magnitude of variations in the value of triple point of water cells, including the observation that corrections for isotopic composition (and for the impurity effects arising from the solubility of borosilicate glass in water, to a lesser extent) are now possible based on work done over the past several years at the MSL, NIST, NMi VSL, NPL, NRC, VNIIM, and elsewhere, and published in the proceedings of recent conferences. It is expected that the CCT-K7 results will shed some light on the inter-laboratory differences in the realization of the triple point of water, which will be useful in conjunction with the amended *Supplementary Information* in preparation by Working Group 1.

5 DISCUSSION OF THE STATUS AND RESULTS OF RMO COMPARISONS

Discussion of this agenda item took place alongside the presentation of the Working Group 7 report, and during the presentations of the ongoing CCT key comparisons.

There are no known regional or bilateral comparisons planned or in progress related to CCT-K1. CMCs in this temperature region have been submitted for inclusion in Appendix C by COOMET, and it is anticipated that further submissions will be forthcoming from other RMOs.

A report on the bilateral key comparison equivalent to CCT-K2 between the NRC and the VNIFTRII has been submitted to Working Group 7. A speedy resolution is anticipated, and the corresponding Appendix B entries are expected to appear in the BIPM key comparison database during the summer.

There are regional key comparisons equivalent to CCT-K3 underway by the APMP and EUROMET, as discussed in the Working Group 7 report. Dr Ripple reported that the SIM is undertaking some supplemental comparisons in this temperature region, and that there have been some difficulties related to customs and transportation of artefacts between the countries. Also, a bilateral key comparison between the CENAM and the NIST is planned, and expected to start this year.

An APMP comparison equivalent to CCT-K4 is planned. The protocol has been under discussion among the participants with involvement from Working Group 7. The pilot presented the most recent version of the protocol at the working group meeting immediately prior to this CCT meeting to address issues related to linking the two loops of the comparison; formal approval from Working Group 7 is pending.

Two regional key comparisons equivalent to CCT-K5 are being undertaken by the APMP and EUROMET. Working Group 7 has been involved in the examination of protocols, and APMP-K5 was approved at the last CCT meeting. In addition, two bilateral comparisons, NRC-NIST and NRC-PTB, equivalent to (and using the same protocol as) CCT-K5 are underway, with the approval of Working Group 7.

An RMO key comparison corresponding to CCT-K6 has been completed within the APMP, and a similar exercise will begin within EUROMET in the coming year. A bilateral key comparison between the NIST and INMETRO will take place within the SIM.

There are no known regional or bilateral comparisons planned or in progress related to CCT-K7.

SADCMET intends to undertake a series of supplementary comparisons in a variety of temperature regions. Although no formal involvement from Working Group 7 is required, the participants were reminded that the existing CCT infrastructure offers the possibility for information sharing, so that the benefits of experience can be shared among regions.

6 SITUATION OF CMC ASSESSMENT; RELATIONSHIP BETWEEN CMC CLAIMS AND KEY COMPARISONS

Mr de Groot presented a protocol for identifying laboratory CMC claims that require further scrutiny prior to publication in Appendix C as developed by the Inter-RMO CMC committee. This mechanism is based on a simple relation between the difference between the KCRV and laboratory result and the combined uncertainties of KCRV and laboratory result. The protocol is given in Annex 3 of working document CCT/03-32. The use of an “average reference value” (ARV), defined as the average of the mean, the weighted mean and the median, along with a simple normalized deviation rule is described in working documents CCT/03-28 and CCT/03-32. The use of an ARV is recommended only for examining the particular CMCs related to CCT-K3, the measurement values and bilateral degrees of equivalence of which are reported in Appendix B without the use of a KCRV. At the Working Group 7 meeting held in conjunction with TS8, the members discussed the key comparison and reached majority agreement that the Appendix B entry should be left as it currently appears, noting that CMC evaluation can take place independently using the ARV or any other technique deemed suitable. The Inter-RMO CMC Review committee acted under this authority when it calculated the ARV for application of the protocol to the CMCs related to CCT-K3. The creation of the ARV for this purpose alone will have no impact on the presentation of the CCT-K3 results in the KCDB. It is important to note that the normalized deviations from the ARV are used only to identify those laboratory CMC claims that will receive more detailed scrutiny: the scrutiny will be based on supporting technical data to be provided by the laboratory in question; in particular,

the ARV is not intended to be used as the KCRV for this key comparison, nor does it play any role in evaluating degrees of equivalence.

