Bureau International des Poids et Mesures

Consultative Committee for Thermometry (CCT)

20th Meeting (April 2000)

Note on the use of the English text

To make its work more widely accessible the Comité International des Poids et Mesures publishes an English version of its reports.

Readers should note that the official record is always that of the French text. This must be used when an authoritative reference is required or when there is doubt about the interpretation of the text.

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THE BIPM AND THE METRE CONVENTION

The Bureau International des Poids et Mesures (BIPM) was set up by the Metre Convention signed in Paris on 20 May 1875 by seventeen States during the final session of the diplomatic Conference of the Metre. This Convention was amended in 1921.

The BIPM has its headquarters near Paris, in the grounds (43 520 m^2) of the Pavillon de Breteuil (Parc de Saint-Cloud) placed at its disposal by the French Government; its upkeep is financed jointly by the Member States of the Metre Convention.

The task of the BIPM is to ensure worldwide unification of physical measurements; its function is thus to:

- establish fundamental standards and scales for the measurement of the principal physical quantities and maintain the international prototypes;
- carry out comparisons of national and international standards;
- ensure the coordination of corresponding measurement techniques;
- carry out and coordinate measurements of the fundamental physical constants relevant to these activities.

The BIPM operates under the exclusive supervision of the Comité International des Poids et Mesures (CIPM) which itself comes under the authority of the Conférence Générale des Poids et Mesures (CGPM) and reports to it on the work accomplished by the BIPM.

Delegates from all Member States of the Metre Convention attend the General Conference which, at present, meets every four years. The function of these meetings is to:

- discuss and initiate the arrangements required to ensure the propagation and improvement of the International System of Units (SI), which is the modern form of the metric system;
- confirm the results of new fundamental metrological determinations and various scientific resolutions of international scope;
- take all major decisions concerning the finance, organization and development of the BIPM.

The CIPM has eighteen members each from a different State: at present, it meets every year. The officers of this committee present an annual report on

the administrative and financial position of the BIPM to the Governments of the Member States of the Metre Convention. The principal task of the CIPM is to ensure worldwide uniformity in units of measurement. It does this by direct action or by submitting proposals to the CGPM.

The activities of the BIPM, which in the beginning were limited to measurements of length and mass, and to metrological studies in relation to these quantities, have been extended to standards of measurement of electricity (1927), photometry and radiometry (1937), ionizing radiation (1960) and to time scales (1988). To this end the original laboratories, built in 1876 -1878, were enlarged in 1929; new buildings were constructed in 1963-1964 for the ionizing radiation laboratories and in 1984 for the laser work. In 1988 a new building for a library and offices was opened.

Some forty-five physicists and technicians work in the BIPM laboratories. They mainly conduct metrological research, international comparisons of realizations of units and calibrations of standards. An annual report, now published separately in the *Director's Report on the Activity and Management of the Bureau International des Poids et Mesures*, gives details of the work in progress.

Following the extension of the work entrusted to the BIPM in 1927, the CIPM has set up bodies, known as Consultative Committees, whose function is to provide it with information on matters that it refers to them for study and advice. These Consultative Committees, which may form temporary or permanent working groups to study special topics, are responsible for coordinating the international work carried out in their respective fields and for proposing recommendations to the CIPM concerning units.

The Consultative Committees have common regulations (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1963, **31**, 97). They meet at irregular intervals. The chairman of each Consultative Committee is designated by the CIPM and is normally a member of the CIPM. The members of the Consultative Committees are metrology laboratories and specialized institutes, agreed by the CIPM, which send delegates of their choice. In addition, there are individual members appointed by the CIPM, and a representative of the BIPM (Criteria for membership of Consultative Committees, *BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1996, **64**, 124). At present, there are ten such committees:

1 The Consultative Committee for Electricity and Magnetism (CCEM), new name given in 1997 to the Consultative Committee for Electricity (CCE) set up in 1927;

2 The Consultative Committee for Photometry and Radiometry (CCPR), new name given in 1971 to the Consultative Committee for Photometry (CCP) set up in 1933 (between 1930 and 1933 the CCE dealt with matters concerning photometry);

3 The Consultative Committee for Thermometry (CCT), set up in 1937;

4 The Consultative Committee for Length (CCL), new name given in 1997 to the Consultative Committee for the Definition of the Metre (CCDM), set up in 1952;

5 The Consultative Committee for Time and Frequency (CCTF), new name given in 1997 to the Consultative Committee for the Definition of the Second (CCDS) set up in 1956;

6 The Consultative Committee for Ionizing Radiation (CCRI), new name given in 1997 to the Consultative Committee for Standards of Ionizing Radiation (CCEMRI) set up in 1958 (in 1969 this committee established four sections: Section I (X- and γ-rays, electrons), Section II (Measurement of radionuclides), Section III (Neutron measurements), Section IV (α-energy standards); in 1975 this last section was dissolved and Section II was made responsible for its field of activity);

7 The Consultative Committee for Units (CCU), set up in 1964 (this committee replaced the "Commission for the System of Units" set up by the CIPM in 1954);

8 The Consultative Committee for Mass and Related Quantities (CCM), set up in 1980;

9 The Consultative Committee for Amount of Substance (CCQM), set up in 1993;

10 The Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV), set up in 1998.

The proceedings of the General Conference, the CIPM and the Consultative Committees are published by the BIPM in the following series:

- *Comptes Rendus des Séances de la Conférence Générale des Poids et Mesures;*
- *Procès-Verbaux des Séances du Comité International des Poids et Mesures;*
- *Reports of Meetings of Consultative Committees.*

The BIPM also publishes monographs on special metrological subjects and, under the title *Le Système International d'Unités (SI)*, a brochure, periodically updated, in which are collected all the decisions and recommendations concerning units.

