Bureau International des Poids et Mesures

Consultative Committee for Time and Frequency (CCTF)

Report of the 16th meeting
(1– 2 April 2004)
to the International Committee for Weights and Measures

Comité international des poids et mesures

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Note:

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

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

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

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

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR TIME AND FREQUENCY
as of 1 April 2004

President

S. Leschiutta, member of the International Committee for Weights and Measures, Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin.

Executive Secretary

E.F. Arias, International Bureau of Weights and Measures [BIPM], Sèvres.

Members

Bureau National de Métrologie, SYstèmes de Référence Temps-Espace [BNM-SYRTE], Paris.

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

International Astronomical Union [IAU].

International Telecommunication Union [ITU-R], Radiocommunication Bureau.

International Union of Geodesy and Geophysics [IUGG].

International Union of Radio Science [URSI].

Istituto Elettrotecnico Nazionale Galileo Ferraris [IEN], Turin.

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

National Institute of Information and Communications Technology [NICT], Tokyo.

National Institute of Metrology [NIM], Beijing.

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

National Measurement Institute of Australia, [NMIA], Lindfield.

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

National Physical Laboratory [NPL], Teddington.

National Physical Laboratory of India [NPLI], New Delhi.

National Physical Laboratory of Israel [INPL], Jerusalem.

National Research Council of Canada [NRC], Ottawa.

NMi Van Swinden Laboratorium [NMi VSL], Delft.

Observatoire Royal de Belgique [ORB], Brussels.

Office Fédéral de Métrologie et d'Accréditation [METAS], Wabern/Observatoire Cantonal [ON], Neuchâtel.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Real Instituto y Observatorio de la Armada [ROA], San Fernando.

Technical University [TUG], Graz.

U.S. Naval Observatory [USNO], Washington DC.

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

Observers

Astrogeodynamical Observatory [AOS], Space Research Centre, Borowiec.

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

Singapore Productivity and Standards Board [PSB], Singapore.

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

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

The Consultative Committee for Time and Frequency (CCTF) held its 16th meeting at the International Bureau of Weights and Measures (BIPM), at Sèvres. Four sessions took place, on 1 and 2 April 2004.

The following were present: A. Bauch (PTB), T.R. Bartholomew (ITU-R), R. Beard (ITU-R), C. Boucher (IUGG), J.-S. Boulanger (NRC), A. Clairon (BNM-SYRTE), P. Defraigne (ORB), G. de Jong (NMi VSL), N. Dimarcq (BNM-SYRTE), Dr Y.S. Domnin (VNIIFTRI), G. Dudle (METAS), P. Fisk (NML-CSIRO*), T. Fukushima (IAU), F.J. Galindo (ROA), X. Gao (NIM), A. Godone (IEN), D. Henderson (NPL), M. Hosokawa (NICT), T. Ikegami (NMIJ/AIST), K.J. Johnston (USNO), N. Koshelyaevsky, (VNIIFTRI), H.S. Lee (KRISS), S. Leschiutta (President of the CCTF, IEN), J. Levine (NIST), A. Madej (NRC), D. Matsakis (USNO), J. Mc A. Steele (URSI), D. McCarthy (USNO), T. Morikawa (NICT), T. O'Brian (NIST), S. Ohshima (NMIJ/AIST), J. Palacio (ROA), T.E. Parker (NIST), F. Riehle (PTB), P. Tavella (IEN), P. Thomann (ON), P. Uhrich (BNM-SYRTE), A.J. Wallard (Director of the BIPM), D.H. Yu (KRISS).

Observers: H.A. Chua (SPRING), R. Hamid (UME), L. Marais (CSIR-NML), J. Nawrocki (SRC).

Guests: M.N.Z. Abidin (NML-SIRIM), W.J. Klepczynski (Edgewater), C.-S. Liao (TL), R.A. Nelson (Satellite Engineering Research Corporation Bethesda), K. Senior (IGS, NRL).

Also present: P. Giacomo (Director Emeritus of the BIPM), T.J. Quinn (Director Emeritus of the BIPM), E.F. Arias (Executive Secretary of the CCTF), Z. Jiang, W. Lewandowski, G. Petit, P. Wolf (BIPM), J. Ray (BIPM, visiting scientist).

Sent regrets: J. Bergquist (NIST), M. Imae (CRL**).

The President opened the meeting and welcomed the delegates and observers. The welcome was extended to the new Director of the BIPM, Professor Wallard. The President said that the meeting had the special honour of having the attendance of Dr Quinn, Director Emeritus of the BIPM. It was noted that 21 laboratories were represented together with four unions, IAU, ITU, IUGG and URSI.

The President then remarked that the year 2005 will mark 50 years after Essen devised the caesium clock at NPL and that some activities should mark the occasion. He announced that, in Italy, there will be a one–day seminar on Essen's work on the measurement of the speed of light and on the caesium standard.

The President continued by noting some of the progress since the 15th meeting of the CCTF (in 2001). There has been an improvement to the number of caesium fountains. Two-way time transfer has improved via increased automation; in some cases, hydrogen masers are compared several times per day. GPS signals are facilitating an improvement in the accuracy of the frequency comparison of primary standards.

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* Renamed NMIA.

** Renamed NICT.

The President noted that the 15th meeting of the CCTF proposed five recommendations to the CIPM, which were:

- CCTF 1 (2001): Secondary representations of the second.
- CCTF 2 (2001): Time and frequency comparisons using Global Positioning System (GPS) phase and code measurements.
- CCTF 3 (2001): The meaning of the designation "*k*" in UTC(*k*) and TAI(*k*).
- CCTF 4 (2001): Calibration of time links for International Atomic Time.
- CCTF 5 (2001): Technical guidelines for manufacturers of Global Navigation Satellite Systems receivers used for timing.

Finally, the meeting was informed that Dr Henderson had agreed to serve as the *Rapporteur*.

