BUREAU INTERNATIONAL DES POIDS ET MESURES

COMITÉ CONSULTATIF DE THERMOMÉTRIE

Rapport de la 18e session
Report of the 18th Meeting

1993

COMITÉ CONSULTATIF DE THERMOMÉTRIE

SESSION DE 1993

MEETING OF 1993

BUREAU INTERNATIONAL DES POIDS ET MESURES

COMITÉ CONSULTATIF DE THERMOMÉTRIE

Rapport de la 18e session
Report of the 18th Meeting

1993

Édité par le BIPM, Pavillon de Breteuil, F-92312 Sèvres Cedex, France

ISSN 0069-6463

ISBN 92-822-2135-0

LISTE DES SIGLES UTILISÉS DANS LE PRÉSENT VOLUME

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1. Sigles des laboratoires, commissions et conférences
Acronyms for laboratories, committees and conferences

BIPM	Bureau international des poids et mesures
CCT	Comité consultatif de thermométrie
CEI/IEC	Commission électrotechnique internationale/International Electrotechnical Commission
CIPM	Comité international des poids et mesures
CNAM	Conservatoire national des arts et métiers, Paris (France)
CSIRO	(ex NML) CSIRO, Division of Applied Physics, Lindfield (Australie)
EUROMET	European Collaboration in Measurement Standards
IEC	*voir* CEI
IMEKO	International Measurement Confederation
IMGC	Istituto di Metrologia G. Colonnetti, Turin (Italie)
INM	Institut national de métrologie, Paris (France)
IRL	Industrial Research Limited, Lower Hutt (Nouvelle-Zélande)
KOL	Kamerlingh Onnes Laboratorium, Leiden (Pays-Bas)
*KSRI	Korea Standards Research Institute, Taejon (Rép. de Corée), *voir* KRISS
KRISS	(ex KSRI) Korea Research Institute of Standards and Science, Taejon (Rép. de Corée)
*NBS	National Bureau of Standards, Gaithersburg (É.-U. d'Amérique), *voir* NIST
NIM	Institut national de métrologie/National Institute of Metrology, Beijing (Rép. pop. de Chine)
NIST	(ex NBS) National Institute of Standards and Technology, Gaithersburg (É.-U. d'Amérique)
NMi	(ex VSL) Nederlands Meetinstituut, Delft (Pays-Bas)
*NML	National Measurement Laboratory, Lindfield (Australie), *voir* CSIRO
NPL	National Physical Laboratory, Teddington (Royaume-Uni)
NRC	Conseil national de recherches du Canada/National Research Council of Canada, Ottawa (Canada)

* Les laboratoires ou organisations marqués d'un astérisque soit n'existent plus soit figurent sous un autre sigle.

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

NRLM	National Research Laboratory of Metrology, Tsukuba (Japon)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig et Berlin (Allemagne)
SMU	Slovenský Metrologický Ústav, Bratislava (Rép. slovaque)
VNIIFTRI	Institut des mesures physicotechniques et radiotechniques/All-Russian Research Institute for Physical, Technical and Radio-Technical Measurements, Moscou (Féd. de Russie)
VNIIM	Institut de métrologie D.I. Mendéléev/D.I. Mendeleyev Institute for Metrology, Saint-Pétersbourg (Féd. de Russie)
*VSL	Van Swinden Laboratorium, Delft (Pays-Bas), *voir* NMi

2. Sigles des termes scientifiques
Acronyms for scientific terms

CMN	Nitrate de cérium-magnésium/Cerium Magnesium Nitrate
EIPT-68/IPTS-68	Échelle internationale pratique de température de 1968/International Practical Temperature Scale of 1968
EIT-90/ITS-90	Échelle internationale de température de 1990/International Temperature Scale of 1990
EPT-76	Échelle provisoire de température de 1976
HTPRT	Thermomètre à résistance de platine à haute température/High-Temperature Platinum Resistance Thermometer
IPRT	Thermomètre à résistance de platine industriel/Industrial Platinum Resistance Thermometer
IPTS-68	*voir* EIPT-68
ITS-90	*voir* EIT-90
PRT	Thermomètre à résistance de platine/Platinum Resistance Thermometer

COMITÉ CONSULTATIF DE THERMOMÉTRIE

MEETING OF 1993

Note on the use of the English text

To make its reports and those of its various Comités Consultatifs more widely accessible the Comité International des Poids et Mesures has decided to publish an English version of these 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.

Note sur l'utilisation du texte anglais

Afin de faciliter l'accès à ses rapports et à ceux des divers Comités consultatifs, le Comité international des poids et mesures a décidé de publier une version en anglais de ces rapports. Le lecteur doit cependant noter que le rapport officiel est toujours celui qui est rédigé en français. C'est le texte français qui fait autorité si une référence est nécessaire ou s'il y a doute sur l'interprétation.

THE BIPM

AND THE CONVENTION DU MÈTRE

The Bureau International des Poids et Mesures (BIPM) was set up by the Convention du Mètre 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.

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 Convention du Mètre*.

The task of the BIPM is to ensure world-wide unification of physical measurements; it is responsible for:

— establishing the fundamental standards and scales for measurement of the principal physical quantities and maintaining the international prototypes;

— carrying out comparisons of national and international standards;

— ensuring the co-ordination of corresponding measuring techniques;

— carrying out and co-ordinating determinations relating to the fundamental physical constants that are involved in the above-mentioned activities.

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).

The Conférence Générale consists of delegates from all the Member States of the Convention du Mètre and meets at present every four years. At each meeting it receives the Report of the Comité International on the work accomplished, and it is responsible for:

— discussing and instigating 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;

— confirming the results of new fundamental metrological determinations and the various scientific resolutions of international scope;

— adopting the important decisions concerning the organization and development of BIPM.

The Comité International consists of eighteen members each belonging to a different State: it meets at present every year. The officers of this committee issue an Annual Report on the administrative and financial position of BIPM to the Governments of the Member States of the Convention du Mètre.

The activities of the BIPM, which in the beginning were limited to the 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 (1937), ionizing radiations (1960), to time scales (1988) and to amount of substance (1993). 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, in 1984 for the laser work and in 1988 a new building for a library and offices was opened.

Some forty physicists or technicians work in the BIPM laboratories. They mainly conduct metrological research, international comparisons of realizations of units and the verification of standards used in the above-mentioned areas. An annual report published

---

* As of 31 December 1994, forty-eight States were members of this Convention: Argentina (Rep. of), Australia, Austria, Belgium, Brazil, Bulgaria, Cameroon, Canada, Chile, China (People's Rep. of), Czech Republic, Denmark, Dominican Republic, Egypt, Finland, France, Germany, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Korea (Dem. People's Rep. of), Korea (Rep. of), Mexico, Netherlands, New Zealand, Norway, Pakistan, Poland, Portugal, Romania, Russian Federation, Singapore, Slovak Republic, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, U.S.A., Uruguay, Venezuela.

in the Procès-Verbaux des séances du Comité International des Poids et Mesures gives the details of the work in progress.

In view of the extension of the work entrusted to the BIPM, the CIPM has set up since 1927, under the name of Comités Consultatifs, bodies designed to provide it with information on matters that it refers to them for study and advice. These Comités Consultatifs, which may form temporary or permanent Working Groups to study special subjects, are responsible for co-ordinating the international work carried out in their respective fields and proposing recommendations concerning units. In order to ensure world-wide uniformity in units of measurement, the Comité International accordingly acts directly or submits proposals for sanction by the Conférence Générale.

The Comités Consultatifs have common regulations (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1963, **31**, 97). Each Comité Consultatif, the chairman of which is normally a member of CIPM, is composed of delegates from the major metrology laboratories and specialized institutes, a list of which is drawn up by CIPM, as well as individual members also appointed by CIPM and one representative of BIPM. These committees hold their meetings at irregular intervals; at present there are nine of them in existence:

1. The Comité Consultatif d'Électricité (CCE), set up in 1927.
2. The Comité Consultatif de Photométrie et Radiométrie (CCPR), new name given in 1971 to the Comité Consultatif de Photométrie (CCP) set up in 1933 (between 1930 and 1933 the preceding committee (CCE) dealt with matters concerning Photometry).
3. The Comité Consultatif de Thermométrie (CCT), set up in 1937.
4. The Comité Consultatif pour la Définition du Mètre (CCDM), set up in 1952.
5. The Comité Consultatif pour la Définition de la Seconde (CCDS), set up in 1956.
6. The Comité Consultatif pour les Étalons de Mesure des Rayonnements Ionisants (CCEMRI), set up in 1958. In 1969 this committee established four sections: Section I (Measurement of 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 Comité Consultatif des Unités (CCU), set up in 1964 (this committee replaced the "Commission for the System of Units" set up by the CIPM in 1954).
8. The Comité Consultatif pour la Masse et les grandeurs apparentées (CCM), set up in 1980.
9. The Comité Consultatif pour la Quantité de Matière (CCQM), set up in 1993.

The proceedings of the Conférence Générale, the Comité International, the Comités Consultatifs, and the Bureau International are published under the auspices of the latter 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;*
— *Sessions des Comités Consultatifs;*
— *Recueil de Travaux du Bureau International des Poids et Mesures* (this collection for private distribution brings together articles published in scientific and technical journals and books, as well as certain work published in the form of duplicated reports).

The Bureau International also publishes monographs on special metrological subjects and, under the title "*Le Système International d'Unités (SI)*", a booklet, periodically up-dated, in which all the decisions and recommendations concerning units are collected.

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

Since 1965 the international journal *Metrologia*, edited under the auspices of the CIPM, has published articles on the more important work on scientific metrology carried out throughout the world, on the improvement in measuring methods and standards, on units, etc., as well as reports concerning the activities, decisions, and recommendations of the various bodies created under the Convention du Mètre.

Comité International des Poids et Mesures

Secretary	*President*
J. Kovalevsky	D. Kind

MEMBERS

OF THE

COMITÉ CONSULTATIF DE THERMOMÉTRIE

President

L. Crovini, Member of the Comité International des Poids et Mesures, Director of the Istituto di Metrologia G. Colonnetti, Turin.