The approach is a pragmatic solution to a difficult problem, where the range of stated measurement uncertainties among the participating laboratories is quite large. The Inter-RMO CMC Review committee acknowledged the gracious attitude of the NIST to suggest a test mechanism that would require them to submit their own uncertainty budgets and measurement procedures for the most demanding examination, in order to satisfy the concerns expressed by partners in EUROMET. It was emphasized that the use of the ARV in this particular situation was not intended to become a binding precedent for any future key comparisons, and the arbitrary nature of this reference value within the context of the ill-conditioned data set is explicitly acknowledged. Some discussion surrounding the uncertainty of the ARV took place, and the Inter-RMO CMC Review committee will revisit their initial suggestion to take the standard deviation of the three usual estimators of central tendency, and will consider the effect of using the average uncertainty for these statistics instead. The fact that much work has already been performed within the RMOs toward evaluating this group of CMCs using the ARV approach was highlighted, and accepted as a supporting rationale for proceeding in such a pragmatic fashion. The arbitrary nature of the ARV was cited as one of its strengths, since it avoids any appearance of promoting one of the usual statistics above the others – especially when this has been demonstrated to be a non-physical interpretation in the final comparison report. When asked whether this same approach is used by the Inter-RMO CMC Review committee when evaluating the CMCs related to CCT-K4 (which had technical difficulties in identifying a meaningful KCRV), the response indicated that the review is based on the agreed-upon reference value calculated in the final comparison report. Although the question of linking RMO comparison results to the CCT-K3 data was raised, the issue was deferred since Working Group 7 has taken on board the task of examining significant deviations and related matters in order to prepare some guidance documentation for use by the CCT and Working Group 8 in particular.

The CCT recognizes the efforts of the Inter-RMO CMC Review Committee to resolve the difficulties in evaluating CMCs related to CCT-K3, and recommends that when using the ARV for this purpose that the uncertainty of the ARV be taken as the simple average of the respective uncertainties of the mean, the weighted mean, and the median.

There was much discussion surrounding the role of the CCT and its working groups in the CMC evaluation, particularly since this activity is explicitly within the purview of the RMOs. It was suggested that Working Group 7 provide a clear statement of closure for each key comparison, indicating that the MRA process was followed and that the summary and KCDB entry are correct. There was general agreement that the scientific expertise in thermometry rests within the CCT to act on behalf of the JCRB, and that taking an active role in these matters – such as providing a statement of support to the practices of the RMOs – would lend credibility and add legitimacy to the process, and would provide a venue for input from the entire metrological community. Dr Quinn indicated that the chairman of the JCRB would look favourably on the linking of responsibilities between the CCT and the RMOs, since it is important that the expert knowledge of the CCT be used in close collaboration with the Inter-RMO CMC Review committee, and as the inter-regional coordination falls within the remit of the CCT. The updated terms of reference for Working Groups 7 and 8 reflect these discussions.

7 REVIEW OF WORKING GROUP TASK DEFINITIONS, ROLES, RESPONSIBILITIES AND OPERATIONAL PROCEDURES

7.1 Working Group 1: defining fixed points and interpolating instruments

Terms of reference:

- to improve techniques for the realization of defining fixed points and for interpolating instruments (T_{90} > 3 K);
- to study non-uniqueness;
- to update the *Supplementary Information for the ITS-90.*

Working Group 1 is tasked to continue with the updates to the Supplementary Information, including uncertainties in fixed-point realizations.

Membership:

- D.C. Ripple (NIST, chairman)
- BNM-INM (Y. Hermier)
- IMGC (P. Marcarino)
- IPQ (E. Filipe)
- KRISS (K.H. Kang)
- NMi VSL (M.J. de Groot)
- NRC (K. Hill)
- PTB (B. Fellmuth)
- VNIIM (A. Pokhodun)

Providing assistance: P. Bloembergen (NMi VSL, retired), M. Matveyev (VNIIM)

7.2 Working Group 2: secondary reference points and techniques for approximating the ITS-90

Terms of reference:

- to revise the *Techniques for Approximating the ITS-90*;
- to revise and update the list of secondary reference points.