The President continued by inviting comment from the new Director of the BIPM. The Director, A. Wallard said that, on behalf of the BIPM, he was pleased to welcome the delegates and observers, and to be able to contribute to the meeting. He remarked that, given his scientific background in stabilized lasers, he was especially pleased to observe the collaboration between the Consultative Committee for Length (CCL) and the CCTF (in the form of the Joint Working Group on Secondary Representations of the Second). Finally, he noted that the meeting was honoured by the presence of two Directors Emeritus, P. Giacomo and T.J. Quinn.

2 PROGRESS IN PRIMARY FREQUENCY STANDARDS

2.1 Operating primary frequency standards and new primary standards under development

Turning to the second item on the agenda, the President invited the representatives of each laboratory to present brief reports on progress in primary standards, summarizing their written submissions (which are available on the BIPM website).

Summaries of the following reports from the laboratories were then presented by the speakers indicated.

- CCTF/04-02 (METAS, Dr Dudle):

The primary frequency standard (FOCS-1), based on a continuous beam of cold atoms, has been moved from ON to METAS. Currently, the best short-term stability achieved with FOCS-1 is $\sigma_y(\tau) = 2.5 \times 10^{-13}\ \tau^{-1/2}$. An evaluation of uncertainties has begun, but no frequency has been reported to the BIPM.

- CCTF/04-03 (NMIJ/AIST, Dr Ikegami):

There is activity on two primary standards; one (NRLM-4) is an optically pumped beam device, the other (JF-1) is a fountain. NRLM-4 was relocated in the year 2000 and is being re-assembled. A comparison with TAI is expected in approximately two months time. With JF-1, a stability of $\sigma_y(\tau) = 5 \times 10^{-13}\ \tau^{-1/2}$ has been achieved. Uncertainties in the second order Zeeman shift, the blackbody radiation shift, the cold collision shift, and the shift due to the distributed cavity phase shift have been estimated as 3×10^{-16}, 4×10^{-16}, 6×10^{-16}, and 5×10^{-16}, respectively.

The President, noting that the BIPM wishes to have reports from more fountains, asked Dr Ikegami whether he could predict when the evaluation of JF-1 would be complete. Dr Ikegami replied that a report could be expected in six months to one year.

- CCTF/04-04 (KRISS, Dr Lee):

An evaluation of the optically pumped standard, KRISS-1 has recently been completed. The accuracy is limited by the end-to-end cavity phase shift at 6.8×10^{-14}. It is expected that an uncertainty of 1×10^{-14} will be reached, limited by the comparatively short length of the microwave cavity. Work on a fountain standard has continued. Several problems have led to the decision to build a second fountain, which includes improved fluorescence collection, and a new microwave cavity. The evaluation of the second fountain system is expected to be completed this year.

Noting that KRISS has been working on two devices, the Director commented that it is desirable for a laboratory to have two sets of apparatus; one device can serve as a standard whilst the second is serving as a research device.

- CCTF/04-05 (NIM, Dr Gao):

Work on a caesium fountain began in 1997. An evaluation in December 2003 demonstrated a stability of $\sigma_y(\tau) = 8 \times 10^{-13}\ \tau^{-1/2}$, with a type-B uncertainty of 8.5×10^{-15}. It is possible that frequency data will be contributed by the end of the year. Work has also begun on a second fountain.

- CCTF/04-06 (NML-CSIRO, Dr Fisk):

Whilst not developing a caesium standard, there is work on an Yb ion microwave standard. About two years ago, the systematic uncertainty was limited to 6 parts in 10^{14} by inhomogeneity in the magnetic field. Work is continuing on a replacement vacuum system, made from copper, though progress has been slow. The new system should provide an immediate improvement of the uncertainty, to 6 parts in 10^{15}, reaching a limit of 3 to 4 parts in 10^{15}.

- CCTF/04-09 (PTB, Dr Bauch):

Three primary clocks are in operation, CSF1, CS1, and CS2. The operation of CS3 as a clock has been abandoned. There has been no change to the configuration of CSF1 since 2001, but the reliability of the lasers and electronics has been improved. There have been a total of 15 contributions to TAI from CSF1, when the fountain was operated, typically, for 15 to 20 days with 95 % coverage. Bilateral frequency comparisons between the fountains, NIST-F1, SYRTE-FO2, SYRTE-FOM, IEN-CSF1 and NPL-F1, and PTB-CSF1 have been performed.

CS2 has operated since 1987, and CS1 since 1997. There is a significant offset between CS1 and CS2. The mean frequency difference is $y(\mathrm{CS1} - \mathrm{CS2}) = -6.05 \times 10^{-15}$. The difference, CSF1 - CS2 of 5×10^{-15} is well within the uncertainty of CS2. CS2 has realized the SI unit continuously for ten years.

- CCTF/04-10 (NICT, Dr Hosokawa):

CRL-O1 is the first optically pumped caesium primary frequency standard in the NICT. In 2003, a paper on the accuracy evaluation of CRL-O1 was submitted to *Metrologia*. The typical type-B uncertainty of CRL-O1 is 5.4×10^{-15} but the combined uncertainty is currently dominated by the type-A uncertainty, at 9×10^{-15}. The signal to noise ratio has deteriorated and a re-bake is planned.

For the fountain standard, a stability of 9×10^{-15} can be reached in half a day. Construction of an improved, smaller fountain is planned. Research and development on the single Ca^+ ion optical region atomic frequency standard has begun. A miniature trap, cooling laser systems and a

729 nm clock laser system is under development. Completion of the probe laser this year is anticipated.

- CCTF/04-14 (IEN, Dr Godone):

The apparatus of the fountain was completed in 2001. Evaluation began in 2002, with data being sent to the BIPM in 2003 on three occasions. The type-B uncertainty is 1.6×10^{-15}. Doubts have arisen regarding the uncertainty of the correction for the blackbody radiation. The stability of the fountain is $\sigma_y(\tau) = 3 \times 10^{-13}\ \tau^{-1/2}$. Consideration is being given to building a second fountain; this might include launching of multiple cold atom clouds (more than one cloud undergoing ballistic flight at one time). A 1,1,1 geometry may be used for the second fountain.