Members

All-Russian Research Institute for Physical, Technical and Radiotechnical Measurements [VNIIFTRI], Moscow.

Bureau National de Métrologie, Paris : Institut National de Métrologie [INM] du Conservatoire National des Arts et Métiers, Paris.

CSIRO, Division of Applied Physics [CSIRO], Lindfield.

D. I. Mendeleyev Institute for Metrology [VNIIM], Saint-Petersburg.

Istituto di Metrologia G. Colonnetti [IMGC], Turin.

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

National Institute of Metrology [NIM], Beijing.

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

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

NATIONAL RESEARCH LABORATORY OF METROLOGY [NRLM], Tsukuba.
NEDERLANDS MEETINSTITUUT [NMi/VSL], Delft.
PHYSIKALISCH-TECHNISCHE BUNDESANSTALT [PTB], Braunschweig and Berlin.
SLOVENSKÝ METROLOGICKÝ ÚSTAV [SMU], Bratislava.

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

AGENDA
for the 18th meeting

---

1. Opening of the meeting.
2. Appointment of the rapporteur.
3. Approval of the agenda.
4. Documents presented to the meeting.
5. Results of the inquiry on the realization and application of the ITS-90 in the national standards laboratories.
6. Further problems arising from the ITS-90 application.
7. International traceability in temperature measurements and needs for international comparisons.
8. Studies concerning the ITS-90:
   a) non-uniqueness;
   b) reproducibility of the fixed points;
   c) other problems stemming from the realization of the interpolating instruments;
   d) new information on $(T - T_{90})$.
9. Report of Working Group 2 (secondary fixed points, approximations to the ITS-90, new international thermocouple and industrial platinum resistance thermometer tables).
10. Uncertainty of the ITS-90 realization.
11. Problems arising below 1 K and extension of the scale below 0,65 K.
12. Thermometry work at the BIPM.
13. Establishment and composition of working groups.
14. Report to the CIPM and recommendations.
15. Other business:
   a) next meeting;
   b) other business.

REPORT

OF THE

COMITÉ CONSULTATIF DE THERMOMÉTRIE

(18th Meeting — 1993)

TO THE

COMITÉ INTERNATIONAL DES POIDS ET MESURES

by M. DURIEUX, Rapporteur

The eighteenth meeting of the Comité Consultatif de Thermométrie (CCT) took place at the Pavillon de Breteuil, Sèvres, on 7, 8 and 9 September 1993.

Present:

L. CROVINI, Member of the CIPM, President of the CCT.

Delegates from the member laboratories:

Bureau National de Métrologie, Paris : Institut National de Métrologie [INM] du Conservatoire National des Arts et Métiers (G. BONNIER).

CSIRO, Division of Applied Physics [CSIRO], Lindfield (T. P. JONES).

D. I. Mendeleyev Institute for Metrology [VNIIM], St. Petersburg (A. I. POKHODUN).

Istituto di Metrologia G. Colonnetti [IMGC], Turin (T. RICOLFI, F. PAVESE).

Korea Research Institute of Standards and Science [KRISS], Taejon (CHUNGHI RHEE, DAESUNG CHI).

National Institute of Metrology [NIM], Beijing (ZHAO QI).

National Institute of Standards and Technology [NIST], Gaithersburg (B. W. MANGUM).

National Physical Laboratory [NPL], Teddington (R. L. RUSBY, M. V. CHATTLE).

National Reseach Council of Canada [NRC], Ottawa (R. E. BEDFORD).

National Research Laboratory of Metrology [NRLM], Tsukuba (H. Sakurai).

Nederlands Meetinstituut [NMi/VSL], Delft (P. Bloembergen).

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig and Berlin (H.-J. Jung, K. Grohmann).

Slovenský Metrologický Ústav [SMU], Bratislava (M. Borovicka, S. Duris).

The Director of the Bureau International des Poids et Mesures [BIPM] (T. J. Quinn).

Invited guests:

M. Durieux, Kamerlingh Onnes Laboratorium [KOL], Leiden.

R. P. Hudson, Arlington.

J. Nicholas, Industrial Research Limited [IRL], Lower Hutt.

Excused:

All-Russian Research Institute for Physical, Technical and Radio-Technical Measurements [VNIIFTRI], Moscow.

Also present:

P. Giacomo, Director Emeritus of the BIPM; J. Bonhoure and R. Köhler (BIPM).

Introduction

Since this was the first meeting of the CCT after the introduction of the International Temperature Scale of 1990 (ITS-90), an important task was to monitor the progress in the realization and dissemination of the new international scale in the fourteen national laboratories that are members of the CCT. The results of an *ad hoc* inquiry show that all laboratories disseminate the ITS-90, having realized it directly over a substantial part of its range. Where the ITS-90 is not yet realized, mostly at low temperature, the resulting gap is bridged either by a wire scale or by an approximation to the ITS-90. Current projects in the laboratories will reduce these gaps.

The CCT considered some problems in the application of the ITS-90, particularly those concerning the recommended values of ($t_{90} - t_{68}$) from 630 °C to 1064 °C in the light of a new direct determination. The disagreement with the values given in the text of the ITS-90 can be explained – at least partially – by the non-uniqueness of the International Practical Temperature Scale of 1968 (IPTS-68) which specifies values separated by at least 0,2 °C. A note on this matter and a new recommended table will soon be published as will the new table of secondary fixed points referred to in the ITS-90.

The need for international traceability of the temperature measurements was thoroughly examined, in the light of the results from the inquiry. Such a task is particularly complex and requires close cooperation both within and between regional groups. The CCT, in its Recommendation T 1 (1993), has addressed the need to communicate information promptly to the CCT and the BIPM on comparisons within regional groups, and to perform comparisons between regional groups at the highest level of accuracy.

The CCT recognizes the need to undertake further experiments to assess the limit of uniqueness of the ITS-90 and to study improvements in the techniques by which the defining fixed points are realized. Particular attention is required by the triple point of water. The relatively poor reproducibility found in the BIPM experiments under particular conditions still needs to be confirmed by other laboratories and explained. For this reason, in Recommendation T 2 (1993), the national laboratories have been encouraged by the CCT to undertake suitable experiments and to supply water triple point cells to the BIPM.

The CCT discussed a possible definition for an international scale between 2 mK and 0,65 K based on the ^{3}He melting curve, as proposed in documents reporting on experiments carried out in some laboratories. Such a scale should join the ITS-90 smoothly. The discussion also concerned the thermodynamic accuracy of the ITS-90 in the light of some new determinations. On these grounds, the CCT has re-enforced the content of its previous Recommendation T 1 (1987) with Recommendation T 3 (1993) which encourages the national laboratories to pursue the measurement of thermodynamic temperature in the regions below 0,65 K, near 150 K and 700 K, and at higher temperatures, and recommends that the BIPM take advantage of its acquisition of a cryogenic radiometer to contribute to this work.

Recommendations of the Comité Consultatif de Thermométrie submitted to the Comité International des Poids et Mesures

Links between regional comparisons of temperature standards

Recommendation T 1 (1993)

The Comité Consultatif de Thermométrie,

considering

— the need for world-wide recognition of the results of comparisons of temperature standards carried out under the auspices of regional groups of national laboratories and, bilaterally, between national laboratories,

— that many national laboratories have developed new temperature standards to realize the International Temperature Scale of 1990 (ITS-90),

— that the demonstration of equivalence of measurements between national laboratories over a wide range of temperature is a particularly complex task,

taking note of Recommendation 1 (CI-1992) of the Comité International des Poids et Mesures (CIPM),

encourages the national laboratories to

a) take part in the comparisons of temperature standards organized within regional groups,

b) propose and support other comparisons where a need is perceived,

recommends

— that information pertaining to, and the results of, comparisons within regional groups or in the framework of bilateral agreements be promptly communicated to the Bureau International des Poids et Mesures (BIPM) and the Comité Consultatif de Thermométrie (CCT), and

— that links be established between regional groups, at the highest level of accuracy, through comparisons organized under the auspices of the CCT in consultation with the BIPM.

Triple point of water cells

Recommendation T 2 (1993)

The Comité Consultatif de Thermométrie,

considering

— the results recently obtained at the Bureau International des Poids et Mesures (BIPM) with some triple point of water cells using different techniques of preparation,

— the role of the triple point of water in the definition of the kelvin,

— the importance of improving the accuracy of realization of the triple point of water to allow full advantage to be taken of the high reproducibility of the International Temperature Scale of 1990 (ITS-90),

recommends that national laboratories

a) investigate the effects of different types of cell construction,

b) investigate the effects of different techniques of preparation of the ice mantle,

c) exchange cells with other laboratories, including cells of different origin,

d) supply representative cells to the BIPM upon demand.

Thermodynamic temperature measurements *

RECOMMENDATION T 3 (1993)

The Comité Consultatif de Thermométrie,

considering

— the importance of accurate measurements of thermodynamic temperature, as emphasized in its Recommendation T 1 (1987),

— the inconsistencies which still exist in determinations of thermodynamic temperature, especially in the regions near 150 K, 700 K and at higher temperatures,

— the desirability of extending the range of the International Temperature Scale of 1990 (ITS-90) below its present lower limit of 0,65 K,

— the importance of the national laboratories and the Bureau International des Poids et Mesures (BIPM) having a capability for thermodynamic temperature measurements using a variety of techniques,

recommends

— that national laboratories pursue fundamental research in thermometry, and in particular the measurement of thermodynamic temperature in the ranges referred to above,

— that the BIPM take advantage of its acquisition of a cryogenic radiometer to contribute to this work.

* This Recommendation was approved, with a slighly modified wording, by the Comité International des Poids et Mesures at its 82nd meeting as Recommendation 5 (CI-1993).