The collection of the *Travaux et Mémoires du Bureau International des Poids et Mesures* (22 volumes published between 1881 and 1966) and the *Recueil de Travaux du Bureau International des Poids et Mesures* (11 volumes published between 1966 and 1988) ceased by a decision of the CIPM.

The scientific work of the BIPM is published in the open scientific literature and an annual list of publications appears in the *Director's Report on the Activity and Management of the Bureau International des Poids et Mesures*.

Since 1965 *Metrologia*, an international journal published under the auspices of the CIPM, has printed articles dealing with scientific metrology, improvements in methods of measurement, work on standards and units, as well as reports concerning the activities, decisions and recommendations of the various bodies created under the Metre Convention.

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR THERMOMETRY

as of 12 April 2000

President

Dr H. Ugur, member of the Comité International des Poids et Mesures, National Metrology Institute of Turkey/Ulusal Metroloji Enstitüsü [UME], Gebze-Kocaeli.

Executive secretary

Dr R. Köhler, Bureau International des Poids et Mesures [BIPM], Sèvres.

Members

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

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], Taejon.

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 [CSIRO-NML], Lindfield.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

National Research Laboratory of Metrology [NRLM], Tsukuba.

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

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

The Director of the Bureau International des Poids et Mesures [BIPM], Sèvres.

Observers

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

Instituto Português da Qualidade [IPQ], Caparica.

Singapore Productivity and Standards Board [PSB], Singapore.

Consultative Committee for Thermometry

Report of the 20th meeting

(12–14 April 2000)

to the Comité International des Poids et Mesures

Agenda

1 Opening of the meeting; appointment of the rapporteur; approval of the agenda.

2 Report of the working groups:

- 2.1 Working Group 1: defining fixed points and interpolating instruments;
- 2.2 Working Group 2: secondary fixed points and techniques of approximation to the ITS-90;
- 2.3 Working Group 3: international equivalence of temperature measurements and corresponding international comparisons;
- 2.4 Working Group 4: thermodynamic temperature determinations and extension of the ITS-90 to lower temperatures;
- 2.5 Working Group 5: joint CCT/CCPR working group on thermodynamic temperature determinations for high-temperature black bodies;
- 2.6 Working Group 6: humidity measurements.

3 Status of the CCT key comparisons:

- 3.1 Mutual Recognition Arrangement;
- 3.2 Key comparison CCT-K1: realizations of the ITS-90 from 0.65 K to 24.5561 K using rhodium-iron resistance thermometers;
- 3.3 Key comparison CCT-K2: realizations of the ITS-90 from 13.8 K to 273.16 K using capsule-type standard platinum resistance thermometers;
- 3.4 Key comparison CCT-K3: realizations of the ITS-90 from 83.8 K to 933.5 K using long-stem standard platinum resistance thermometers;
- 3.5 Key comparison CCT-K4: comparisons of Al-Ag fixed points;
- 3.6 Key comparison CCT-K5: realizations of the ITS-90 between the silver point and 1700 °C using vacuum strip lamps as transfer standards.

4 Studies concerning the ITS-90.

5 Role of the CCT in instrumentation and measurement classification for Appendix C of the MRA.

6 Report to the CIPM and recommendation.

7 Establishment and composition of working groups of the CCT.

8 Other business.

9 Date of next meeting.

Remark:

This meeting came to an abrupt halt when Dr John Nicholas had a heart attack. His subsequent death was a shock to all present. The meeting reconvened to commemorate this dear friend and colleague and thereafter discussed only the issues that needed immediate attention. Consequently, some items were not discussed in great detail.

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

The twentieth meeting of the Consultative Committee for Thermometry (CCT) took place at the Pavillon de Breteuil, Sèvres, on 12, 13 and 14 April 2000.

Present: D.N. Astrov (VNIIFTRI), M. Ballico (CSIRO-NML), R.E. Bedford (NRC), G. Bonnier (BNM-INM), Y. Duan (NIM), S. Duris (SMU), M.J. de Groot (NMi-VSL), Y. Hermier (BNM-INM), K.D. Hill (NRC), P. Huang (NIST), K.H. Kang (KRISS), M. Kühne (PTB), P. Marcarino (IMGC-CNR), K. Nara (NRLM), J. Nicholas (MSL), A. Ono (NRLM), F. Pavese (IMGC-CNR), A.I. Pokhodun (VNIIM), T.J. Quinn (Director of the BIPM), T. Ricolfi (IMGC-CNR), D.C. Ripple (NIST), R. Rusby (NPL), J. Seidel (PTB), A. Steele (NRC), H. Ugur (UME, President of the CCT).