- CCTF/04-21 (NRC, Dr Boulanger):

A thermal beam standard has been operated for many years. There has been work on a "tall" fountain (1.8 m) but there were difficulties with the vertical alignment and it was shown that there was no advantage conferred by the extra height. A new, smaller, fountain has been designed and assembly may begin this summer, as most of the parts have been built. The new fountain will incorporate atoms continuously in the Ramsey interaction (one ball up and one down at the same time). The Ramsey interrogation is to be via phase modulation.

- CCTF/04-22 (NIST, Dr O'Brian):

The fountain NIST-F1 has reported to the BIPM twelve times since 1999. The most recent evaluation achieved a combined uncertainty of 7×10^{-16}, the uncertainty available to the BIPM being limited by time transfer, to 1.2×10^{-15}. Work on NIST-F1, towards evolutionary improvements, will continue. A second fountain is being designed. The fountain will reduce the uncertainty due to the blackbody radiation, by using a cryogenically cooled drift tube. A multi-toss system will be employed to lower the atom density. It is intended to make frequent reports to the BIPM.

- CCTF/04-23 (BNM-SYRTE, Dr Clairon):

Four caesium standards are operated; three are fountains, the other a beam device. FO1 has been modified and now achieves a stability of $\sigma_y(\tau) = 3 \times 10^{-14}\ \tau^{-1/2}$. FOM, the mobile fountain, is to be moved to CNES, in Toulouse, at the end of the year. FO2 has an accuracy of 8×10^{-16}, achieved by using a new method to evaluate the shift due to cold collisions, to better than one percent, when using "large" atom numbers.

- CCTF/04-24 (VNIIFTRI, Dr Domnin):

The beam standard, CS102 continues to operate with an estimated type-B uncertainty of 3×10^{-14}. CS102 has demonstrated a mean time unit difference with TAI of 1.3×10^{-15} from 2001 to 2003. The critical technologies for a fountain standard have been demonstrated; atoms have been cooled to 1 μK and Ramsey fringes, width 1 Hz, have been observed. The Zeeman shift has been measured using the $m_f = 1$ to $m_f = 1$ transition. A new microwave synthesizer is nearing completion and it is hoped to begin work soon, to construct a fountain standard.

- CCTF/04-25 (NPL, Dr Henderson):

NPL has completed an evaluation of NPL-F1. A second, experimental device, has been constructed to evaluate the benefit conferred on a fountain standard by lattice cooling of the caesium atoms.

The President noted that the meeting had covered all the documents relating to the development of primary standards.

2.2 Report of the CCTF Working Group on the Expression of Uncertainties in Primary Frequency Standards

The President continued, by noting that there was no formal report from the Working Group on the Expression of Uncertainties in Primary Frequency Standards and opened the topic for discussion. There being no contribution from the delegates, the next topic was addressed.

2.3 Report of the CCL/CCTF Joint Working Group (JWG) on Secondary Representations of the Second and the *Mise en Pratique* of the Metre

The President noted that the Joint Working Group had met two days previously; Drs Riehle (PTB) and Gill (NPL) had chaired the meeting. He invited Dr Riehle to present his report.

Dr Riehle presented a summary of report CCTF/04-28. He began by reminding the delegates of Recommendation CCTF 1 (2001). Dr Riehle continued with a brief sketch of the history of the JWG. A working group of CCTF on secondary representations of the second was established in June 2001, comprising representatives from BNM-SYRTE, IEN, NIST, NMIJ, NPL, NRC, PTB and VNIIFTRI. The then-Director of BIPM, Dr Quinn, proposed to the meeting of the CCL in 2001 that links be established with the working group, as there was the possibility of an overlap of activities between the CCTF working group and the CCL Working Group on *Mise en Pratique* (MeP) of the Metre.

The CIPM recommended in 2001 that a JWG be formed. The remit of the group was to create a single list of frequencies and to strengthen the definition of the metre. Dr Riehle noted that it was clear that the requirements of the length and time communities are not the same; an iodine-stabilized He-Ne laser is not suitable for timekeeping, and microwave clocks and femtosecond laser based optical standards are not yet a practical tool for length metrology.

In February 2002, a questionnaire was sent by PTB to the members of the CCTF WG on Secondary Representations of the Second. In May 2003, the CCTF WG met with CCL guests at the EFTF/FCS scientific conference to discuss the replies to the questionnaire.

In September 2003, a JWG was formally founded under Dr Chung (President of the CCL) and Prof. Leschiutta. The JWG members were drawn from the CCTF WG and the CCL MeP WG, under the joint chair of Dr Gill and Dr Riehle. The JWG worked on devising the requirements of a standard, for consideration as a secondary representation of the second and agreed that: “The SI value of the unperturbed frequency of a quantum transition suitable as a secondary representation of the second must have an uncertainty that is evaluated and documented so as to meet the requirements adopted for the primary frequency standard for use in International Atomic Time”; and “this uncertainty should be no larger than about a factor of 10 of the primary standards *of that date* that serve as the best realizations of the second”.

Dr Riehle continued by giving the current working procedure of the JWG, the joint group will review and discuss the proposed standard's uncertainty budget and evaluate its validity before making their recommendation to the CCTF for the standard being added to the list of frequencies appropriate for secondary representations of the second. The JWG will keep the CCL informed about its activity.

Dr Riehle then identified the frequencies that were considered. These were three microwave standards and seven optical standards. The recommendation of the JWG was then presented. At this stage, the unperturbed ground-state hyperfine quantum transition of ^{87}Rb may be used as a secondary representation of the second (detailed at item 12 in the agenda). He noted that, with the continuing activity of the JWG, a single list of frequencies is ensured and that no numerical ambiguity can occur with frequencies that may be used for the realization of the metre or with those recommended as secondary representations of the second. The list has the further capability of including frequency standards that are neither recommended for the realization of the metre nor as secondary representations of the second, but that have applications in basic research or applied technology.

Dr Riehle concluded by acknowledging the contributions from Dr Quinn, Professor Wallard and the BIPM, the members of CCTF WG on Secondary Representations of the Second, the members of the CCL WG MeP, and the members of the CCL/CCTF JWG.

The President thanked Dr Riehle for his report and invited discussion.

Dr Parker asked whether it is intended that measurements of the Rb transition should contribute to TAI. Dr Arias replied that this is not the intention.