Recommendation
adopted
by the Comité International des Poids et Mesures

Thermodynamic temperature measurements

RECOMMENDATION 5 (CI-1993)

The Comité International des Poids et Mesures,

considering

— the importance of accurate measurements of thermodynamic temperature, as emphasized in Recommendation T 1 (1987),

— the inconsistencies which still exist in determinations of thermodynamic temperature, especially in the regions near 150 K, 700 K and at higher temperatures,

— the desirability of extending the range of the International Temperature Scale of 1990 (ITS-90) below its present lower limit of 0,65 K,

— the importance of the national laboratories and the Bureau International des Poids et Mesures having a capability for thermodynamic temperature measurements using a variety of techniques,

recommends that national laboratories pursue fundamental research in thermometry, and in particular the measurement of thermodynamic temperature in the ranges referred to above.

Minutes of the 18th meeting of the CCT

1. Opening of the meeting

The President calls the meeting to order, and welcomes all delegates. He also extends a warm welcome to Mr Durieux, Mr Hudson, and Mr Nicholas, who are present by invitation. He thanks Mr Quinn and his staff for preparing the meeting.

The President points out that the CCT entered a new era after it approved the International Temperature Scale of 1990 (ITS-90) at its last meeting in 1989. In this new "post ITS-90" phase of life, attention has to be given to the development of improved techniques for realizing the scale. There is also the question as to how far the scale has been implemented in the national standards laboratories (*see* Item 5 of the Agenda). Applying the ITS-90 and making it generally applicable in metrology is important and will require much work. There is also the important question of the extension of the scale to lower temperatures, i.e. to below 0,65 K (*see* Item 11 of the Agenda). In connection with all of this, the CCT will have to re-examine the terms of reference and the memberships of the working groups (*see* Item 13 of the Agenda).

2. Appointment of the rapporteur

Mr Durieux is appointed as rapporteur.

3. Approval of the agenda

The provisional agenda is approved.

4. Documents presented to the meeting

The documents presented to the meeting are listed in Annexe T 1 (*see* p. T 34). The President says that they will not be considered in detail under this item, but that where necessary they will be discussed under the appropriate items of the agenda to which they pertain. Mr Quinn reminds the members of an earlier decision of the CCT that the documents will not be published in the report of the Comité Consultatif de Thermométrie.

They will be retained at the BIPM where they are available on request, however bound copies will be sent to committee members.

5. Results of the inquiry on the realization and application of the ITS-90 in the national standards laboratories

A "Questionnaire on the Realization of the ITS-90" was sent at the beginning of 1993 to the member laboratories of the CCT. The replies to this inquiry from fourteen laboratories are collected in Document CCT/93-1. A summary of the replies prepared by the President and Mr Steur (IMGC) is given in Document CCT/93-1(R). The President introduces the item by saying that it is important to know how far the national laboratories have come in realizing the ITS-90, adding that some other laboratories, not represented on the CCT, have also realized parts of the scale. He recalls the points on which information was asked in the questionnaire:

1. General information on the realization of the ITS-90 (and the realization of an approximation to the ITS-90);
2. Detailed information on the realization of the ITS-90 (subranges, fixed points and their reproducibilities, types and sources of PRTs which are used);
3. Application and use of the ITS-90 (most accurate transfer standards which a laboratory can calibrate);
4. Experiments planned or under way to examine the thermodynamic accuracy of the ITS-90.

There follows an extensive discussion centring around the replies to the inquiry. A few misprints are corrected. The President mentions that, in retrospect, not all questions were worded sufficiently clearly. For example, in Item 2.2 of the questionnaire, the question about the estimated reproducibility of the defining fixed points was interpreted in different ways, causing the replies to differ by a factor of ten or more.

Mr Quinn, referring to Figure 1 of Document CCT/93-1(R), which shows that none of the national standards laboratories has realized the ITS-90 in the range below 14 K, asks whether the effort to define the scale in this range was, perhaps, misplaced. Mr Rusby says no, and adds that the logarithmic presentation does emphasize the low-temperature region. Mr Bonnier points out that the low temperature range is very important for many scientific researchers. The President adds that work in this low temperature part of the scale, for example on interpolating gas thermometers, is in progress in many national laboratories. Thus it is a false impression that the low temperature range is not important.

Referring to Table I of Document CCT/93-1(R), where reproducibilities as low as 0,1 mK are given for the defining fixed points, Mr Pokhodoun remarks that these numbers reflect too optimistic an outlook. For example, current work at the BIPM, the NRC, and the NIST on the triple point of water is not reflected in the replies. He considers that the higher value of 0,2 mK given by the CSIRO for the reproducibility is more realistic. Regarding the freezing or melting points, it is the opinion of Mr Pokhodoun's colleagues that there are three sources of uncertainty: contamination of the sample, structural changes in the solid phase, and the effects of different methods of initiating the freeze. In this respect, Mr Pokhodoun agrees that the reproducibility of the freezing points may be 1 mK. Mr Bonnier agrees that the reproducibility of the freezing points and their precise definitions deserve further study and proposes that this be the task of a working group. The President agrees. Referring to Document CCT/93-1(R) again, the President notes that only one laboratory (KRISS) uses an interpolating gas thermometer for realizing the ITS-90. Mr Rusby adds that interpolating gas thermometers are in process of construction at the PTB and the VNIIFTRI.

Regarding the use of secondary realizations of the ITS-90 (Section 3 and Figure 7 of Document CCT/93-1(R)), Mr Quinn notes that many laboratories use secondary realizations in the low temperature range. Regarding the use of fixed-point black-body radiators (Table I and Figure 6 of Document CCT/93-1(R)), the President notes that all three reference points (silver, gold and copper) are used, but there is a preference for silver. Almost all laboratories realize all of the other fixed points above 273,15 K (Document CCT/93-1(R), Figure 5); fewer laboratories realize the fixed points below 84 K (Document CCT/93-1(R), Figure 4). The same trends hold for the subrange realizations. On the use of standard PRTs, Table II and Figures 8, 9 and 10 of Document CCT/93-1(R) display the details of current usage. Table III of Document CCT/93-1(R) lists the most accurate transfer standards for the ITS-90 used by the different laboratories. The President points to the use of rhodium-iron and germanium thermometers at low temperatures, platinum-rhodium/platinum, palladium/platinum, and gold/platinum thermocouples up to 1100 °C and, more and more, radiation thermometers at higher temperatures. Mr Quinn observes that tungsten ribbon lamps are still widely used even though they are now difficult to obtain. Experiments planned or under way to examine the thermodynamic accuracy of the ITS-90 are listed in Section 6 of Document CCT/93-1(R). From the following discussion it is clear that the information in Section 6 is incomplete.

In view of the foregoing remarks, the President says that a revised document will be sent to all members. Mr Bonnier asks whether the document will be published. He feels that many people think that the ITS-90 is simple to realize; such a publication will show that much future work is necessary. It is decided that a short note or summary will be submitted to *Metrologia*. The President asks the members to send their comments or corrections or items which they may wish to delete before 15 October 1993.

6. Further problems arising from the application of the ITS-90

The President introduces the topic of problems arising from the application of the ITS-90 by mentioning, with reference to several of the submitted documents, some of the problems that require discussion. Referring to Documents CCT/93-2 and 3, Mr Bedford remarks that Mr Ancsin (NRC) has found, not from planned experiments but from observations of a platinum heater wire wound on quartz cloth, evidence of a eutectic reaction between platinum and silicon at temperatures above 830 °C. In HTPRTs, then, a reaction between platinum and the quartz former could be the reason why these thermometers exhibit increasing instability from 800 °C to the silver point. The work was not pursued further. Mr Mangum says that the results could not be reproduced at the NIST. Mr Bedford mentions a paper by Messrs. Ancsin and Hill (NRC), in press in *Metrologia**, about the diffusion of silver through the walls of graphite crucibles and silica wells, with resultant contamination of the platinum sensor of the PRT when used in a silver-point furnace. Mr Bonnier agrees that this is a serious problem, one that makes graphite crucibles unsuitable for use at the aluminium and silver points. In reply to a question by the President on whether graphite should be replaced by some other material, Mr Bedford notes that, as an alternative, a suitable barrier between the crucible wall and the thermometer may be found.

There follows a discussion on the use of platinum/palladium thermocouples. Mr Rhee mentions research at the KRISS on these thermocouples in the temperature range 962 °C to 1300 °C. The NIST and the NMi/VSL have also started such work. Mr Chattle says that secondary laboratories do not use platinum/palladium couples because manufacturers do not offer them. Mr Bonnier considers that highest purity palladium is not necessary and may not even give the best results. Nevertheless, the President believes that reference tables should refer to highest purity materials for the thermocouples. There is also a discussion about whether to use the thermocouples in an atmosphere of air or argon. Mr Bonnier feels that an earlier recommendation by the CCT for the study of platinum/palladium thermocouples should be reinforced in a recommendation to the CIPM. Mr Jung remarks that the use of palladium from different sources gives different results, but that the differences are linear with temperature. He also says that these thermocouples sometimes break at the high-temperature junction due to the different expansion coefficients of the wires. Use of a thin spring at the junction reduces the probability of breakage. Mr Bedford recalls that this was also the technique used by Mr McLaren at the NRC with gold/platinum thermocouples.

---

* Ancsin J., Hill K. D., Contamination of Platinum Resistance Thermometers by Silver, *Metrologia*, 1993/94, **30**, 507-509.

Mr Bonnier believes that the main reason for breakage is not the difference in expansion coefficients but the re-crystallization that takes place in the wires. Slip in the crystals can cause the wires to break. Use of the highest purity wires may promote re-crystallization and breakage.