Invited and observers: V. Chimenti (CEM), M. Durieux (KOL), P. Bloembergen (NMi-VSL), M.E. Filipe (IPQ), R.P. Hudson, H. Liedberg (CSIR-NML), E. Mendez (CENAM), Wang Li (PSB).

Also present: P. Giacomo (Director Emeritus of the BIPM); R. Köhler (Executive Secretary of the CCT), C. Thomas and M. Stock (BIPM).

Dr Quinn reviewed the work accomplished at the BIPM during the past four years on behalf of the CCT and reflected that, at the 1996 meeting, key comparisons had been launched prior to regulations coming into place with reference to the Mutual Recognition Arrangement (MRA), copies of which were distributed among the participants. Copies were also made available of the CIPM report “National and International Needs Relating to Metrology” and of the March 2000 version of the “Directory of Consultative Committees”, the last update of which is also accessible from the BIPM web pages.

It was announced that Dr Ugur is the new President of the CCT.

The president expressed the gratitude of the CCT for the long-standing work of Dr M. Durieux who had acted as rapporteur at the CCT meetings for the last thirty years. Mr M. de Groot was appointed rapporteur.

The agenda was approved with minor modifications. It was agreed that documents presented to the meeting should be discussed under the appropriate items of the agenda. These documents are listed in Appendix T 1.

2 REPORT OF THE WORKING GROUPS

2.1 Working Group 1: defining fixed points and interpolating instruments

Representing the working group, Dr Bloembergen summarized the work reported in CCT/2000-11 and -13. The working group is making progress with the revision of the *Supplementary Information for the ITS-90*: the text is being revised and the references are to be updated. Dr Bloembergen requested the laboratories to provide the working group with relevant information; the revisions are to include improved techniques for the realization of fixed points and the use of interpolation thermometers. New data on non-uniqueness are to be included; special concern will be given to a detailed description of uncertainty and its propagation in the ITS-90. The working group aims to include the low-temperature extension of the ITS-90 subject to the outcome of its discussions at this meeting.

Following some discussion it was decided that the working group should address the issue of impurities in fixed points.

2.2 Working Group 2: secondary fixed points and techniques of approximation to the ITS-90

According to Dr Bedford, chairman of Working Group 2, the working group considered that its tasks were not of an urgent character, as argued in document CCT/2000-3. The representative to the working group of the PTB is Dr Tegeler, not Mr Edler as stated in the document. The revision of the document *Techniques for Approximating the ITS-90* is now needed and it is therefore important that the working group continue its activities. A timetable was proposed that would result in a first draft of a monograph in one year, but in the discussion that followed it was agreed that before moving to a first draft the working group should produce an outline to be circulated to the CCT members for comment. An item deserving more attention in the revised monograph concerns the uncertainties that can be obtained with the approximation techniques.

2.3 Working Group 3: international equivalence of temperature measurements and corresponding international comparisons

Dr Bonnier described the activities of this large working group. Further details can be found in document CCT/2000-15. A major item for the group to discuss was the progress of the key comparisons. In January 2000, a meeting in Washington was held between the coordinators of the key comparisons and Working Group 3. A second meeting involving these parties immediately preceded this CCT meeting. For the purpose of these meetings the working group members were allowed to read the draft A reports of the key comparisons. Individual key comparisons were discussed under the relevant items of the agenda. Dr Ugur suggested that the CCT call for a workshop on the uncertainty analysis of one fixed point (water triple point). The working group was called upon to identify those fixed points where no consensus had been reached in the area of uncertainties.

Regarding protocols for key comparisons, it was decided to require these for all key comparisons, including those that are ongoing, so that RMO key comparisons (carried out by Regional Metrology Organizations) can be verified to match the CCT key comparisons. With respect to key comparison CCT-K3, it was felt that the protocols of proposed regional key comparisons need not necessarily be completely identical to that of the CCT key comparison. The protocols must guarantee that the results of the RMO key comparison are compatible with and can be compared with those of the CCT key comparison. For the protocols of RMO key comparisons relating to key comparison CCT-K3 it was concluded that the temperature range need not be extended to the aluminium point. Coordinators of ongoing key comparisons were called upon to provide the protocols of their key comparisons to the executive secretary of the CCT, Dr Köhler. [Later in the meeting, under item 7, it was decided that the chairman of the newly appointed Working Group 7 on Key Comparisons, Dr Pavese, would collect all protocols of the ongoing key comparisons.]

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

Dr Rusby referred to documents CCT/2000-26 and -26a, where section 1 of document CCT/2000-26 contains the main conclusion of the work of Working Group 4. The working group proposed the provisional scale “PLTS-2000" as defined in document CCT/2000-26a. This scale is a compromise comprising

various supporting scales rather than the result of a consensus. However, this provisional scale was proposed for adoption by the CCT in the absence of new measurements. Appendix 1 of document CCT/2000-26 is an abstract of the 21 January 2000 meeting of the working group. Full minutes of this meeting can be obtained from the working group chairman.

It was decided that the working group should draw up a recommendation for adoption by the CCT with respect to the temperature scale extension before the end of the meeting. The working group will provide information on the provisional scale for the document *Supplementary Information*.