Dr Parker then asked how the JWG arrived at the uncertainty to be attributed to the frequency given in the proposed recommendation. Dr Riehle explained that there were uncertainties over the shift due to blackbody radiation, particularly due to the recent work at IEN.

Dr Parker then commented that there was a question whether the best realization of the SI second could be found in a laboratory measurement, or in the calculation of Terrestrial Time (TT) and that it was important to include the peer review process in judging the accuracy of a laboratory realization of the SI second. Dr Riehle said he agreed completely and that the JWG considered what could be concluded about the accuracy of the estimation of the type-B uncertainty of the fountain standards, given the level of agreement achieved during frequency comparison. Dr Petit had presented an analysis, which showed that the degree of agreement was consistent with the type-B uncertainties, as they have been stated by the individual laboratories.

Dr Parker then observed that, when considering TT data last December 2003, two points out of four were more than two standard deviations from the mean, which indicated that there was a problem and continued by asking if there was a mechanism for changing the uncertainty of a secondary representation. Dr Riehle reminded Dr Parker that the work of the JWG was a recommendation for the CCTF to consider, and that the CCTF could take the view that the uncertainty was too small. Dr Madej then added the clarification that the JWG considered that the suggested uncertainty was composed of two parts: the frequency ratio between the hyperfine transition in Rb and in Cs (as measured in the laboratory); and the accuracy of that laboratory’s Cs standard (as compared to TT), as demonstrated by time transfer. This combination led to the total uncertainty proposed by the JWG.

Professor Wallard then pointed out that the CCL MeP WG meetings always reconsidered radiations and that the approach to estimating uncertainty was conservative. He noted that it was hoped for the JWG to meet again in September 2005, when it would look again at Rb. At that time, there might be several optical transitions being put forward and it was possible that there might also be a measurement of Rb from more than one national metrology institute (NMI). The President thanked Dr Riehle for his clarifications and asked him to inform the chair of the CCL about the progress achieved at the meetings (of the JWG and of the CCTF). The President added that he believed that the work of the JWG should continue.

2.4 Realization of TT(BIPM)

Dr Petit presented a summary of report CCTF/04-17 on the realization of TT. The definition of TT was adopted by the General Assembly of the IAU meeting in 1991 but was revised in 2000. TT is an “ideal” timescale in a coordinate, general relativistic, reference frame. The BIPM routinely realizes an approximation to TT. The uncertainty of that approximation has improved over the last ten years from 6×10^{-14} to 0.1×10^{-14}, which integrates to a time uncertainty of less than 1 µs. Since 1999 there has been a drift between the frequencies of TT and of TAI, the difference being between 6×10^{-15} and 10×10^{-15}. It is necessary to consider whether the current procedure for steering TAI so as to realize the SI second, is optimal. The BIPM was drafting a resolution for suggesting new goals in steering TAI. Dr Petit then moved to the subject of the accuracy of primary standards. He presented a plot of the frequency difference between TT(BIPM) and all the contributions from primary standards for the previous five years; the plotted difference was normalized by the standard's uncertainty, including the time transfer. He pointed out that the distribution is "more or less" consistent with a normal distribution. Dr Petit concluded by noting that, at the recent meeting, the WG on TAI concluded that the BIPM might benefit from more information about the calculation of the uncertainty of a contributing primary standard, and that a draft recommendation was being circulated.

The President thanked Dr Petit for his contribution and noted that the meeting should anticipate seeing two recommendations on the basis of Dr Petit's presentation.

3 PRESENT STATUS OF TAI

3.1 Report of the BIPM Time section

Dr Arias presented the report of the BIPM Time Section CCTF/04-19. Changes to the monthly produced *Circular T* were introduced in April 2003, giving [*UTC - UTC(k)*] and [*TAI - TAI(k)*] to 0.1 ns resolution, justified by the quality of the time transfer link. In January 2004, Section six was introduced, containing information about those time transfer links, and their uncertainties used to calculate the UTC(k) offsets. The delay in publishing *Circular T* has been reduced to about the 12th of each month due to increased automation, with checks done manually. The annual reports have been published.

Of the clocks contributing to TAI, 68 % are caesium clocks of the type HP5071A, 16 % are masers and the remaining 16 % is comprised of lower quality clocks, and PTB CS1 and CS2. The stability of EAL is $\sigma_y(\tau) = 0.6 \times 10^{-15}$ over 20 to 40 days. There were changes to the weighting procedure for clocks (detailed in the document), based on empirical calculations of the stability achieved in EAL, with different maximum weighting. The maximum weight of a clock is now $2.5/N$, where N is the number of participating clocks.

On the accuracy of TAI, nine primary standards are reporting; five are fountains. The deviation of TAI from the estimation TT(BIPM) of the SI step interval has varied from 5×10^{-15} to 11.9×10^{-15}.

Regarding time links, there are now three techniques in use, GPS C/A code, GPS P3, and two-way (TWSTFT). TWSTFT is now done daily for the Europe-North America links and, in some cases, sub-daily. A diagram was presented showing the time links between laboratories. In some cases, laboratories are linked by three different techniques. For multi-technique links (GPS C/A common-views, GPS P3, TWSTFT) one is used to calculate TAI, the others are computed as a backup. 50 % of the GPS time receivers used to calculate TAI are now calibrated, a result of calibration campaigns organized by the BIPM. The IGS/BIPM pilot project (1998-2002) on dual frequency receivers (using P-code) has resulted in the calibration of P3-code-based links in TAI.

On space and time references, the continuity of the collaboration between the BIPM and the IAU was assured when, in January 2001, the Executive Committee of the IAU created the IAU Working Group on Relativity for Celestial Mechanics, Astrometry and Metrology (RCMAM).

The BIPM and the USNO have been working together to provide the Conventions Product Centre (CPC) of the IERS since January 2001 (detailed at item 7 of the agenda). The BIPM is represented on the IGS Working Group on Clock Products and is a Sector Member of the ITU-R.

Collaboration was maintained with radio-astronomy groups analysing pulsar data, by providing them with the post-processed realization of Terrestrial Time, TT(BIPM). A small collaboration is continuing with the Observatoire Midi-Pyrénées (OMP) in Toulouse to complete the processing of observations already carried out.