The President asks Mr Rusby to comment on Document CCT/93-29 from the NPL, which deals with the mutual consistency of the temperatures assigned to the triple point of mercury and the melting point of gallium in the ITS-90. Mr Rusby says that a linear relationship between values of W_{90} (Hg) and W_{90} (Ga) was found for fifty PRTs calibrated at the NPL, the NIST, and the IMGC. The values of W_r (T_{90}) for mercury and gallium from the ITS-90 reference functions do not lie on this line ; these points are the equivalent of about 1 mK higher. Consistent with this, it was found at the NPL that in the calibration of PRTs for the temperature ranges immediately below and above the triple point of water, the values of the coefficient *a* in the corresponding deviation functions differ by about 3×10^{-5}. This discrepancy leads to an inconsistency of about 1 mK deriving from the ITS-90 assigned values of the mercury and gallium fixed point temperatures. Mr Bonnier recalls that the mercury point temperature was adjusted in setting up the ITS-90, but Mr Rusby says that that shift was only 0,3 mK. The President recalls that the gallium point was introduced mainly in order to satisfy the need for very accurate temperature measurements near room temperature in other fields of metrology such as in electrical and length measurements. In connection with this, the CCT's goal was to have a non-uniqueness of the scale not greater than 0,1 mK from 0 °C to 30 °C. He asks if this been achieved. Mr Bonnier and Mr Rusby doubt whether such a low value of non-uniqueness can be guaranteed and ask whether an accuracy in temperature of better than 1 mK is needed for length measurements. The President replies that the lengths of gauge blocks will change measurably if temperatures change by more than 1 mK, so it should be made clear what is the achievable accuracy in temperature measurements near 30 °C.

The President next asks Mr Pokhodoun to comment on the work in his laboratory on the *R* vs T_{90} relation of HTPRTs between 962 °C and 1085 °C (Document CCT/93-9). Mr Pokhodoun summarizes that the VNIIM tried to repeat earlier work at the NPL and the PTB in comparing platinum thermometers with the optical pyrometer. The thermometers are of a new design in which the platinum wire spirals around a re-entrant cavity in the thermometer which serves as the black body. At 1085 °C the total uncertainty of the comparison is estimated to be 0,19 °C, most of which is due to the optical pyrometer used at the VNIIM. The work described in Document CCT/93-9 was essentially preliminary and measurements are continuing at the IMGC with a better pyrometer. Nevertheless, they are having difficulty in duplicating the earlier results from the PTB. Comparisons of thermocouples and radiation thermometers are planned. Mr Bloembergen asks what reference temperature was used for the optical pyrometer; Mr Ricolfi replies that it was the silver point. Mr Jung asks about possible temperature differences between the coil of the HTPRT and the bottom of the black body. He suggests changing the aperture of the black body to see if the results are affected. Mr Ricolfi remarks that at the IMGC a heat pipe liner was used in the furnace. The position of the HTPRT in the heat pipe was changed in steps of 1 cm and, over a distance of 9 cm, the difference in temperatures indicated by the PRT and the radiation thermometer did not change by more than 0,1 °C. The President closes the discussion, suggesting that the various technical problems be discussed privately.

The next discussion is on the results of new measurements of ($t_{90} - t_{68}$) between 630 °C and 1064 °C (Document CCT/93-18), which give values differing appreciably from those in Table VI of the ITS-90 text. Mr Mangum summarizes the work. A total of twenty-four Pt-10% Rh/Pt thermocouples, calibrated on the IPTS-68, have been compared with HTPRTs calibrated on the ITS-90 in seven laboratories. As these measurements represent a direct comparison between the two scales, it is believed that the results represent ($t_{90} - t_{68}$) better than the data in Table VI of the ITS-90. The President remarks that the new data show the degree of uncertainty in t_{68} as derived from the thermocouple calibrations. This uncertainty in t_{68} is presumably part of the reason for the differences between the new data and those in Table VI. He says that there are two questions: what is the reason for the differences and what should be done with Table VI and with the new data. Mr Rusby summarizes how Working Group 4 derived the ($t_{90} - t_{68}$) data in Table VI above 630 °C. Differences between thermodynamic temperatures, as obtained from noise and radiation measurements, and t_{68}, as measured with Pt-10% Rh/Pt thermocouples, were plotted between 630 °C and 1085 °C and a difference curve of ($t - t_{68}$) vs t was drawn. Because direct measurements of ($t_{90} - t_{68}$) were unavailable at the time, ($t - t_{68}$) was chosen to be synonymous with ($t_{90} - t_{68}$). Mr Rusby suspects that the large differences between these values and the newly-determined values (Document CCT/93-18) arise from older thermodynamic temperature measurements differing appreciably from the more recent thermodynamic data from the PTB on which t_{90} is based. Mr Mangum points out that the new comparisons were, in fact, designed to allow the derivation of new thermocouple reference tables on the ITS-90, not for measuring ($t_{90} - t_{68}$). In the past, Mr Evans (NIST) derived tables that approximated ($t - t_{68}$); they are more consistent with the older data in Table VI. Mr Rusby remarks that, besides values for ($t - t_{68}$), the size of the discontinuity in the slope of t_{68} vs t at 630 °C as found by Evans and Woods and by Bedford were used for obtaining the difference curve in Figure 1 of the ITS-90.

Mr Bonnier asks how many thermocouples were used to derive the final curve in Figure 1 of Document CCT/93-18 (since only one was used to obtain the thermocouple reference function). He also says that the iteratively-reweighted least-squares regression fitting eliminated many data but did not take account of all of the uncertainties in that data.

Mr Bloembergen remarks that if all data had been considered, maybe the new and old data would reconcile. Mr Hudson elaborates on Working Group 4 deliberations in deriving values for ($t - t_{68}$) (*Metrologia*, 1991, **28**, 9). He stresses that there were large uncertainties in both t and t_{68}. For lack of better data, t was then simply called t_{90}. He adds that, as Mr Rusby explained, there is little correlation between the ($t_{90} - t_{68}$) graph in the ITS-90 and the new one in Document CCT/93-18. The President notes that, according to the new data, the changes from t_{68} to t_{90} are much less than thought. Mr Mangum says that the standard deviation of the iteratively-reweighted fit to the ($t_{90} - t_{68}$) data was 63 mK for the initial model that used all data from the twenty-four thermocouples, but it reduced to 18 mK after five iterations, during which process the fitted curve changed by about 0,02 K. Mr Bonnier emphasizes that the 18 mK standard deviation does not account for the measurement uncertainty in t_{68} and feels that data for all thermocouples should be included in the uncertainty estimate.

The President summarizes the discussion to this point: Values of ($t_{90} - t_{68}$) in graphical and tabular form have been recommended in the ITS-90 text and their origin has been described. The uncertainty of the new curve in Document CCT/93-18 has been discussed. The new values for ($t_{90} - t_{68}$) are to be preferred and should be published.

There follows a long discussion involving many of the members. Mr Quinn points out that, although the analytic techniques applied to the new data give a standard deviation of 18 mK, such a small value is misleading. The spread in the data indicates that thermocouple temperatures t_{68} might differ by 0,3 K or 0,4 K. The uncertainty of a new curve ($t_{90} - t_{68}$) vs t will still really be of the order of 0,2 K. Commenting on the radiation measurements at the NPL that formed part of the old values, he says that at about 800 °C, where the hump in the old curve is, the radiation measurements were not nearly as accurate as they were nearer to the gold point reference. In his opinion, the main uncertainty in ($t - t_{68}$) came from the thermodynamic temperature measurement. The thermocouples (Type R) were not used for unduly long times at high temperatures, but their thermal stabilization was not the same as that used now. The emfs at the gold point, measured before and after the radiation thermometer/thermocouple comparisons, differed by no more than 1 μV (0,1 °C). He is somewhat surprised that the present results for ($t_{90} - t_{68}$) differ from the older ones by more than 0,25 K. The President says that the IMGC noise thermometer measurements of ($t - t_{68}$) may also have had an uncertainty of 0,25 K, whereas the uncertainty in t_{68} may not have been more than 0,1 K. Commenting on the more recent radiation data, Mr Jones remarks that results at the CSIRO agree with those from the PTB so a large error in these data is unlikely.

Mr Bonnier is unconvinced that the ($t_{90} - t_{68}$) of Document CCT/93-18 is based on all twenty-four thermocouples. Moreover, the uncertainty given is only statistical. He warns that there may be other and larger components. Mr Mangum says that the NIST thermocouples came from the same wire batches as those used for the IPTS-68 reference table for Type S couples.

There then follows a wide discussion on how the new data for ($t_{90} - t_{68}$) should be published. Mr Rusby asks whether the new ($t_{90} - t_{68}$) values agree precisely with the differences between the type S thermocouple table based upon the ITS-90 and that based upon the IPTS-68 (it turns out they do, not exactly, but within about 0,05 K). It is finally decided that Working Group 4 should prepare a draft document giving the new values for ($t_{90} - t_{68}$) with an explanation of why they differ from the data in the ITS-90 text. The Chairman of Working Group 4, referring to this task as "a poisoned chalice", says that Working Group 4 will prepare the document but that it may take some time.

7. International traceability in temperature measurements and the need for international comparisons

The President draws attention to the general recommendation from the CIPM on the need for world-wide traceability in metrology which, in turn, requires comparisons of measurement standards. The President emphasizes that temperature is a very special case in metrology; meaningful comparisons are difficult to perform and must be made in all temperature ranges. Direct world-wide comparisons are impractical. Consequently, regional comparisons are necessary, and will be the responsibility of such organizations as EUROMET. However, they have to be interconnected at the highest level of accuracy. The President suggests that, first, information on regional and bilateral comparisons should be made available to the BIPM; second, areas where comparisons between regional groups are needed should be identified; third, comparisons and world-wide traceability of measurement standards need defined terminology in order to guarantee that measurement results are all analyzed on the same basis. He proposes that all of this should be the task of a specific working group. He opens the topic to discussion.

Mr Quinn remarks that, whereas most thermometric comparisons in the past were for specific scientific purposes, we have now the need to show that ITS-90 calibrations are internationally equivalent. The CCT should identify which international comparisons are required to demonstrate that the Convention du Mètre is fulfilling its purpose in unifying temperature measurement standards world-wide. He reads Recommendation 1 (CI-1992) of the CIPM which calls for world-wide recognition of the result of comparisons of measurement standards.

Mr Bonnier emphasizes three points:

1. Comparisons do not arise spontaneously but have to be organized by some laboratory. The BIPM and national standard laboratories have fewer resources to do this than in previous times;
2. Comparisons may take a long time, sometimes several years, and it is necessary to identify from the beginning the facilities which are needed;
3. The terms of reference of comparisons must be clearly specified. Otherwise, the results may not be comparable world-wide.