Working Group 2 is tasked to continue with the updates to the *Techniques for Approximating the ITS-90*, including advice on fixed-point construction and operation. Mr Hill has been chairman (replacing Dr Steele) for the past eighteen months, and will continue in this role.

Membership:

- K. Hill (NRC, chairman)
- CSIR (H. Liedberg)
- IMGC (P. Marcarino)
- KRISS (Y.G. Kim)

- MSL (D.R. White)
- NIM (Y. Duan)
- NMIJ (Y. Yamada)
- PTB (F. Edler)
- UME (M. Kalemci)
- Co-opted: P. Bloembergen (NMi VSL, retired); M. Gotoh (Tamagawa University); B. Fellmuth (PTB)

7.3 Working Group 3: uncertainties

Terms of reference:

- to establish and recommend methods for quoting uncertainties in realizing the ITS-90 using contact thermometry;
- to ensure notational consistency in methods for quoting uncertainties for other areas of interest to the CCT (including optical thermometry and humidity).

Working Group 3 is tasked with continuing the production of a general-purpose document on uncertainty budgets for contact thermometry, and to act in an oversight role for similar documents produced by other working groups. Dr Bonnier announced his intention to retire during this term, prior to the next CCT meeting. Mr White was appointed vice-chairman with unanimous consent from the working group members, with the explicit understanding that he would assume the role of chairman upon Dr Bonnier's retirement.

Membership:

- G. Bonnier (BNM-INM, chairman)
- D.R. White (MSL, vice-chairman)
- BIPM (M. Stock)
- CEM (V. Chimenti)
- CENAM (E. Mendez-Lango)
- CSIRO (M. Ballico)
- IMGC (F. Pavese)
- IPQ (E. Filipe)
- NMIJ (M. Arai)
- NMi VSL (A. Peruzzi)
- NIST (C. Meyer)
- PTB (J. Seidel)
- SMU (S. Duris)
- UME (A. Kartal Dogan)
- VNIIM (A. Ivanova)

7.4 Working Group 4: thermodynamic temperature determinations and extension of the ITS-90 to lower temperatures

Terms of reference:

- to review and make recommendations concerning thermodynamic temperature determination and extension of the ITS-90 to lower temperatures.

Working Group 4 is tasked with continuing the production of *Supplementary Information for the PLTS-2000*.

Membership:

- R. Rusby (NPL, chairman)
- IMGC (P. Steur)
- MSL (D.R. White)
- NIST (M. Moldover)
- NRC (A. Reesink)
- PTB (J. Fischer)
- Available for assistance: M. Durieux (University of Leiden); R. Hudson (retired)

7.5 Working Group 5: radiation thermometry

Terms of reference:

- to study, develop and advise the CCT on issues related to optical methods for temperature measurement in the framework of the ITS-90, including the reporting of uncertainty budgets;
- to maintain good links/interface with the radiometry community;
- to provide formal liaison between the CCT and CCPR.

Working Group 5 is tasked with producing a document on uncertainty in radiation thermometry at temperatures below the Ag melting point, and with continuing the examination of the carbon-metal eutectics.

Membership:

- J. Fischer (PTB, chairman)
- BNM-INM (M. Sadli)
- CSIRO (M. Ballico)
- IMGC (M. Battuello)
- KRISS (S.N. Park)
- MSL (P. Saunders)
- NIM (Yuan Zundong)
- NIST (C. Johnson)
- NMIJ (F. Sakuma)
- NMi VSL (E.W.M. van der Ham)
- NPL (G. Machin)

- PSB (Wang Li)
- UME (S. Ugur)
- VNIIM (M. Matveyev)
- CCPR liaison: N. Fox (NPL)
- Co-opted: Y. Yamada (NMIJ); P. Bloembergen (NMi VSL, retired)

7.6 Working Group 6: humidity

Terms of reference:

- to advise the CCT on matters relating to humidity;
- to produce a working document on principal uncertainty components in humidity measurements for input to Working Group 3.

Working Group 6 is tasked with continuing production of the document on uncertainty in humidity, and with the operation of CCT-K6.