A member of the BIPM Time section, Peter Wolf, took a one-year, grant-funded, leave of absence to work with CNES (Centre National d'Études Spatiales) to study possible applications in fundamental physics and metrology, of atomic interferometry using laser-cooled atoms. The work was done at the BNM-SYRTE.

The President thanked Dr Arias for her very comprehensive report.

3.2 Report of the CCTF Working Group on TAI

Dr Tavella, chair of the CCTF Working Group on TAI presented the report of the 6th meeting of representatives of laboratories contributing to TAI (BIPM, 31 March 2004). She made only general comments as much of the output of the meeting appears as reports under other agenda items. (The presentations from the meeting have been posted on the BIPM website.)

Dr Tavella noted that 52 people attended the meeting from 25 laboratories, the subjects covered could be split into two groups: timescales and algorithms; and time links, calibration techniques and their uncertainties.

On algorithms, the WG noted the increased automation in the computation of TAI, reported by Dr Arias (CCTF/04-19). The Sub-Working Group on Algorithms held a successful workshop in March 2002 and invited suggestions for a further workshop, possibly to be held in 2007.

On time links for TAI, the WG received the report (CCTF/04-19). The WG noted the increased number of GPS receivers now calibrated due to the action of the BIPM and encouraged the Regional Metrology Organizations (RMO) to become involved. The WG would like to see more links used for the computation of TAI, to be calibrated by more than one technique at the same time.

The WG aired the possibility of holding a workshop on GPS receiver calibration, related to this item. Dr Tavella suggested that there might be interest in organizing a workshop on uncertainties. The President welcomed the suggestion.

Dr Bauch asked what might be the terms of reference of a WG on GPS receiver calibration. Given that receiver calibrations were done by the BIPM, and within EUROMET, would the proposed WG be required to document this work?

The President said that he did not know if GPS receiver calibration was within the terms of reference of the CCTF Working Group on TAI, but that this calibration was definitely an interest of the BIPM Time section.

Mr de Jong added that the WG on the MRA has discussed the uncertainties given by the BIPM on time links and found that there may be a need for reduced uncertainties. He said that the WG on MRA would like to have a sub-group to formulate procedures for such calibrations as they were important for the traceability to the SI second for the customers of NMIs.

Dr Koshelyaevsky suggested that the CCTF Working Group on TAI use the term GNSS rather than GPS. The President made note of this suggestion and deferred further discussion to Agenda item 10.

On primary frequency standards in TAI, the WG supported further study of the optimal way to use these in steering TAI.

3.3 Report of the sub-group on algorithms of the CCTF WG on TAI

Dr Tavella, the chair of the sub-group on algorithms of the CCTF WG on TAI reported that the main activity has been the symposium on algorithms, held at the BIPM in 2002 and co-organized by the BIPM, the IEN and the USNO. Dr Tavella noted that the symposium followed from several previous meetings on the topic. The symposium served to bring together the small scientific community working on algorithms, so as to identify the topical issues and to further the community's ability to extract information from timing data. There were 35 scientific contributions from colleagues working in the fields of time, space applications, geodetic survey, and industry. Many of the papers were published in a special issue of *Metrologia* (2003) and the others can be accessed via a CD-Rom. Dr Tavella noted that the President has suggested that the symposium had been overdue, there having been fourteen years since the previous meeting. Dr Tavella invited comments on the proposal that a further symposium be held in 2007 or 2008, to include tutorial sessions.

The President expressed thanks to Dr Tavella for her report and her organizational input, and to Dr Arias and Dr Matsakis for organizational input to the symposium.

4 FUTURE DEVELOPMENTS FOR UTC AND TAI

Dr Arias presented the proposal of the BIPM Time section, for developments. She began by noting that it was clear that the continuing support of time laboratories was essential. She recalled that at the 15th meeting of the CCTF, it was intimated that the BIPM would work towards including uncertainties on [*UTC* - *UTC(k)*] in *Circular T*. Although this has not been achieved, uncertainties are included for time links. It is hoped to have the [*UTC* - *UTC(k)*] uncertainties before the next meeting of the CCTF.

The algorithm for computing TAI will remain unchanged but work is planned to improve the frequency prediction of clocks contributing to TAI. Given the diversity of time links, it is appropriate to work on comparing the performance of links. There is the opportunity to use multiple links, weighting their contribution. The BIPM will continue its work towards improving the access to other timescales, including GLONASS, IGS, and in the future, Galileo. It is planned for the BIPM to consider further the steering strategy for TAI.

Dr Petit then indicated that there were two draft recommendations: on the steering of TAI and concerning the reporting of primary standards.

Dr Arias recalled that the reporting of primary standards and how to improve their contribution to TAI was discussed at the meeting of laboratories contributing to TAI. Guidelines had been suggested. Laboratories might be encouraged to provide contributions from primary standards more regularly, though the competing demands of research and operation was well recognized. The latter recommendation was the result of discussions between some attendees to the meeting of TAI contributing laboratories.

Dr Petit presented the draft recommendation on reporting primary standards (01-04-2004). He drew attention to the words “operate them on a regular basis”. Some were of the opinion that a more rigid schedule be defined, but the present level of clarity was intentional. He pointed out that the recommendation now required that successive evaluations be accompanied by a statement of uncertainty together with a report describing changes to the standard since the first referenced full evaluation. The BIPM would archive this information and it would be publicly available so that others could evaluate the uncertainty. The recommendation also directed that all submitted evaluations be used for steering TAI except in the case where a mutual decision was reached, between the BIPM and the reporting laboratory that a submission’s use would be to the detriment of TAI. Dr Petit was of the opinion that there is no need to have “strict” rules but that there is some utility in being able to exclude some measurements.

Dr Parker offered comment on the five points within the recommendation. He agreed that laboratories should strive to achieve regular realizations and offered that this is the goal at the NIST. He believed that the published uncertainty of the standard should include a discussion of the whole system, including the time transfer, and not just the physical standard. He has no objection to the requirement that successive evaluations be accompanied by a report, NIST already did this (though not in as much detail as the first publication); he encouraged the scheme whereby the reports were public, and on the last point (the option of excluding an evaluation), he thought that a process was required whereby a new fountain standard could be evaluated.