2.5 Working Group 5: joint CCT/CCPR working group on thermodynamic temperature determinations for high-temperature black bodies

The CCT proposed that the working group be abandoned since the aims of this group had been completed. The meeting of 1996 saw the result of the work of this working group summarized in CCT Recommendation T 2 (1996). There has not been enough progress in experimental work as called for in this recommendation to justify continuation of this working group. The CCPR was also requested to dissolve this group.

2.6 Working Group 6: humidity measurements

Dr Huang presented a report on this new group. The working group indicated that it had not been able to draft a proposal for a key comparison on humidity despite lengthy discussions. The working group and CCT regard such a key comparison as imperative for the related laboratories. One key comparison was approved for which this working group is called upon to draft a key comparison protocol for approval by the CCT by correspondence. Once the CCT has approved the protocol, the president of the CCT has to inform the coordinator of the BIPM key comparison database. It was noted that there is room in the database for provisional comparisons such as the ongoing APMP dew point comparison.

3 STATUS OF THE CCT KEY COMPARISONS

3.1 Mutual Recognition Arrangement

Dr Quinn introduced the Mutual Recognition Arrangement of National Measurement Standards and of Calibration and Measurement Certificates issued by National Metrology Institutes (MRA) that was approved by the CGPM in 1999 and signed by directors of the national metrology institutes in October 1999. The objectives of the MRA are stated on page 28 of the document. This MRA will remain unchanged until the next CGPM meeting in 2003. Only then will amendments be possible based on the experience gained.

The BIPM key comparison database contains appendices A (list of signatories to the MRA), B (results of CIPM/RMO/supplementary key comparisons), C (Calibration Measurement Capabilities, CMCs) and D (listed key comparisons) as explained on page 41 of the MRA. The tasks of the CCT involve the choice and implementation of key comparisons as well as affirming the validity of the results as stated in T.8, page 39 of the MRA. The CCT decided to establish a working group on key comparisons to approve the results of key comparisons.

Moreover, as part of ongoing activities, the CCT has the task of updating the CMCs in Appendix C. The RMOs screen the data, and the CCT is required to examine the results to see if there are anomalies. This point returns under item 5 of this meeting.

The CCT was called for a decision on the procedure for arriving at a key comparison reference value. This is related to the BIPM key comparison database entries for MRA Appendix B.

3.2 Key comparison CCT-K1: realizations of the ITS-90 from 0.65 K to 24.5561 K using rhodium-iron resistance thermometers

Dr Rusby reported that the key comparison CCT-K1 had been ongoing since 1996 and that the NPL had made the first measurement run on thermometers supplied by the NIST, NMi-VSL, NPL, NRC, NRLM and PTB in 1998. Thermometers from the KRISS and VNIIFTRI are now being measured. No information will be released from the NPL because not all the data are yet available. Consequently, draft A is not ready. Few of the participating

laboratories fully realized the ITS-90 in this range. It was decided that all laboratories can participate that realize the scale to the best of their abilities, either through direct realization of the ITS-90 or through approximation techniques. Standard uncertainties for key comparisons have to be expressed at a 95 % confidence interval.

Some initial and non-identifiable results were shown.

3.3 Key comparison CCT-K2: realizations of the ITS-90 from 13.8 K to 273.16 K using capsule-type standard platinum resistance thermometers

Dr Steele mentioned that capsule-type standard platinum resistance thermometers (SPRTs) were measured for the BNM-INM, IMGC, KRISS, NIST, NMi-VSL, NPL, NRC, PTB, and VNIIFTRI. The NMi-VSL and VNIIFTRI withdrew from the key comparison for technical reasons. The NMi-VSL withdrew before draft A was distributed between the partners. A new measurement cycle is under way. The thermometers were compared in a comparator block at all ITS-90 fixed points and at sufficient temperatures between the fixed point temperatures. This will allow conclusions to be drawn from this comparison about the agreement of the scale realizations of the laboratories and about the non-uniqueness of the scale between the fixed points. Draft A for the first measurement cycle is under discussion between the participating laboratories.

It was recognized that the key comparisons had started prior to the MRA and before the guidelines for CIPM key comparison (Appendix F to the MRA) had been decided and defined. Deviations from these guidelines for all ongoing key comparisons are to be inventoried by a new working group on key comparisons established during this meeting under item 7. Deviations, such as withdrawal from the key comparison unrelated to the travelling standard or a clear phenomenon, can only be accepted for the ongoing CCT key comparisons with the approval of all the participating laboratories to the key comparisons and need to be discussed in the key comparison report.

3.4 Key comparison CCT-K3: realizations of the ITS-90 from 83.8 K to 933.5 K using long-stem standard platinum resistance thermometers

The coordinator of this key comparison (Dr Mangum) did not present the results to this meeting because the draft B of the report was not yet available. Discussions on draft A of the report are ongoing. Dr Ripple of the coordinating laboratory commented that there were some discrepancies in the results of this key comparison that were to be resolved by further bilateral comparisons. The report did not contain a key comparison reference value by preference of the coordinator. The CCT was asked to decide on the necessity of reference values in this report. Because of further developments during the meeting this item was deferred until the next meeting of the CCT and for this report a solution must be reached between the coordinator and the afore-mentioned CCT Working Group on Key Comparisons.