Membership:

- P. Huang (NIST, chairman)
- BNM (B. Cretinon)
- CENAM (E. Martines)
- IMGC (V. Fernicola)
- KRISS (Hyun-Soo Nham)
- MSL (J. Lovell-Smith)
- NMIJ (H. Kitano)
- NMi VSL (J. Nielsen)
- NPL (S. Bell)
- NRCCRM (Y. Hong)
- PSB (Wang Li)
- PTB (G. Scholz)
- UME (S. Ugur)
- VNIIM (M. Mamontov)

7.7 Working Group 7: key comparisons

Terms of reference:

- to examine all relevant documents for each key comparison, starting with the protocol and ending with the draft B report;
- to advise the pilot laboratory in preparing the text of the entry to Appendix B of the MRA as required, and to prepare a recommendation on these subjects for approval by the CCT;
- to prepare guidance documents on identifying significant deviations for use by the pilot laboratories;

- to advise the pilot laboratory in preparing a comparison status document, and to prepare a recommendation for this summary for the CCT.

Working Group 7 is tasked with continuing the oversight of key comparisons, and with the production of guidance documents on comparison deviations. Dr Pavese resigned as chairman, and is succeeded by Dr Steele as a result of an election by the membership.

Membership:

- A. Steele (NRC, Pilot CCT-K2, chairman)
- Pilot CCT-K1 (NPL, R. Rusby)
- Pilot CCT-K3 (NIST, G. Strouse)
- Pilot CCT-K4 (PTB, E. Tegeler)
- Pilot CCT-K5 (NMi VSL, M.J. de Groot)
- Pilot CCT-K6 (NPL, S. Bell)
- Pilot CCT-K7 (BIPM, M. Stock)
- chairman of CCT Working Group 3 (G. Bonnier)
- CSIRO (M. Ballico)
- IMGC (F. Pavese)
- KRISS (K.H. Kang)

7.8 Working Group 8: calibration and measurement capabilities

The remit of Working Group 8 was expanded substantially to include broad responsibilities related to Appendix C entries. One member is drawn from each of the regional metrology organizations to ensure consistency between the technical expertise offered by the CCT and the administrative and technical roles of the RMOs; additional technical experts will be co-opted on a short-term basis to provide assistance on issues related to the particular field under discussion and review. The terms of reference are identical to those recommended by the JCRB in the document *JCRB-10/6(3)*.

Terms of reference:

- to establish and maintain lists of service categories and, where necessary, rules for the preparation of CMC entries;
- to agree on detailed technical review criteria;
- to coordinate and, where possible, conduct inter-regional reviews of CMCs submitted by RMOs for posting in Appendix C of MRA;
- to provide guidance on the range of CMCs supported by particular key comparisons;
- to identify areas where additional Key Comparisons are needed;
- to coordinate the review of existing CMCs in the context of new results of key and supplementary comparisons.

Working Group 8 is tasked with providing technical oversight in the Review of CMCs for Appendix C.

Membership:

- M.J. de Groot (EUROMET, chairman, NMi VSL)
- APMP (M. Ballico, CSIRO)
- COOMET (A. Pokohodun, VNIIM)
- SADCMET (H. Liedberg, CSIR)
- SIM (G. Strouse, NIST)

7.9 Working Group 9: thermophysical properties

Terms of reference:

- to advise the CCT on matters related to thermophysical properties, and to assess the need in this field for a key comparison.

Working Group 9 is tasked with continuing the production of a document on uncertainty, and with identifying suitable pilot studies to establish the state of measurement and maturity of the field.

Membership:

- J. Redgrove (chairman, NPL)
- BNM-LNE (J.-R. Filtz)
- IMGC (G. Bussolino)
- IPQ (N. de Castro)
- KRISS (Sang Hyun Lee)
- NIM (Ping Qiu)
- NIST (L. Hanssen)
- NMIJ (J. Ishii)
- PTB (S. Sarge)
- VNIIM (name to be notified)

8 DISCUSSIONS ON ITS-20XX

Dr Rusby summarized the results of the workshop entitled “Towards ITS-XX”, held in conjunction with the Temperature Symposium in Chicago (see CCT/03-01). The full collection of presentations from this interesting and useful day is available, and was distributed to the participants. Dr Ripple and the TS8 organizers were thanked for their assistance in hosting the workshop.