Dr Parker developed his last point, one fountain operating in a given month could make a significant impact on the calculation of TT – TAI. This has been less of an issue with the previous, thermal beam, devices, as they had “more noise”. Dr Parker noted that although disagreement between one fountain and a group of other fountains did not necessarily mean that it was “wrong” he did think that there was a need for monitoring, to check whether the long-term stability of a fountain was consistent with its type-B uncertainty, over a period of perhaps a year.

The President invited comment from Dr Clairon, who expressed agreement with Dr Parker.

Dr McCarthy indicated his opinion that the Recommendation was not sufficiently specific and that it would benefit from the clarity evidenced by the CCL MeP WG.

The President offered the point that the timescale warranted its own, unique, approach and that the MeP approach was not appropriate. Dr Bauch said that the report of the CCTF Working Group on the Expression of Uncertainties in Primary Frequency Standards (CCTF/99-09 and Recommendation S 3 (1999)) should be used as an input. He too judged that the use of MeP terminology was inadvisable and would provide an opportunity for confusion between time standards and length standards. The President indicated that the CCTF is able to accept the historical record as input, despite the fact that the 1996 WG (on the expression of uncertainties in primary frequency standards) is not currently convened.

Dr Petit suggested that it was the responsibility of the laboratory to follow the guidelines contained in Recommendation S 3 (1999). He added that including the uncertainty in the time transfer would not be the “whole story” as that uncertainty was not yet given in *Circular T*. The report of the uncertainty should be restricted to the uncertainty that is “local” to the laboratory. Dr Petit added that the steering of TAI was based on frequency comparisons taking place over “some months” and that one incorrect determination does not affect the steer directly.

The President urged Dr Parker, Dr Clairon, Dr Petit and Dr Bauch to continue their work on the text in order to agree upon some rules within the time constraint of the meeting.

The President invited Dr Petit to present the draft recommendation on the steering of TAI.

Dr Petit began by recalling that the main goal of steering TAI is that it should realize a timescale whose step interval was the SI second on the rotating geoid. However, steering has an impact on stability.

Dr Fukushima suggested that, regarding steering of TAI, a more specific definition of the geoid was required as, at present, the geoid was not uniquely defined. He suggested that a contribution could be sought from the IUGG.

Dr Matsakis commented that the wording was "slightly vague" and that the CCTF WG TAI should be consulted on the steering process.

Dr Tavella offered that she, as chair of the CCTF WG on TAI, would invite input from the "larger" time community.

Dr Arias suggested that the proposed steering procedure be circulated within the WGs of the CCTF, that opinion and agreement be sought and that the BIPM revise its process on the basis of this agreement. It would be advantageous to be able to make the agreed changes before the next meeting of the CCTF.

Professor Wallard enquired about the formality of the process of agreement. The President replied that the CCTF would choose whether to adopt the recommendation later in the meeting (at item 12 in the agenda). The suggestion that the BIPM seek input from the WG on TAI in deciding the steering process could be included in a revised draft recommendation.

There followed a discussion on the relative importance of stability and accuracy for TAI. Dr Madej and Dr Parker sought to establish how the competing demand for stability and accuracy might be managed. Dr Petit showed the historical record of the offset between TT(BIPM) and TAI. Dr Parker noted that the increasing offset of the step interval from the SI second was in part due to the frequency drift of HP5071A clocks contributing to the EAL. It was evident that the current rules, being used for steering TAI, could largely halt the frequency drift of TAI from TT but could not bring the rate back to that of TT.

The President concluded the discussion under item 4 of the agenda and noted that there would be an opportunity to reach agreement on steering TAI at item 12 of the agenda.

5 REDEFINITION OF UTC: PRESENT SITUATION

The President began the discussion by stating that it was not within the remit of the CCTF to agree a redefinition of UTC, as UTC is defined by the ITU (ITU Recommendation TF-460). However, the agenda item was included as the CCTF is an interested party to these matters.

Dr Beard presented a report from the Special Rapporteur Group (SRG) on UTC of the ITU-R Working Party 7A. The issue arose from the problem caused to some timescale users, such as communications systems, by the discontinuity resulting from leap seconds. The working group has been asked to study the problem and suggest solutions. Dr Beard recalled that the definition of UTC was ITU-R TF460-6 and was one of the more fundamental recommendations of the ITU. He then listed the members of the study group. These were: Jacques Azoubib (BIPM), Thomas Bartholomew (USA), Francoise Baumont (France), Ronald Beard (USA, Chairman), Michel Brunet (France), Yury Domnin (Russian Fed.), Donald Hanson (USA) and William Klepczynski (USA, IAU). Other organizations were represented by: Felicitas Arias (BIPM), Dennis McCarthy (IAU), Daniel Gambis (IERS) and Sigfrido Leschiutta (CCTF).

The SRG has defined the questions to be answered: What are the requirements of the time scale in terms of accuracy, stability, relation to the SI Second, uniformity, accessibility, reliability, and availability for civil and national timekeeping; what tolerance could be accommodated in [*UT1 - UTC*]; does the current leap second procedure satisfy the needs of the users or should an alternative be developed? In addition, other issue to be considered were: satellite systems utilizing independent system time; the use of TAI; and multiple systems with different timebases. The SRG planned to investigate possible changes in coordination with ITU-R Sector Members and CCTF and report results for consideration by ITU-R.

Dr Beard said that a special colloquium had been held at IEN in May 2003, where the SRG has reported its findings. He listed the subject matter of the contributions at that meeting and the issues addressed. These included the question: "Should UTC be decoupled from solar time"? It was noted that the IERS accepted the responsibility of continuing UT1 regardless of changes to UTC and also that astronomers may not have a need for a real time representation of UT1. The IEN meeting agreed that there were long-term deficiencies in UTC due, in part, to the increasing number of leap seconds.