There were some changes in subsequent versions of draft A that the meeting required to be documented in the report. These will be identified in collaboration with the Working Group on Key Comparisons. The coordinator was asked to analyze the data in collaboration with the subcoordinators. To assure participating laboratories' confidence in the reported data, the CCT agreed that all data and uncertainties will be supplied to the participating laboratories to allow them to verify the correctness of their entries in the report before a deadline that is fixed by the coordinator. The report will be based upon the consensus between the participating laboratories and presented to the next meeting of the CCT.

Despite the retirement of the coordinator of CCT-K3, the CCT asked the NIST to continue its activities in this comparison.

3.5 Key comparison CCT-K4: comparisons of Al-Ag fixed points

Dr Seidel reported on behalf of the coordinator that draft A of the key comparison of aluminium and silver fixed points for contact thermometers was not yet available as the last measurements are in progress. The data are incomplete and cannot be analysed yet. The coordinator asked the CCT to declare whether it was for or against the use of a key comparison reference value. As the meeting was not able to resolve the issue, this question was left open for response from the CCT Working Group on Key Comparisons.

3.6 Key comparison CCT-K5: realizations of the ITS-90 between the silver point and 1700 °C using vacuum strip lamps as transfer standards

Mr de Groot gave a report on the tungsten ribbon lamp key comparison. Draft A had been distributed to the participating laboratories and was under discussion. These discussions focus at present around an uncertainty budget, as was decided during the CCT Working Group 3 meeting in January 2000. A proposal was made to arrive at a list of entries in the uncertainties that could be used by all participants to report their uncertainty budget. The list of entries as proposed by the coordinator was not acceptable for many of the participants. The CCT decided that such a list would be useful and needed for comparability of results, but could not be a reason for delaying the report of this key comparison. The coordinator was asked to continue his work for this uncertainty budget as a separate activity, but to emphasize the priority of a draft B report in which the uncertainties are to be reported by the participants in the same manner as they do in their laboratory reports.

The CCT was also asked by the CCT Working Group 3 to discuss the issue that the NRC wishes to amend its data to the key comparison for technical reasons, as elaborated in document CCT/2000-12. The laboratory argued that the coordinator had not identified their results as anomalous before the circulation of the draft report and had not allowed the NRC to check the data. It was decided that the coordinator would ask all the participants in CCT-K5 to give their approval to the NRC for its proposed changes. If all the laboratories agreed, the data would be amended with proper reference and explanation in the report. The CCT agreed unanimously that the Working Group on Key Comparisons has to be informed on this and other matters that could be in conflict with the guidelines. The Working Group on Key Comparisons would decide on all questions that could conflict with the guidelines for key comparisons and summarize their findings in a recommendation to be approved and authorized at the next CCT meeting. Those issues on which the working group cannot reach a conclusion will be left for detailed discussion in the CCT. Thus, the working group can provide the basis for new key comparisons that can take place in clear agreement within the existing guidelines, while all problems that occur in ongoing key comparisons because of the unclear status of the guidelines can now be resolved separately.

As to the withdrawal of NMi-VSL and VNIIFTRI from CCT-K2, the CCT agreed to their removal once arguments by the NRC had been made

attributing these two cases to a faulty travelling standard, and as all participants in the key comparison had agreed to the withdrawals.

The case when a coordinator of a key comparison is not willing to present the findings to the CCT was discussed. It was accepted that such an instance could occur if financial restrictions prevented the pilot from performing its coordinating duties. The CCT or the Working Group on Key Comparisons would make a decision on each issue as it occurred.

In instances where the travelling standard fails, the meeting considered it possible that measurements of a single laboratory could be repeated before disclosure of the data. In such cases all the participants have to be informed. Dr Quinn added that the guidelines were written so as to avoid the possibility of unilateral action by a participant and therefore agreement is required by all participants. The decisions by the key comparison participants are to be confirmed by the CCT when approving the key comparison report.

Is the Working Group on Key Comparisons allowed to question each other's results and/or uncertainties? The ongoing key comparisons do not have protocols that describe the uncertainty evaluation in great detail. The coordinator can ask the uncertainties of individual laboratories to be clarified on the request of other participating laboratories. It was proposed that each other's uncertainties be accepted. There can be no leverage on a laboratory to change its uncertainties. Leverage is possible when the input for Appendix C is screened.

The matter of a key comparison reference value was left for the coordinators of ongoing key comparisons to handle in contact with the participants. The CCT will discuss the issue for CCT key comparisons during its next meeting.

4 STUDIES CONCERNING THE ITS-90

It was decided that there should be CCT-sponsored workshops on studies related to the ITS-90 with reliance on the role of CCT documents. CCT documents cannot be discussed in sufficient detail during the CCT meetings. Instead, these discussions could be held during workshops dedicated to specific subjects.

5 ROLE OF THE CCT IN INSTRUMENTATION AND MEASUREMENT CLASSIFICATION FOR APPENDIX C OF THE MRA

The CMC entries (Appendix C of the MRA) for thermometry are on the agenda of the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) for its meeting in March 2001 [note: the date has since been postponed]. To meet this date, CMC data for national thermometry laboratories are to be circulated within regions during and before October 2000. Replies from the RMOs can be obtained until January 2001.