Dr Rusby also summarized document CCT/03-02, concerning the need for a revision of the ITS-90, and a survey to identify circumstances in which the ITS-90 limits the activities of users of the scale. No answers were collected prior to the meeting, and the CCT was asked to consider whether or not the questions and assumptions of user-driven requirements for the next revision of the scale are the

correct starting points. There was much discussion concerning the requirement for anticipating future needs for an improved scale, and on the lack of reliable information from industry on what will be required in ten years time. There was general agreement that the role of the CCT is to look ahead to identify and anticipate the changes that will be required, including the possibility of an officially promoted, useful approximation to the ITS-90 that would be helpful in terms of cost and application. Lower temperature applications for radiation thermometry and new thermocouple functions for use both above and below 0 ºC were cited as practical potential improvements. The Director of the BIPM recommended the creation of an ongoing CCT activity to study future needs in thermometry, keeping in mind that history has shown the very long timescales required to produce an improved scale. There was general agreement that the CCT should not be passive, and is in fact already taking an active role in this area, including the activities of Working Group 4 to establish and implement the PLTS-2000, and the activities of Working Group 5 to examine and develop the metal-carbon eutectic fixed points.

9 OTHER BUSINESS

The Director of the BIPM expressed his thanks to Dr Durieux, who has attended seventeen CCT meetings and acted as Rapporteur for fifteen (since 1971). On behalf of the thermometry community as a whole, Dr Quinn expressed appreciation for Dr Durieux's scientific contributions to metrology and to IPTS-68 and the low-temperature scales in particular, and for his exemplary efforts in recording the minutes of all discussions. There was enthusiastic applause in support of this pronouncement.

10 REPORT TO CIPM AND RECOMMENDATIONS

The report of the President to the CGPM and CIPM will be prepared before the end of June 2003, to allow time for translation and formatting at the BIPM.

There was some discussion of the Working Group 2 recommendation on the formal adoption and endorsement of the thermocouple reference functions; although this is not specifically a recommendation for action on the part of the CIPM, it was agreed that the Report of the President should indicate that the CCT has accepted the Working Group 2 recommendation, as a means of highlighting this action.

11 NEXT MEETING

The CCT recommends that the CIPM schedule the next meeting for Spring 2005, since there will be an opportunity to meet and conduct other business during the week of TempMeko 2004.

A.G. Steele, Rapporteur

APPENDIX T 1.
Working documents submitted to the CCT at its 22nd meeting

Open working documents of the CCT can be obtained from the BIPM in their original version, or can be accessed on the BIPM website (http://www.bipm.org/cc/AllowedDocuments.jsp?cc=CCT).

Document
CCT/

03-01 NPL (United Kingdom), MSL (New Zealand). — CCT Workshop: Toward the ITS-XX, Chicago, 25 October 2002, Summary of the proceedings, R. Rusby and R. White, 8 pp.

03-02 NPL (United Kingdom), MSL (New Zealand). — Toward the ITS-XX – a survey of needs, R. Rusby and R. White, 1 p.

03-03 CCT Working Group 5. — CCT-WG5 on radiation thermometry: Uncertainty budgets for realisation of scales by radiation thermometry, J. Fischer *et al.*, 25 pp.

03-04 CCT Working Group 7. — WG7: Proposed Resolution on an Interpretation of the MRA, F. Pavese, 2 pp.

03-05 IMGC-CNR, IAC-CNR (Italy). — Classes of inter-comparisons and the case of temperature standards, F. Pavese and P. Ciarlini, 12 pp.

03-06 IMGC-CNR (Italy). — On the definition of "significant unresolved deviation" in the MRA frame, F. Pavese, 4 pp.

03-07 IMGC-CNR (Italy). — On the advantages of using the "temperature amplifier" for accurate temperature measurements between 660 °C and 960 °C, P. Marcarino and A. Merlone, 4 pp.

03-08 NMIJ/AIST (Japan). — Anomalies on the heat capacity just below the triple points of e-H_2 and e-D_2 with catalysts, T. Nakano, O. Tamura and H. Sakurai, 3 pp.