The conclusion of the SRG was that the creation of a new time scale, to be known as "International Time", was not recommended, as a new name and scale would create confusion and complications. The necessity of broadcasting DUT1 was largely unsupported as most users were using UTC directly as an approximation to UT1. The broadcast of DUT1 should be discontinued; the IERS was assuming responsibility for maintaining UT1 and its dissemination. Redefinition of a new "UTC" was not necessary; rather there should be an adjustment to the current definition to continue the continuous broadcast of the time scale on the transition date. The approach would capitalize on what was current: organizational and systems support structure, and timing centres coordinating their real-time realizations. A long-term continuous timescale would be achieved. Gradual divergence from solar time might be an issue in low precision "civil" timekeeping; the increasing error has been estimated as a few seconds over three years growing to one hour not before year 2600.

The SRG was now working on a transition plan to be reported to the ITU-R in October 2004. Dr Beard said that 2010 was a possible date for the transition.

The President thanked Dr Beard for his contribution.

Dr Boulanger observed that some groups, such as astronomers, would have to create a new timescale. It was not clear to him why those for whom leap seconds were a problem could not use TAI.

Dr Bauch asked for clarification on what was in the transition plan. Dr Beard explained that it meant that leap seconds would be discontinued and that UT1 would be disseminated for those who required correspondence with solar time. Dr McCarthy added that the IERS provided UT1 for those who needed a timescale with correspondence to solar time.

Dr Boulanger repeated his question regarding the alternative of some groups using TAI for a timescale devoid of leap seconds. Dr Beard explained that converting to the use of TAI was a more expensive step for these users.

The President recalled that the current recipe for UTC has been in place for 30 years (having been devised by Dr Steele and himself). At that time, ninety percent of the users needed UTC for navigation. His personal opinion was that the current UTC formula should be changed.

Dr Boulanger expressed the opinion that it was wrong to change the definition of the (UTC) timescale without changing its name as it could lead to a diminution of trust. Dr McCarthy pointed out that there was a precedent for this. The frequency steps which were once part of UTC has been dispensed with. Dr Arias said that the word “universal” would no longer be appropriate for UTC. Dr McCarthy recalled that the word “coordinated” was chosen to reflect the coordinated change in the different timescales, then in use in the UK and the USA, to the (new) UTC. Dr Arias clarified her earlier point; she believed that the word “universal” was appropriate only for a timescale that was “linked” to the rotation of the Earth.

The President, reiterating that it was not for the CCTF to make decisions on this matter, offered that the name of a unit was not always ideal; an example was the kilogram – it being a multiple of another unit. He could see the value in keeping the name the same because of its familiarity. He continued by thanking Dr Beard for his efforts in seeking the input from so many organizations.

Dr Bauch sought further clarification on the timing of the abandonment of leap seconds; would it be 2010 or 2022? Dr Beard explained that an earlier transition than 2022 was “preferred” and that 2010 was a suggestion.

The President then introduced the letter (CCTF/04-20) from Dr Jorg Hahn of the Galileo Project Office at ESA, addressed to Prof. Leschiutta and Dr Arias with regard to this meeting. The letter informed the meeting that the Galileo Project Office was aware of the discussions on the future of leap seconds. It added that the (GNSS system) Galileo intends to follow international standards and recommendations and that the Project Office would prefer that any decision to discontinue leap seconds (together with its implementation date) be made well before the Galileo system starts to operate. (The start of full operation is planned for 2008). The President noted the assurance that the Galileo system would follow international time. The intention stated in CCTF/04-20 is to steer Galileo's System Time (GST) towards TAI and to disseminate all information with respect to UTC to the users. He added that it was not for CCTF to act on this letter; rather it was for the ITU to do so.

6 TIME AND FREQUENCY TRANSFER METHODS

The President invited summaries and additions to the reports from laboratories, on time and frequency transfer. Summaries of the following reports were presented by the speakers indicated:

- CCTF/04-01 (USNO, Dr Matsakis):

In a study of the error budget of TWSTFT calibration, USNO has observed an RMS deviation of 0.5 ns over a six-month period in links with multiple customers. A component is added to the uncertainty to account for changes that may occur between calibrations.

- CCTF/04-02 (METAS, Dr Dudle):

A priority has been the TAI P3-project conducted by the BIPM, aiming at using the data of geodetic-type receivers for common view time links. An IGS station has been constructed. Work is advancing on a TWSTFT station.

- CCTF/04-04 (KRISS, Dr Lee):

A system for short baseline precise time comparison using carrier phase is under development.

- CCTF/04-03 (NMIJ/AIST, Dr Ikegami):

There has been participation in the TWSTFT experiment, to link the Asia-Pacific region.

A geodetic-type GPS receiver, Ashtech Z12-T (Metronome) has been introduced. There has been participation in the international campaign initiated by the BIPM to calibrate geodetic-type GPS receivers. There was involvement in the calibration trip of the BIPM receiver in Asia, starting on November 2001. Regular reports of Z12-T data to the BIPM had begun.

- CCTF/04-05 (NIM, Dr Gao):

Two commercial single channel GPS common view receivers (TTR-6, Datum9390) and two multi-channel GPS common view receivers were used to link to UTC.

The fractional frequency for [*UTC* – *UTC*(NIM)] over one and a half years was shown to be within 5×10^{-14}.

A GPS common view receiver was developed in NIM in order to strengthen the link to TAI and establish a remote time and frequency calibration service. The receiver's time interval card satisfies the CCTF recommendation for the hardware of GPS common view receivers.

- CCTF/04-06 (CSIRO-NML, Dr Fisk):

The NML has developed a portable version of its dual frequency GPS common view time transfer system. The system has been calibrated at SYRTE and will begin a round-robin of APMP laboratories in April. The carrier-phase RINEX observation files from the system can be post-processed to calculate the coordinates of APMP laboratory antennas with centimetre-level accuracy.

NML's C-Band TWSTFT link with the NIST's Fort Collins facility has been extended to include the TL in September 2002, and a three-way comparison had been conducted for several months. The NML also maintains a Ku-Band TWSTFT link with the NICT (formerly CRL) in Tokyo, and in early 2003 the link was upgraded with the installation of a new modem developed by the NICT.