The President agrees that there are certainly difficulties in organizing comparisons. He wonders if each should be assigned to a dedicated working group that can take account of Mr Bonnier's points and ensure that a minimum effort is required from the participating laboratories. Mr Jones draws a parallel to a working group in the Asia-Pacific region that was set up to organize a comparison of gauge blocks. This worked well, but he agrees that comparisons in thermometry are more difficult. Mr Quinn suggests that comparisons might take place between, say, two laboratories in each regional group, and regional groups would then compare to obtain a world-wide result. This may be a quicker method. Mr Grohmann sympathizes with the idea of minimum effort. He proposes to start with an exchange of information, and mentions that EUROMET has advised that all information on comparisons be relayed to the BIPM. Mr Ricolfi says that comparisons in thermometry are not necessarily time consuming if planning is well done, as was recently demonstrated by a comparison of radiation thermometers between 800 °C and 2000 °C among four laboratories in which one radiation thermometer, calibrated at the NRLM, was carried to the other laboratories. Mr Bonnier says that this proves his point because the comparison could only be carried out in a short time because of the efforts of the organizing laboratory in preparing the project and analyzing the results. He emphasizes again that some laboratory must take charge and that the task cannot be left, in general, to the BIPM. Mr Pokhodoun stresses the importance of comparisons for improving techniques for the realization of the scale and improving the *Supplementary Information for the ITS-90*. In particular he stresses the need for uniform techniques for the realization of fixed points; this could be a task for a working group. The President agrees with Mr Grohmann that, as a first step, information has to be collected on what international comparisons are required. He closes the discussion on this topic by saying that the aim of any international comparison must be very clear, and this will be reflected in the terms of reference of any new working group.

8. Studies concerning the ITS-90

The President opens the discussion by drawing attention to the large number of documents that touch on the ITS-90 – evidence of its importance.

There was of course a great deal of information available in 1989 when the ITS-90 was approved, but it was understood at the time that new information would be forthcoming.

8.1 Non-uniqueness

The President says that one of the important problems is to determine the amount of non-uniqueness of the ITS-90, especially in the PRT range of definition. The concept of non-uniqueness may now have become a little fuzzy, however, and semantics may play a role. In the ITS-90 there are new temperature ranges with overlapping definitions and overlapping instruments. The distinction of non-uniqueness from other types of uncertainty may not be so clear; for example in its distinction from fixed point realization uncertainties or sub-range inconsistencies. As yet, there seems to be little information regarding uncertainty due to the overlap of the ranges of the PRT and the gas thermometer, or of non-uniqueness due to the possibility of three different defining fixed points for the radiation thermometer range. Studies are required to identify the ultimate precision of the ITS-90. The CCT should continue to monitor this question. This item is opened to general discussion.

Mr Bonnier is of the opinion that the level of non-uniqueness of the ITS-90 has still to be established and, indeed, it may be near zero. To detect non-uniqueness, one must first properly account for all other sources of uncertainty, even when only one thermometer is used. He refers to Documents CCT/93-1 and CCT/93-1(R). Here, various laboratory estimates of uncertainties are listed, among them values as low as 0,1 mK for some fixed points. He says that it is next to impossible to detect differences at the level of 0,1 mK. Mr Bonnier also suggests that a method should be devised for deriving uncertainties at all temperatures in the ITS-90 intermediate between fixed points. Mr Bloembergen agrees in principle with some of the points made by Mr Bonnier, but thinks some of this work has already been done. He also believes that non-uniqueness and sub-range inconsistency are real, significant and different one from the other. On the latter point, Mr Mangum agrees. Mr Pavese says we must distinguish between non-uniqueness and the propagation of fixed point uncertainties. He believes that non-uniqueness arises from the defining instruments and equations, and is only one of three components in the overall uncertainty. The President agrees with Mr Pavese. Referring to the Ward-Compton experiments, he says that non-uniqueness in the IPTS-68 was established, but for a particular temperature range. In some parts of the ITS-90 it is not possible to apply closely similar conditions; for example, in the range between the aluminium and silver points, it is difficult to compare PRTs to better than 1 mK, even in a sodium heat pipe. It is also difficult to reduce fixed point errors to below 1 mK, so the detection of non-uniqueness at sub-millikelvin levels will be very difficult. Mr Quinn, referring to the earlier remarks of Mr Bonnier, suggests that experiments can be carried out to determine non-uniqueness, and that it may not be as complicated as suggested by Mr Bonnier to distinguish between non-uniqueness and fixed point uncertainty propagation. Mr Bloembergen is of the opinion that non-uniqueness arises from the thermometers and sub-range inconsistency from the equations.

Mr Ricolfi draws attention to a current EUROMET project that involves four European laboratories, the NIST, and the NIM. Information on non-uniqueness between the aluminium and silver points should be obtained, but there are no results yet. Mr Bedford says that studies are also in progress at the NRC. Mrs Zhao says that some experiments carried out at the NIM between the argon and water points show very small non-uniqueness. Mr Durieux says that between 2 K and 4 K the ^{3}He and ^{4}He scales agree to within 0,2 mK, which is the limit of experimental uncertainty. Several members point to Document CCT/93-32 as a possible source of pertinent information. In response to questions, Mr Sakurai says that the fixed point uncertainties (of the measurements with five PRTs) are smaller than the PRT differences between fixed points, but it is difficult to separate the IPTS-68 and ITS-90 components. Mr Rusby points out that some ambiguities may arise in interpreting the results because, for example, the ITS-90 uses the triple point of neon as a defining point whereas the IPTS-68 does not.

Mr Pokhodoun then reviewed the state of affairs at the VNIIM where studies of non-uniqueness and scale uncertainties have high priority. Fixed point uncertainties should be dissociated from PRT non-uniqueness. He believes that the method of realization of fixed points can affect the resulting temperature values, and so the uncertainties. A more uniform method of fixed-point realization among national laboratories would lead to smaller differences between realizations in different laboratories. He believes that the many small values shown in Document CCT/93-1 may typify uncertainties within a laboratory, but that interlaboratory differences are much higher. Non-uniqueness, on the other hand, depends on the characteristics of the PRTs such as, for example, the expansion of platinum, the crystal structure, and the mobility of defects. The contributions of each are unknown. He proposes that an experimental programme be carried out in the national laboratories, under the auspices of the BIPM, to examine in detail the performance of PRTs of different manufacture. The VNIIM is willing to contribute PRTs for this work. Such a study is more likely to produce concrete results than theoretical studies based upon physical principles.

The President summarizes the discussion: although we all agree that non-uniqueness can be well-defined, experiments to measure it are obviously difficult to perform with sufficient precision; some studies are in place; all cannot be done in a single laboratory; the CCT should encourage further studies, has no resources for active participation, but can help in clarifying the concepts.

8.2 Reproducibility of the fixed points

The President opens discussion of Item 8*b* of the Agenda by noting that realization of the fixed points to a high degree of accuracy is turning out to be more difficult than had been envisaged. For example, some documents submitted to this session are concerned with the accuracy of realization of the triple point of water, suggesting it is not as good as claimed earlier. Somehow we must come to a more realistic view of the accuracy of fixed point realizations. Drawing a comparison with the realization of other units, he believes that temperature is more complicated. High precision is required by many users; perhaps the CCT should examine the available procedures to see if they lead to the same precision and, if not, recommend specific procedures.

Mr Mangum recalls that it is important to measure the immersion characteristics of PRTs when determining metal freezing points so as to ensure that a measurable hydrostatic gradient exists, and thus that proper thermal equilibrium has been attained. This entails proper furnace design and insulation. Mr Bonnier wonders if the reproducibility of a phase transition is being measured, or simply that of some particular device. What do we really mean by fixed point reproducibility? We must distinguish between PRT instability and fixed point irreproducibility. Mr Pavese says it may be more meaningful to speak of reproducibility of the fixed point realization, which includes an experimental component in addition to the physical transition. Referring to earlier remarks by Mr Pokhodoun, he says we can obtain better reproducibility by adopting common procedures, but this is not what we want. The President points out that the *Supplementary Information* provides for alternative methods of realization. Should we be more restrictive and define specific realization techniques? Mr Pavese says it would be better to solve the physical problems, and draws an analogy with the earlier international comparisons of sealed cryogenic triple point cells. Mr Bedford says it would be dangerous to restrict the method of realization; for example, some metal triple points are now realized by both adiabatic sealed-cell and conventional techniques and, at higher temperatures, pseudo-adiabatic and conventional realizations are made. It is highly advantageous not to restrict the method. Mr Jung agrees, saying it is better to study the physical problems than to rewrite the *Supplementary Information*. Mr Quinn asks whether we should now become interested in accuracy, that is, in closeness to definition. For triple points there is no argument about definition, but for melting or freezing points, do we have a definition? The *Supplementary Information* addresses the question in an experimental way. Should we now be more specific? This may entail a closer scrutiny of the definitions of the points. Mr Bonnier agrees that proper definitions are difficult. For example, changes in isotopic composition can affect the water and neon triple points significantly yet apparently not the freezing point of tin, although naturally-occurring tin has a distribution of isotopes similar to that of neon. The President agrees that proper definition is extremely important and says it may not be possible to give a generally-applicable fixed point definition. The definition must be amenable to critical tests. It is pointless to produce a "nice but useless" definition! Mr Rhee believes the fixed point definitions as thermodynamic equilibrium states are clear. Regarding reproducibility versus accuracy, however, the latter depends upon purity and many other things. The reproducibilities quoted in Document CCT/93-1 are those for particular instruments in particular laboratories. Perhaps it is the definition of accuracy that should be clarified. Mr Grohmann approves of a suggestion of Mr Pavese that more comparisons be made between laboratories. It would help to elucidate some of the key problems. However, the kind of comparison must be clearly identified.

After contributions from a number of members, Mr Hudson comments that the discussion has been very broad and wide-ranging. It might be better to focus on current needs so as to satisfy future aims. Should a working group be formed to prepare some ideas for discussion? The President agrees. He proposes to make this part of the terms of reference of a new long-term working group.