03-09 PTB (Germany). — Uncertainty budget for the realisation of the Provisional Low Temperature Scale PLTS-2000 at PTB, J. Engert, B. Fellmuth and A. Hoffmann, 3 pp.

03-10 PTB (Germany). — Mechanical stability of Pt/Pd thermocouples, F. Edler and H. Lehmann, 5 pp.

03-11 CCT Working Group 6. — Report to the CCT by Working Group 6 on Humidity Measurements, P. Huang *et al.*, 2 pp.

03-12 PTB (Germany). — Comments on the underestimation of the change of fixed-point temperatures by impurities due to a non-justified application of Raoult's law, B. Fellmuth, 3 pp.

03-13 PTB (Germany) *et al.* — Dependence of the triple-point temperature of diluted mixtures of deuterium (as HD) in protium on the deuterium content, B. Fellmuth *et al.*, 3 pp.

03-14 CCT Working Group 2. — Report of Working Group 2 to the CCT: April 2003, K. Hill, 2 pp.

Document
CCT/

03-15 NMi VSL (The Netherlands). — Evaluation of the uncertainty in the realization of the PLTS-2000 at NMi, A. Peruzzi and M.J. de Groot, 6 pp.

03-16 CCT Working Group 1. — Proposal of a provisional integration of the ITS-90 definition concerning the temperature of the triple point of equilibrium hydrogen, F. Pavese *et al.*, 1 p.

03-17 VNIIM (Russian Federation). — Analysis of the requirements to SPRTs in the ITS-90 definition, N. P. Moiseeva, 5 pp.

03-18 IEN, IMGC-CNR (Italy). — Acoustic measurements of the thermodynamic temperature between the triple point of mercury and 380 K, G. Benedetto et al., 6 pp.

03-19 NIST (United States). — NIST methods of estimating the impurity uncertainty component for ITS-90 fixed-point cells from the Ar TP to the Ag FP, G. Strouse, 18 pp.

03-20 NMi VSL (The Netherlands), MSL-IRL (New Zealand), NPL (United Kingdom). — Uncertainty in the generation of humidity, J. Nielsen, J. Lovell-Smith, M. de Groot and S. Bell, 33 pp.

03-21 MSL (New Zealand), NIST (United States). — Evaluation of the depression constants for D and ^{18}O isotopes for the triple-point temperature of water, R. White and W.L. Tew, 6 pp.

03-22 CCT Working Group 3. — Report of WG 3 to the CCT: May 2003, G. Bonnier, 15 pp.

03-23 CCT Working Group 1. — Report presented to the CCT by WG1, D. Ripple, 3 pp. (restricted access)

03-24 VNIIM (Russian Federation). — The role of impurity component in the budgets of uncertainty, N.P. Moiseeva, 2 pp.

03-25 NMIJ/AIST (Japan).— Influence of the heat capacity anomaly on the triple point temperature of equilibrium hydrogen, H. Sakurai, 3 pp.

03-26 CCT Working Group 4. — WG 4 report to the CCT: May 2003, R. Rusby *et al.*, 6 pp.

03-27 IMGC (Italy). — How the weighted mean affects the ARV (NIST-meeting protocol), P.P.M. Steur, M. Battuello, P. Marcarino and F.Pavese, 3 pp.

03-28 NIST (United States). — Analysis of CCT-K3 using an average reference value, G. Strouse and D. Ripple, 4 pp. (restricted access)

03-29 VNIIM (Russian Federation). — VNIIM's comments to the draft of uncertainties budget for SPRT calibration at the defined fixed points, A.G. Ivanova, A.I. Pokhodun and S.F. Gerasimov, 2 pp. (restricted access)

03-30 CCT Working Group 9 . — Working Group 9 report to CCT: May 2003, J. Redgrove *et al.*, 7 pp.

03-31 NMi VSL (The Netherlands). —Key comparison 5, progress report, M. de Groot and E. van der Ham, 2 pp. (restricted access)

03-32 CCT Working Group 8. — Report of WG8 to the 22nd session of the CCT, M. de Groot *et al.*, 16 pp. (restricted access)

Document
CCT/

03-33 CCT Working Group 7. — Report of WG7 on key comparisons (13 May 2003), K. Hill *et al*., 5 pp.