There are two formats proposed for the CMC entries. One is described in document CCT/2000-27 as a result of discussions within the APMP. The EUROMET arrived through similar discussions at the format given in CCT/2000-32. The APMP format is user-oriented, while the EUROMET format follows a metrological approach.

The structure of the CMC tables has been decided by the JCRB. Changes of this structure, as proposed by the APMP in document CCT/2000-30, can only be brought about on the long term and through the JCRB. The interpretation of the column headings as prescribed by the JCRB is a matter for the RMOs.

6 REPORT TO THE CIPM AND RECOMMENDATION

The extension to ITS-90 below 0.65 K was discussed. This extension is named Provisional Low Temperature Scale of 2000, PLTS-2000. The scale is labelled provisional because its uncertainty below 10 mK is larger than desirable. Also, not all the work supporting this scale has been published in refereed journals. The scale is reliable, however, and there is a genuine need for it. The PLTS-2000 overlaps with ITS-90 between 0.65 K and 1 K to correct for the deviations of ITS-90 as shown by thermodynamic measurements. Such an overlap also existed between the IPTS-68 and EPT-76 at the low end of the IPTS-68. In the overlapping range the temperatures can be distinguished by the index: T_{2000} refers to the PLTS-2000, while T_{90} refers to ITS-90. The CCT unanimously accepted the PLTS-2000 and its text is attached to the recommendation to the CIPM.

7 ESTABLISHMENT AND COMPOSITION OF THE WORKING GROUPS OF THE CCT

In general the working groups will be continued until the next meeting of the CCT under the same directives as established at the last meeting. Changes are recorded below. It should be noted that members are laboratories, not persons. In some cases, where members of the working group were already active in the former working group, their personal membership can be continued.

Working Group 1 on Defining Fixed Points and Interpolating Instruments will be continued with Dr Ripple of NIST as chairman. The meeting decided to add the BNM-INM and the NRC as new members to the existing working group, the latter comprising the IMGC-CNR, NMi-VSL, PTB and the VNIIM.

Working Group 2 on Secondary Fixed Points and Techniques of Approximation to the ITS-90 will be continued with Dr Steele of NRC as chairman. Of the existing members, i.e. the IMGC, KRISS, NIM and PTB, the IMGC and KRISS have decided to withdraw. The CCT accepted the NRLM as a new member of this working group and invited the MSL to be a member.

Working Group 3 (on International Equivalence in Temperature Measurements and Corresponding International Comparisons) will continue with Dr Bonnier of the BNM as chairman. The working group will no longer be involved in key comparisons. It will be called the "Working Group on Uncertainties". Present members are the CSIRO-NML, IMGC, KRISS, NIST, NMi-VSL, PTB and SMU. The KRISS has decided to withdraw from the group. The NRLM has been accepted as a new member.

Working Group 4 on Thermodynamic Temperature Determinations and Extension of the ITS-90 to Lower Temperatures will continue with Dr Rusby of NPL as chairman. Members of the working group are Dr M. Durieux of the KOL, Dr R.P. Hudson, as an expert, and the IMGC, MSL and PTB. The IMGC has withdrawn from the working group. The NIST was asked to provide a member to this working group and accepted the invitation.

Working Group 5 was established as a new Working Group on Radiation Thermometry. Dr Fischer of the PTB was appointed unanimously as chairman. Members are the CSIRO, IMGC-CNR, KRISS, NIM, NIST, NMi-VSL, NPL, NRLM, PSB and VNIIM. The MSL was invited to be a member.

Working Group 6 on Humidity Measurements will continue with P. Huang of the NIST as chairman. Members are the IMGC, NPL, NRLM and VNIIM. The CCT accepted the BNM-INM, KRISS, NIM and PSB as new members.

Working Group 7 on Key Comparisons was established as a new working group. Members of the working group are the pilot laboratories of ongoing key comparisons. Whenever a new key comparison is started, the pilot laboratory of that key comparison will be a new member of this working group until the key comparison is completed and its report accepted by the CCT. From this rule it follows that the NIST, NMi-VSL, NPL, NRC and PTB are members of this working group. The chairman of Working Group 3 is a personal [*ex officio*] member. The IMGC-CNR and the KRISS were accepted by the CCT as regular members. The chairman of the working group is Dr Pavese of IMGC-CNR. The executive secretary of the CCT provides support to the working group and is a non-voting member.

Working Group 8 was newly established as the "CMC Working Group". As members the regions are invited to nominate one representative through their presidents. Additional participants are the IMGC-CNR and the NPL. Dr Ono of the NRLM is the chairman. The first task for this working group is to finalize the equipment list for the CMC table by 15 June 2000.

These working groups take effect as of this CCT meeting.

8 OTHER BUSINESS

Key comparisons. The procedure is that proposed key comparisons are first discussed by the Working Group on Key Comparisons and then finalized by the CCT. Bilateral supplementary comparisons can start when they have been registered by the executive secretary of the CCT, as laid out in paragraph 10 of the guidelines.

During the next meeting the CCT will discuss voting and decisions by correspondence.