8.3 Other problems stemming from the interpolating instruments

The President asks for specific input to the item of the agenda concerning problems stemming from the realization of the interpolating instruments. Mr Bedford briefly reviews the findings at the NRC of contamination of PRTs by silver after extended periods in silver ingots. He also mentions the increasing commercial unavailability of standard instruments. Mr Rhee draws attention particularly to the small number of manufacturers of HTPRTs and the consequent difficulty of obtaining these instruments. He notes also that he has found the reproducibility of some HTPRTs is not good. A few other difficulties are mentioned by some other committee members.

8.4 New information on ($T - T_{90}$)

Mr Rusby summarizes the report of Working Group 4 (Document CCT/93-25) which had not been circulated to the members before the meeting. The report is mainly concerned with measurements of thermodynamic temperatures made since 1989. Mr Rusby mentions the now-published work of Weber (PTB). His earlier provisional measurements of gas thermometric isotherms at 90 K, 54 K and 27 K are consistent with other thermodynamic data on which the ITS-90 is based. Re-analysis of the data, however, shows that a correction is necessary for the dead-space volume, as a result of which the three isotherm temperatures published by Weber are lower by 9,1 mK, 7,4 mK and 3,5 mK respectively. To compare different gas thermometry measurements made using copper bulbs, the same thermal expansion coefficient for copper should be used throughout.

Kemp et al. used the expansion data of Kroeger and Swenson. Weber's data, recalculated on the basis of the coefficient of expansion given by Kroeger and Swenson (whereas Weber had originally used slightly different PTB-measured values), is again increased slightly (by 2,7 mK at 90 K). On the other hand, the copper expansion values used in the experiments of Astrov et al. (VNIIFTRI) differ substantially from those of Kroeger and Swenson. Working Group 4 recalculated the data of Astrov et al. and found that the values of T are reduced substantially from the published values, and furthermore agree with the recalculated Weber data. This change was more or less confirmed (although not the agreement with Weber) in a recent document from the VNIIFTRI (Document CCT/93-38) which reports new measurements of expansivity near those of Kroeger and Swenson and so new values of T near those calculated by Working Group 4. All of this substantially lowers the mean value of $(T - T_{68})$ at temperatures between 90 K and 200 K, and leaves the data of Kemp et al. significantly higher than the results from the VNIIFTRI and the PTB, as do the radiation measurements of Quinn and Martin. The recalculated gas thermometry results are supported by new acoustic thermometry measurements (Document CCT/93-28). Also, new acoustic thermometry results from the NIST (currently in the process of publication) are expected to be about midway between these new values and the older ones.

Mr Rusby also summarizes recent information regarding $(T - T_{68})$ above 0 °C. The total radiation experiment at the NPL has been shut down. Spectral radiation measurements at the PTB agree with the ITS-90 within measurement uncertainties, as do absolute radiometric measurements based upon cryogenic radiometers. Some more of these latter experiments are being planned. Noise thermometry results by Brixy et al. at the zinc point have uncertainties large enough to encompass the data of both Edsinger and Schooley and of Guildner and Edsinger. More noise thermometry measurements are planned for temperatures near the silver point (Brixy et al.) and the copper point (Crovini et al.).

The President asks what we are to make of all this new data that is largely discrepant with results available in 1989, and suggests that even more measurements are now required. Mr Bedford comments that the new results for $(T - T_{68})$ below 0 °C essentially confirm the old NRC results of Preston-Thomas and Kirby on which the IPTS-68 was based. He asks if Working Group 4 thinks the newer data below 0 °C are more reliable than the older data, as the report seems to imply, and if so, why. Mr Rusby replies no: Working Group 4 is simply reporting the results available. Mr Nicholas comments that the new data agree better with his attempts to establish a thermodynamic relation between temperature and the electrical resistivity of platinum between 100 K and 300 K. There follows a general discussion regarding what is known about $(T - T_{90})$ below 0 °C.

The President then summarizes: obviously, more data are now required to sort out the discrepancies in this range; explanations for the uncertainties in the existing data are required; and the CCT should take no precipitate action. Mr Rusby says that Working Group 4 will continue to monitor the situation and will publish recommended values of $(T - T_{90})$ in due course when sufficient reliable information is available. Mr Pokhodoun proposes that an international comparison of measurements of the thermal expansion of copper be carried out; the VNIIM is willing to supply samples of copper. The suggestion is favourably received, but no specific proposals are made. It seems that samples of copper have already been exchanged bilaterally (CSIRO to VNIIFTRI, IMGC to CSIRO); no information is available on the former; results of the latter confirm already-known values.

The President concludes this item by repeating that the CCT should take no immediate action in publishing newly recommended values of $(T - T_{90})$ below 0 °C.

9. Working Group 2 report

(secondary fixed points, approximations to the ITS-90, new international thermocouple tables and industrial platinum resistance thermometer tables)

Mr Bedford briefly reviews the report of Working Group 2, which had been submitted in two parts (Documents CCT/93-16*a* and 16*b*). At the 1989 meeting of the CCT, Working Group 2 was given three tasks. Working Group 2 has met three times in the intervening years: in 1991 in Paris, in 1992 in Toronto, on 6 September 1993 at the BIPM. Its first task, to prepare the monograph *Techniques for Approximating the International Temperature Scale of 1990,* is complete and the monograph was published by the BIPM in 1990. It seems to have been successful: 1500 copies were printed and about 260 remain. Translations in both French and Italian are now available. Working Group 2 is looking towards an eventual revision. The second task, to assist with the publication of new thermocouple and industrial platinum resistance thermometer (IPRT) tables, has also been completed. After beginning the compilation of new thermocouple tables, Mr Burns (NIST) concluded that new experimental data were required for the emf of Pt-10% Rh/Pt vs t_{90} in the region 600 °C to 1000 °C. This had also been suggested at the 1989 meeting of the CCT by Mr Rusby. The details of this were laid out at a meeting at the NIST in 1990, following which Mr Bedford advised all member laboratories of the CCT and invited them to participate in the measurements. Eventually, eight laboratories submitted data, the data analysis was carried out at the NIST, and the results were published in the proceedings of the temperature symposium in Toronto in 1992. During all of this period Mr Bedford kept Working Group 5 of the IEC SC65B informed of progress. New thermocouple tables based upon the ITS-90 for all of the commonly-used letter-designated basemetal and noble-metal thermocouples have subsequently been published by Burns et al. (*NIST Monograph* 175, April 1993), and republished by the American Society for Testing and Metals. In parallel with this, new IPRT tables were prepared by Crovini et al. based largely upon data acquired at the IMGC using a wide variety of IPRTs. These results were also published in the proceedings of the 1992 Toronto symposium. In June 1992 Mr Bedford represented Working Group 2 of the CCT at a meeting at the NIST of Working Group 5 of IEC SC65B. At this meeting, after considerable discussion, Working Group 5 agreed to recommend the new thermocouple tables and a slightly modified version of the IPRT tables to the IEC for its approval. The CCT subsequently approved the tables, and the formal approval of the IEC is expected later in 1993 with (IEC) publication early in 1994.

Mr Bedford continues that the third task of Working Group 2, to revise and update temperature values for secondary reference points, has been the most time-consuming. A draft of the revised publication appears in Document CCT/93-16*b*. Mr Bedford looks to the CCT for comments on, and criticism of, this draft table. He outlines some of the technical details involved in the preparation of the table, summarizes the make up of the table, and points out some of the differences between this draft table and the earlier 1984 publication. He also draws attention to several misprints in the draft. Mr Bedford goes on to describe a particular difficulty that influences the uncertainties of the secondary fixed point temperatures on the ITS-90. Almost all of the measurements on which the tabular values are based were made on the IPTS-68. Many of the points below 500 °C have a sub-millikelvin uncertainty on the IPTS-68. However, the uncertainties inherent in the equations for converting T_{68} to T_{90} are larger than this and are not known exactly. So we have the anomaly that many secondary reference temperatures are known more precisely on the less precise IPTS-68. One solution to this dilemma is, in the final version, to list the secondary fixed temperatures to within only 1 mK, which should be sufficient for most needs. Another small difficulty in the conversion to T_{90} is that the equations for the ranges above and below 83 K do not give exactly the same value at 83 K. In retrospect, this singularity should have been removed: following the analysis made by Mr Pavese in preparing the conversion to T_{90} of the vapour pressure equations (documents CCT/93-16*b* and CCT/93-4), the junction should have been made near 63 K instead of the middle of the oxygen vapour pressure range.

Mr Bedford concludes with the following suggestions from Working Group 2:

1. Comments on, or criticism of, the draft from the CCT should reach Mr Bedford in written form before 15 October 1993;

2. Working Group 2 will subsequently prepare a revision for circulation to the CCT, probably within a few months;

3. After consideration of the comments on this revised version, the article will go to *Metrologia* for publication.

There follows a lengthy discussion of the Working Group 2 report involving most of the members. This discussion dealt with several matters: should points below the range of the ITS-90 be included (decision, no); how should the assignment of uncertainties be handled (majority opinion to give T_{90} to no better than 1 mK, as Working Group 2 suggested, but some members said give two values of the uncertainty, with and without the conversion uncertainty); how to obtain (t_{90} – t_{68}) more accurately, for example, by converting calibrations of specific PRTs used in the fixed point measurements from the IPTS-68 to the ITS-90 (in Mr Bedford's opinion, possible in principle but impossible in practice for several reasons); singularity at 83 K between the two (t_{90} – t_{68}) equations (different equations could be used, but the original ones are now widely publicized).

10. Uncertainties of the ITS-90 realization

The President opens the item on the uncertainties of the ITS-90 realization with the remark that it may become very important in the future. There is a need for common and concrete terminology and uncertainty estimation procedures, especially as many international comparisons are expected between laboratories and regional groups. He doubts the usefulness of opening the meeting to this topic, anticipating that it would simply "ignite an endless discussion". Instead, he proposes that the topic form part of the terms of reference of a new Working Group 3, to be set up during this meeting. Mr Bonnier recommends that a revision of the *Supplementary Information* should include the mathematical formulae for fixed point error propagation, including covariances. Mr Bloembergen agrees in principle. The President says that considerations such as this can be part of the Working Group 3 task. Mr Quinn says this identical discussion was heard by the CCT in 1989. He recommends that individual laboratories prepare and publish their own papers on this subject. The results of these could then be published as CCT documents.

11. Problems arising below 1 K and extension of the scale below 0,65 K

Mr Rusby summarizes the current situation on problems arising below 1 K and the extension of the scale below 0,65 K by referring to Document CCT/93-25, and also to Documents CCT/93-6 to 8, 27, 30 to 32, 39 and 40. He proposes to discuss the range below 1 K in two parts, above and below 0,5 K. In the first case, rhodium-iron thermometers that carried the T_{X1} scale were compared with cerium magnesium nitrate (CMN) at the PTB and in the USA; it was found that these new CMN scales differ systematically from T_{X1} below 1,2 K by up to 1,2 mK near 0,5 K. This suggests that the scale T_{X1} is in error. Also, thermodynamic calculations of ^{3}He vapour pressures at the PTB and the KOL that include the results of newly-measured thermal data agree with the CMN measurements. The implication is that T_{90}, which is in accord with T_{X1}, may also be in error. New ^{3}He vapour pressure measurements are planned (PTB, NMi/VSL) to confirm, or not, this suspected error in the ITS-90. Mr Grohmann emphasizes that it is really T_{X1} which is wrong, but not necessarily the ITS-90. The newly-planned vapour pressure measurements will check if T_{90} is also in error, i.e. departs from thermodynamic temperatures. Simultaneously with the new PTB vapour pressure measurements, measurements will be made on the ^{3}He melting curve. Mr Rusby then went on to discuss the second part of the range (below 0,5 K). He outlined the ^{3}He melting experiments carried out at the Lawrence Berkeley and Naval Research Laboratory (Document CCT/93-27) and the resulting temperature scale below the range of the ITS-90 to about 6 mK. The PTB (Document CCT/93-7) has a similar magnetic scale down to about 50 mK. These scales could form the basis for a low temperature extension of the ITS-90. Referring to Document CCT/93-25, he says that an extension based upon ^{3}He melting pressures is likely to be the more practical basis. Given suitable overlap with the ITS-90, this could be the basis for a scale from about 1 mK to 1 K.

The President then opens this item for general discussion. Mr Bloembergen asks if it is the intention of the CCT to recommend an ITS-90 extension at this meeting. Mr Durieux says no, because many experiments are still in progress. Several members agree. Nevertheless, the question leads to a brief discussion of the protocol for such a step, analogies being made with the former helium vapour pressure scales and the EPT-76 in the past. There follows an extended discussion on the necessity for such an extension, the best means for defining it, how to best join it to the ITS-90, whether it should overlap with the ITS-90, the pseudo-thermodynamic nature of the proposed extension, and whether values of $(T - T_{90})$ in this general temperature range should now be published. Mr Quinn suggests finally that it is too early to make any specific proposals: Working Group 4 should be asked to analyze the situation and bring a specific proposal to the next meeting of the CCT. Mr Rusby suggests that the encouragement of further research in this area form part of a recommendation to the CIPM. The President concludes the discussion on this item with the instruction that Working Group 4 should undertake the task of looking into a possible extension of the ITS-90 below 0,65 K.

12. Thermometry at the BIPM

Mr Quinn says that it is customary to ask for the advice of the CCT regarding the thermometry programme at the BIPM. In recent years the programme has been reduced substantially, with many of the resources being transferred to radiometry. The programme now encompasses only a range near room temperature. There are no resources for work at higher or lower temperatures. He asks for comments from the CCT. Mr Bonnier suggests that a letter of complaint be sent to the CIPM about the reduction in the thermometry programme. If such letters are not sent, the CIPM never hears the objections of the consultative committees. Mr Quinn says that, of course, the CCT can do whatever it likes, but such a letter should not make some trivial recommendations, and would have to address the question of why the priority is higher now than it was five years ago. In the opinion of the President, it is not the prerogative of the CCT to question now priorities that have been set by the BIPM with the approval of the CIPM. Mr Jones notes that the BIPM will soon have a cryogenic radiometer. Can it not also be used for measurement of thermodynamic temperatures, especially in view of the current state of uncertainty about the magnitude of ($T - T_{90}$) near 100 K? Mr Quinn agrees that it might be possible to perform some measurements in radiation thermometry, especially in view of recent improvements in the quality of black bodies. With the agreement of the CCT, Mr Jones undertakes to draft a recommendation that the BIPM, and any national standards laboratory that has one, take full advantage of the cryogenic radiometer by using it also to measure thermodynamic temperatures.

[At the invitation of BIPM staff a small sub-committee of the CCT had visited the thermometry laboratory to see the results of some triple point of water cell comparisons. Of the cells involved, two had shown anomalous, hitherto unreported, long term drift several days after formation of the mantle.]

The President reports on the visit of the small sub-committee to the triple point of water laboratory. The BIPM staff showed the results of a comparison of five cells from three manufacturers. The problem concerned the long term stability of the triple point temperature after formation of the mantle. Two techniques were used to prepare the mantle: insertion of a liquid-nitrogen-cooled rod, and insertion of dry ice (solid CO_2) into the thermometer well. When the mantle was prepared with the liquid-nitrogen-cooled rod, two of the cells (one of German and one of Japanese manufacture), after initial agreement with the other three, began to disagree by rather large amounts with a more or less steady drift reaching about 0,5 mK after several days. The effect did not occur when the mantle was prepared with dry ice. No other laboratory has reported such behaviour. The President concludes that the CCT should recommend to the national standards laboratories that: *a*) they investigate the long-term stability of water triple-point cells; *b*) they exchange cells with the BIPM in order to compare techniques. The exchange should involve, especially, anomalous cells.

13. Establishment and composition of working groups

During the course of the meeting several tasks were identified as being most appropriately and efficiently handled by assignment to small working groups; these groups should submit reports to the next meeting of the CCT and interim reports one year before the next meeting. Following some discussion it is agreed that four working groups are required. Two of these (Working Group 2, Working Group 4) continue with largely the same tasks and membership as previously. The new Working Group 1 and Working Group 3 replace two former working groups whose tasks have been completed. After some further discussion it is agreed that the memberships and tasks of the working groups will be as follows:

Working Group 1. — Defining Fixed Points and Interpolating Instruments: improved techniques for the realization of defining fixed points and interpolating instruments ($T_{90} \geqslant 3$ K); non-uniqueness; update of *Supplementary Information*.

B. W. Mangum (Chairman)
P. Bloembergen
M. V. Chattle
A. I. Pokhodoun
P. Marcarino

Working Group 2. — Secondary Fixed Points and Techniques of Approximation to the ITS-90: secondary fixed points; approximations to the ITS-90; advice on the application of the ITS-90 to international standards and critical tables; updates of existing documents.

R. E. Bedford (Chairman)
H. Maas
F. Pavese
C. Rhee
Zhao Qi

Working Group 3. — International Traceability in Temperature Measurements: collection of information on regional and bilateral comparisons; organization of suitable comparisons at the highest level of accuracy between regional groups; procedures for the estimation of uncertainty.

G. Bonnier (Chairman)
T. P. Jones
T. Ricolfi
D. C. Ripple
H. Sakurai

Working Group 4. — Thermodynamic Temperature Determinations and Extension of the ITS-90 to Lower Temperatures: new determinations of T and $(T - T_{90})$; information on $(T_{90} - T_{68})$; ^{3}He vapour pressure scale below 3 K; temperature scales below 0,65 K.

R. L. Rusby (Chairman)

M. Durieux

R. P. Hudson

K. Grohmann

H.-J. Jung

P. P. M. Steur

Mr Bedford says that the draft table of secondary reference temperatures was prepared by the former membership of Working Group 2. The final version is soon to be prepared and published. He proposes that the authors of the publication should be the old Working Group 2 members. The meeting agrees. The President says that the same is true for the forthcoming publication from Working Group 4 on $(t_{90} - t_{68})$ from 630 °C to 1064 °C.

14. Report to the CIPM and recommendations

During the meeting the CCT has identified three topics that should form the subject of recommendations to the CIPM: Recommendation T 1, on links between regional comparisons of temperature standards; Recommendation T 2, on investigations of the behaviour of triple point of water cells; Recommendation T 3, on thermodynamic temperature measurements. Successive drafts of each of these recommendations are prepared and extensively criticized until final wordings in both English and French are accepted. The President says that he will prepare the text for his report to the CIPM at its meeting later in September 1993. The three recommendations will be annexed to the report.

15. Other business

15.1 Next meeting

The President recommends that the next meeting of the CCT be held in 1996. The members agree. The precise date will be decided later, taking into account other related events such as the IMEKO Symposium on temperature measurement in 1996 in Turin. The President reminds the working group chairmen that the interim reports are to be sent in due time to prepare the report to the twentieth Conférence Générale.

15.2 Other business

Mr Rusby, referring to Document CCT/93-23, describes recent work on realizing the triple point of deuterium in sealed cells. Three cells of different origin were compared at the NPL, the IMGC, and the VNIIFTRI: these agree to within 1 mK. Hence the possibility of using the deuterium triple point in the ITS-90 instead of the two hydrogen boiling points is attractive. It could certainly be used for secondary realizations. Mr Mangum asks if there is more than one source of sufficiently pure deuterium. Mr Pavese replies that there is currently only one commercial source (Monsanto), but that there will probably also be a Russian source. This leads to a brief discussion among Messrs. Rusby, Pavese, Bloembergen and Mangum on sources of deuterium, means of production of deuterium, effectiveness of different catalysts, the probable long-term reproducibility of the triple point, and the effect on the non-uniqueness of the ITS-90 if the fixed points at 17 K and 20 K are replaced by the single deuterium triple point. Mr Pavese also says that the IMGC has a stock of 100 litres of deuterium (Monsanto) stored in a container stabilized in temperature.