The matching of RMO key comparisons was discussed. The APMP key comparison linked to CCT-K3 and the proposed EUROMET key comparison linked to CCT-K3 do not include the aluminium point. The CCT agreed that

the compatibility between regional key comparisons and CIPM key comparisons is the responsibility of the RMO. If the RMO judges that there might be a difference in protocol that could jeopardize this compatibility the RMO can contact the Working Group on Key Comparisons.

The president introduced document CCT/2000-33. The list contains items for discussion during coming meetings. The aim is to document the rules of operation of the CCT. This list of rules should cover its organization, MRA issues, scientific work and operations. As to organization, the list contains entries on objectives, vision, membership and management that need to be clarified in such a document. The president distributed the list, appreciating feedback on the entries, and requested that all the participants send him other entries before the end of the summer. On the basis of this feedback the president will then produce a draft "Rules of Operation" sufficiently in time (at least two months) before the next meeting to allow discussion within the laboratories. This draft can be finalized during the next meeting of the CCT. The president will inform the members of the CCT directly about progress on this subject through separate e-mail communication.

9 DATE OF NEXT MEETING

The next meeting of the CCT will be held during the week of 10-14 September 2001, on Wednesday through Friday, with working groups meeting on Monday 10 and Tuesday 11 September.

M. de Groot, Rapporteur
November 2000,
revised March 2001

RECOMMENDATION OF THE CONSULTATIVE COMMITTEE FOR THERMOMETRY SUBMITTED TO THE COMITÉ INTERNATIONAL DES POIDS ET MESURES

Recommendation T 1 (2000): Extension of the International Temperature Scale below 0.65 K*

The Consultative Committee for Thermometry,

considering

- Resolution 9 of the 21st Conférence Générale des Poids et Mesures inviting the Comité International des Poids et Mesures to prepare a ^{3}He melting pressure equation as a function of thermodynamic temperature to serve as the basis for an extension of the International Temperature Scale of 1990 (ITS-90) below its present lower limit of 0.65 K,
- that agreement has now been reached on a Provisional Low Temperature Scale, 0.9 mK to 1 K, PLTS-2000,

recommends that the PLTS-2000 be adopted on a provisional basis.

* This recommendation was adopted by the CIPM at its 89th meeting in 2000 as Recommendation 1 (CI-2000).

Appendix to Recommendation T 1 (2000)

The Provisional Low Temperature Scale from 0.9 mK to 1 K, PLTS-2000

1 The scale

The scale is defined by the following equation relating the melting pressure p of ^{3}He to temperature T_{2000}:

$$p / \mathrm{MPa} = \sum_{i=-3}^{+9} a_i (T_{2000} / \mathrm{K})^i$$

$$\begin{aligned}
a_{-3} &= -1.385\,544\,2 \cdot 10^{-12} \\
a_{-2} &= 4.555\,702\,6 \cdot 10^{-9} \\
a_{-1} &= -6.443\,086\,9 \cdot 10^{-6} \\
a_{0} &= 3.446\,743\,4 \cdot 10^{0} \\
a_{1} &= -4.417\,643\,8 \cdot 10^{0} \\
a_{2} &= 1.541\,743\,7 \cdot 10^{1} \\
a_{3} &= -3.578\,985\,3 \cdot 10^{1} \\
a_{4} &= 7.149\,912\,5 \cdot 10^{1} \\
a_{5} &= -1.041\,437\,9 \cdot 10^{2} \\
a_{6} &= 1.051\,853\,8 \cdot 10^{2} \\
a_{7} &= -6.944\,376\,7 \cdot 10^{1} \\
a_{8} &= 2.683\,308\,7 \cdot 10^{1} \\
a_{9} &= -4.587\,570\,9 \cdot 10^{0}
\end{aligned}$$

2 Background to the PLTS-2000

The melting pressure of ^{3}He was chosen as the property on which the extension of the ITS-90 should be based because of the sensitivity and reliability with which it may be measured over a wide range (covering more than three decades of temperature) apart from a narrow region around the pressure minimum at 315.24 mK (see Figure). The pressure minimum itself has the compensating advantage of providing a convenient pressure fixed point for calibrating the pressure transducer (the pressure must be measured using a transducer *in situ* because for temperatures below the minimum a sensing line will be blocked with solid ^{3}He and the cell is therefore isolated).

The pressure minimum is one of four natural features which may be located and used as fixed points of pressure and temperature, the others being the transition to the superfluid 'A' phase, the 'A to B' transition in the superfluid and the Néel transition in the solid. The pressure and temperature values of these four points on the PLTS-2000 are:

Point	p/MPa	T_{2000}/mK
minimum	2.931 13	315.24
A	3.434 07	2.444
A-B	3.436 09	1.896
Néel	3.439 34	0.902

The standard uncertainty of the scale in thermodynamic terms is estimated to be 0.5 mK down to 500 mK, decreasing linearly to 0.2 mK at 100 mK. It decreases further with falling temperature, but in percentage terms it increases to about 0.3 % of T at 25 mK and 2 % of T at 0.9 mK. The standard uncertainties in the absolute pressures are estimated to be about 60 Pa (in about 3 MPa).