The President informs the CCT that Mr Bonhoure will retire from the BIPM in October 1993. He thanks him for his considerable contributions to the work of the CCT over the years – his studies in radiation thermometry, low temperature thermometry, pressure measurements and his assistance in translating bad English into good French. Mr Quinn also pays tribute to Mr Bonhoure for his career at the BIPM and, in particular, for taking over the radiation thermometry work in the 1960s when Mr Hall came from the NPL. In his response, Mr Bonhoure concludes by saying that when he first attended a CCT meeting in 1954, one of the chief topics of discussion at that meeting related to the triple point of water, and now at his last CCT meeting in 1993 the triple point of water is again one of the important items under discussion. The CCT applauds Mr Bonhoure.

The President closes the meeting; thanks members of the CCT for their support, contributions, and effectiveness in handling the large number of items on the agenda. He thanks the BIPM staff for their excellent assistance in handling this particularly large meeting of the CCT. Mr Quinn congratulates Mr Crovini for his superb handling of his first CCT meeting as President.

January 1994

APPENDIX T 1

Working documents submitted to the CCT at its 18th Meeting

(*see* the list of documents on page T 34)

ANNEXE T 1

Documents de travail présentés à la 18[e] session du CCT

Ces documents de travail peuvent être obtenus dans leur langue originale sur demande adressée au BIPM.

Document CCT/

93-1 Questionnaire on the realization of the ITS-90, 4 p.
Answers received to the questionnaire, 57 p.
(R) ITS-90 realisation in 14 national laboratories. Results of a CCT inquiry, by L. Crovini and P.P.M. Steur, 17 p.

93-2 NRC (Canada). — Platinum Resistance Thermometry Beyond 830 °C, the Pt-Si Eutectic Point ?, by J. Ancsin, 4 p.

93-3 NRC (Canada). — Observations Concerning Ag-Al Eutectic and their Relevance to Pt-Si Reaction, by J. Ancsin, 5 p.

93-4 IMGC (Italie). — Recalculation on ITS-90 of Accurate Vapour-Pressure Equations for e-H_2, Ne, N_2, O_2, Ar, CH_4 and CO_2, by F. Pavese. *J. Chem. Thermodynamics*, 1993, **25**, 1351-1362.

93-5 PTB (Allemagne) et INM (France). — A provisional reference function for platinum versus palladium thermocouples in the range 0 °C until 1 084 °C, by F. Edler, H. J. Jung, H. Maas and J. Y. Le Pommelec, 12 p.

93-6 PTB (Allemagne). — Comments on the ^{3}He vapour-pressure scale, by B. Fellmuth and G. Schuster, 2 p.

93-7 PTB (Allemagne). — PTB-92 : A temperature scale below ITS-90, by G. Schuster and D. Hechtfischer, 2 p.

93-8 PTB (Allemagne). — Remarks on a future ^{3}He melting-pressure scale, by B. Fellmuth, W. Buck and G. Schuster, 3 p.

93-9 VNIIM (Féd. de Russie). — Determination of the relationship between the resistance ratio and the temperature of a platinum resistance thermometer above the freezing point of silver, by A. I. Pokhodoun, M. S. Matveyev and N. P. Moiseyeva, 15 p.

Document
CCT/

93-10 NIM (Rép. pop. de Chine). — The Realization of ITS-90 (1,2 K - 273,16 K) at NIM, by Zhang GuoQuan, Liu Yang, Huang NingSheng, Wu HeLian and Wu BiQin, 2 p.

93-11 NIM (Rép. pop. de Chine). — Note : Remark of Radiation Thermometry, by Zhao Qi, Yuan Zundong, Duan Yuning, 2 p.

93-12 NIM (Rép. pop. de Chine). — The present state of the International Temperature Scale of 1990 between 0 °C and 961,78 °C in China, by Li Xumo, 2 p.

93-13 INM-CNAM (France). — About the accuracy of the mercury triple point, by Y. Hermier and G. Bonnier, 7 p.

93-14 INM-CNAM (France). — About the "strange" behaviour of a water triple-point cell, by Y. Hermier and G. Bonnier, 5 p.

93-15 NPL (Royaume-Uni). — A EUROMET intercomparison of rhodium-iron resistance thermometers, by D. I. Head and R. L. Rusby, 8 p.

93-16*a* Report of Working Group 2 to the Comité Consultatif de Thermométrie, July 1993, 6 p.

b Report 2 of Working Group 2 to the Comité Consultatif de Thermométrie, September 1993, 30 p.

93-17 IMGC (Italie). — On the behaviour of Platinum Palladium thermocouple from 600 °C to 1 300 °C, by L. Crovini, A. Actis, V. Fernicola and R. Galleano, 5 p.

93-18 NIST (É.-U. d'Amérique), IMGC (Italie), KRISS (Rép. de Corée), NPL (Royaume-Uni), NRLM (Japon), VNIIM (Féd. de Russie) et VSL (Pays-Bas). — Determination of ($t_{90} - t_{68}$) between 630,615 °C and 1 064,18 °C, by G. W. Burns, G. F. Strouse and B. W. Mangum, P. Marcarino and M. Battuello, H. K. Lee, J. C. Kim, K. S. Gam and C. Rhee, M. Chattle, M. Arai and H. Sakurai, A. I. Pokhodun, N. P. Moiseeva and S. A. Perevalova, and M. J. de Groot, 7 p.

93-19 NPL (Royaume-Uni). — Measurements on Triple Point of Water Cells Following Different Preparation Methods, by M. V. Chattle and Miss J. Butler, 5 p.

93-20 NIST (É.-U. d'Amérique). — The Effect of Hydrostatic Head on the Liquid/Solid Equilibrium Temperature of Mercury During Freezing and Melting, by G. T. Furukawa, 5 p.

Document
CCT/

93-21 NIST (É.-U. d'Amérique). — A Progress Report on the Primary Realization of the International Temperature Scale of 1990 from 0,65 K to 83,8 K at the National Institute of Standards and Technology, by C. W. Meyer and M. L. Reilly, 6 p.

93-22 NIST (É.-U. d'Amérique) et PTB (Allemagne). — A Direct Comparison of Three PTB Silver Fixed-Point Cells with the NIST Silver Fixed-Point Cell, by G. F. Strouse and B. W. Mangum, H. G. Nubbemeyer and H. J. Jung, 9 p.

93-23 NPL (Royaume-Uni), VNIIFTRI (Féd. de Russie) et IMGC (Italie). — Measurement of a VNIIFTRI Deuterium Triple Point Cell at IMGC and NPL, by D. I. Head, D. N. Astrov, V. M. Khnykov and F. Pavese, 5 p.

93-24 NIST (É.-U. d'Amérique). — Preliminary Results of a Comparison of Water Triple-Point Cells Prepared by Different Methods, by G. F. Strouse, G. T. Furukawa and B. W. Mangum, 23 p.

93-25 Information on Measurements of Thermodynamic Temperature. Report to the CCT by Working Group 4, August 1993, 11 p.

93-26 PTB (Allemagne). — Examination of the Thermodynamic Accuracy of ITS-90 in the Range 4,2 K to 24,5 K by Means of a Dielectric Constant Gas Thermometer, by K. Grohmann and H. Luther, 3 p.

93-27 Lawrence Berkeley Laboratory et Naval Research Laboratory (É.-U. d'Amérique). — A Summary of Experimental Results Supporting an Extension of the International Temperature Scale to the Millikelvin Region, by W. E. Fogle, R. J. Soulen Jr. and J. H. Colwell, 10 p.

93-28 University College London et Imperial College of Science, Technology and Medicine (Royaume-Uni). — Primary Acoustic Thermometry Between 100 K and 300 K, by M. B. Ewing and J. P. M. Trusler, 6 p.

93-29 NPL (Royaume-Uni). — The Mercury Point in the ITS-90, by R. L. Rusby, 3 p.

93-30 MSL (Nouvelle-Zélande). — Thermodynamic Smoothness of the ITS-90 as Compared with a Thermodynamic Model for the Resistance, by J. V. Nicholas, 9 p.

93-31 KRISS (Rép. de Corée). — Report to the 18th Meeting of CCT, by C. Rhee, D. Chi, K. H. Kang, K. S. Gam, Y. G. Kim, J. W. Hahn and S. N. Park, 13 p.

Document
CCT/

93-32 NRLM (Japon). — Remarks on the difference equations between the IPTS-68 and the ITS-90, by H. Sakurai, 4 p.

93-33 NRLM (Japon). — Long-term stability of the gallium triple point by sealed glass cells, by M. Arai and H. Sakurai, 2 p.

93-34 NRLM (Japon). — Some Characteristics on High-Temperature Industrial Platinum Resistance Thermometers, by M. Arai and H. Sakurai, 2 p.

93-35 VNIIM (Féd. de Russie). — The effects of the conditions of the tin fixed point realization in the ITS-90 on ITS nonuniqueness, by Yu. V. Tarbeyev, V. V. Kukhar and A. I. Pokhodun, 11 p.

93-36 VNIIM (Féd. de Russie). — Realization of the freezing point of indium, by A. G. Ivanova and A. I. Pokhodun, 9 p.

93-37 VNIIM (Féd. de Russie). — Ga-Sn eutectic alloy melting fixed point, by A. G. Ivanova, 5 p.

93-38 VNIIFTRI (Féd. de Russie). — On the thermal expansion correction of gas-thermometry measurement of VNIIFTRI, by D. N. Astrov, L. B. Belyansky and Y. A. Dedikov, 3 p.

93-39 KOL (Pays-Bas). — Noise thermometry and ^{3}He melting pressure thermometry, by J. Bremer, A. Reesink and M. Durieux, 2 p.

93-40 KOL (Pays-Bas). — A thermodynamic calculation of the vapour pressure vs. temperature relation of ^{3}He, by A. L. Reesink and M. Durieux, 2 p.

TABLE DES MATIÈRES
TABLE OF CONTENTS

COMITÉ CONSULTATIF DE THERMOMÉTRIE

18e session (1993)
18th Meeting (1993)

Pages

English text of the report

Minutes of the 18th meeting of the CCT

Appendix

Imprimerie GAUTHIER-VILLARS, Paris
Dépôt légal, Imprimeur, n° 4388
Dépôt légal : mars 1995 *Imprimé en France*