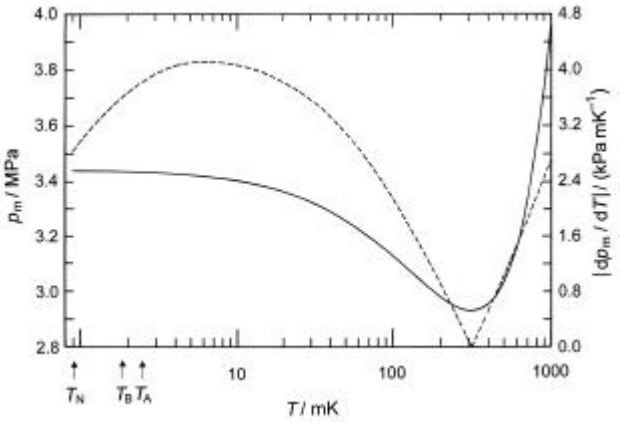

Figure: The ^{3}He melting pressure p (full line) and the absolute value of the derivative dp/dT (dashed line) *vs.* temperature. T_N, T_B and T_A indicate the temperatures of three phase transitions in solid or liquid ^{3}He.

APPENDIX T 1.
Working documents submitted to the CCT at its 20th meeting

(see the list of documents on page 36)

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories, committees and conferences

APMP	Asia/Pacific Metrology Programme
BIPM	Bureau International des Poids et Mesures
BNM	Bureau National de Métrologie, Paris (France)
BNM-CNAM	Bureau National de Métrologie, Conservatoire National des Arts et Métiers, Paris (France)
BNM-INM	Bureau National de Métrologie, Institut National de Métrologie, Paris (France)
CCPR	Consultative Committee for Photometry and Radiometry
CCT	Consultative Committee for Thermometry
CEM	Centro Español de Metrología, Madrid (Spain)
CENAM	Centro Nacional de Metrología, Mexico (Mexico)
CIPM	Comité International des Poids et Mesures
CMA/MIKES	Centre for Metrology and Accreditation/Mittatekniikan Keskus, Helsinki (Finland)
CNAM	Conservatoire National des Arts et Métiers, Paris (France), see BNM-CNAM
CSIR-NML	Council for Scientific and Industrial Research, National Metrology Laboratory, Pretoria (South Africa)
CSIRO-NML	CSIRO, National Measurement Laboratory, Lindfield (Australia)
EUROMET	European Collaboration in Measurement Standards
IAC	Istituto per le Applicazioni del Calcolo « M. Picone », Rome (Italy)
IMGC-CNR	Istituto di Metrologia G. Colonnetti, Consiglio Nazionale delle Ricerche, Turin (Italy)
INM	Institut National de Métrologie, Paris (France), see BNM
IPQ	Instituto Português da Qualidade, Lisbon (Portugal)
JCRB	Joint Committee of the Regional Metrology Organizations and the BIPM
KOL	Kamerlingh Onnes Laboratorium, Leiden (The Netherlands)
KRISS	Korea Research Institute of Standards and Science, Taejon (Rep. of Korea)

Metas	(formerly the OFMET) Office Fédéral de Métrologie et d'Accréditation, Wabern (Switzerland)
MRA	Mutual Recognition Arrangement
MSL	Measurement Standards Laboratory of New Zealand, Lower Hutt (New Zealand)
NIM	National Institute of Metrology, Beijing (China)
NIST	National Institute of Standards and Technology, Gaithersburg (United States)
NMi-VSL	Nederlands Meetinstituut, Van Swinden Laboratorium, Delft (The Netherlands)
NPL	National Physical Laboratory, Teddington (United Kingdom)
NRC	National Research Council of Canada, Ottawa (Canada)
NRC-INMS	National Research Council of Canada, National Institute for Measurement Standards, Ottawa (Canada)
NRLM	National Research Laboratory of Metrology, Tsukuba (Japan)
OFMET*	Office Fédéral de Métrologie, Wabern (Switzerland), see Metas
PSB	Singapore Productivity and Standards Board (Singapore)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin (Germany)
RMO	Regional Metrology Organization
SMU	Slovenský Metrologický Ústav/Slovak Metrology Institute, Bratislava (Slovakia)
SP	Sveriges Provnings- och Forskningsinstitut/Swedish National Testing and Research Institute, Borås (Sweden)
UME	Ulusal Metroloji Enstitüsü/National Metrology Institute, Gebze-Kocaeli (Turkey)
VNIIFTRI	Institute for Physical, Technical and Radio-Technical Measurements, Gosstandart of Russia, Moscow (Russian Fed.)
VNIIM	D.I. Mendeleyev Institute for Metrology, Gosstandart of Russia, St Petersburg (Russian Fed.)
VSL	Van Swinden Laboratorium, Delft (The Netherlands), see NMi

* Organizations marked with an asterisk either no longer exist or operate under a different acronym.

2 Acronyms for scientific terms

CMC	Calibration and Measurement Capability
EPT-76	Provisional Low Temperature Scale of 1976/Échelle Provisoire de Température de 1976
HTPRT	High-Temperature Platinum Resistance Thermometer
IPTS-68	International Practical Temperature Scale of 1968
ITS-90	International Temperature Scale of 1990
KCRV	Key Comparison Reference Value
PLTS-2000	Provisional Low Temperature Scale of 2000
SPRT	Standard Platinum Resistance Thermometer