- CCTF/04-08 (NMi VSL, Mr de Jong):

TWSTFT links were maintained with Europe and with the USA. A link was established twice per week with the TL. The link, at 4.9 degrees elevation demonstrated the same stability as those to the NIST and the USNO.

An automated station delay measurement system with a satellite simulator was under development, enabling improved accuracy in the transmit-receive delay.

An uncertainty evaluation of both GPS CV and TWSTFT was carried out during 2001, between the PTB, the NPL and the NMi VSL in an ESA-Galileo research project. Reports were published and it was shown that TWSTFT has a lower type-A uncertainty.

Data from the NMi VSL is used by the BIPM to publish the values [*UTC - GLONASS time*] in *Circular T*.

A new multi-channel receiver (Topcon) was acquired and will be modified into a timing receiver.

- CCTF/04-09 (PTB, Dr Bauch):

The PTB operates all the standard time transfer techniques: TWSTFT, GPS-P3, GPS-CV, and multi-channel GPS. Maintaining the operation of these redundant systems is resource intensive.

- CCTF/04-10 (NICT, Dr Morikawa):

The NICT's contribution to time transfer by TWSTFT in the Asia-Pacific region is noteworthy. The laboratory has developed a new time transfer modem for TWSTFT. The main feature is the multi-channel operation, capable of simultaneous time transfer among the participating stations. In May 2003, an experimental TWSTFT link with the USA was started, between the NICT and the USNO using the Vandenberg Air Force Base (VDB) station of the USNO. It was planned to use the multi-channel modem for the link between the NICT and VDB.

- CCTF/04-13 (ORB, Dr Defraigne):

The ORB time laboratory is equipped with two Ashtech Z12-3T receivers, one being used for both TAI (within the TAI P3 project) and IGS. There is strong involvement in the EUREF Permanent Network (EPN). Carrier-phase based time transfer was improved, using the Bernese analysis software. A new geodetic receiver (Septentrio PolaRx2) was tested for suitability for time transfer by common view: results demonstrated the suitability of the receiver for very precise time and frequency transfer. Modifications to the CCTF procedure, to adapt it for time transfer between geodetic receivers, were tested.

- CCTF/04-14 (IEN, Dr Godone):

During 2003, IEN regularly sent to the BIPM the GPS-P3 synchronization data supplied by an Ashtech Z12-3T Metronome geodetic GPS receiver (driven by UTC(IEN)). From December 2003, RINEX files, supplied by the same receiver, were regularly sent to the GeoDAF data centre of the Italian Space Agency (ASI – Matera).

Another GPS geodetic receiver, Javad Legacy with timing option, has been operated since July 2003 in the framework of the Galileo System Test Bed V1 (GSTB V1), driven by the H-maser generating the time scale (EGST) for GSTB-V1 experiment. The IEN TWSTFT measurement system is operated since 2001; its operation was been completely automated.

From 2002, the TWSTFT IEN-PTB link was the primary link for TAI calculation. A second TWSTFT station will be ready to operate at IEN during 2004; the TWSTFT signal from TL, at an elevation of eleven degrees, was received in January 2004, demonstrating the possibility of an IEN participation to the Europe-Asia TWSTFT link.

- CCTF/04-15 (ROA, Dr Palacio):

A TWSTFT system has been installed, is now fully automated and is currently running four sessions per day.

The number of tracks per day obtained from the TTR-5 and TTR-6 GPS receivers has been increased to a mean of 84. A GPS link has been established using this method to calibrate a remote caesium clock, giving better results that using only the tracks contained in the traditional BIPM-issued GPS schedule. The CMC table for time and frequency was submitted to EUROMET.

- CCTF/04-21 (NRC, Dr Boulanger):

Data from the single channel GPS receiver is published every day on the NRC website for the previous four days. Some Canadian organizations use this for frequency measurement. It is planned to provide some means of using these measurements, undertaken by the client, as a traceable method of frequency. The intention is to publish, on the website, the Ashtech Z12-T geodetic GPS receiver data as well as the single channel GPS data.

- CCTF/04-22 (NIST, Dr Parker):

The NIST is currently operating one TWSTFT station, necessitating the breaking of the link with USNO, whilst a hardware problem is resolved.

Single channel common view GPS is the preferred back-up as the results from the NIST's multi-channel receiver are no better for periods longer than one day.

Dr Levine added that it is anticipated that GPS carrier phase measurements could prove be the preferred frequency comparison method for caesium fountain primary standards; the method has the potential to reach an uncertainty for frequency transfer of less than 10^{-15} after a few days. At present, a few parts in 10^{-15} can be reached at one week; more work is required on software.

- CCTF/04-23 (BNM-SYRTE, Dr Dimarcq):

BNM-SYRTE implemented the GPS P3 time transfer technique in the Paris Observatory (OP) in 2002. The OP multi-channel receiver was differentially calibrated against the BIPM absolutely calibrated receiver. The link between OP and PTB was characterized over more than one year.

A TWSTFT link was installed in 2001 and the regular schedule is now observed.

In 2003, a direct comparison between TWSTFT and GPS P3 was made on the link OP-PTB.

- CCTF/04-24 (VNIIFTRI, Dr Koshelyaevsky):

The main links between timing laboratories in the Russian Federation and the international timing community are by GNSS. The time transfer can be performed relative to UTC with three nanosecond uncertainty. Dissemination is also undertaken in a few regional networks using television line 6. Again, three nanoseconds per day is achieved. Secondary timing laboratories are linked by GLONASS.

The laboratory now has access to multi-channel GNSS receivers, some dual frequency.

- CCTF/04-25 (NPL, Dr Henderson):

There are now two TWSTFT Earth stations (one fully automated), two geodetic GPS quality time transfer receivers (Ashtech Z12-T and JAVAD Legacy) and several of NPL's own (TimeTrace) GPS common-view receivers, designed in collaboration with Time Frequency Solutions Ltd.

An IGS station has been maintained.

Work is continuing to enhance the TWSTFT stations, and the operation of the geodetic quality GPS receivers.

Time transfer hardware has been evaluated, including a JAVAD geodetic quality receiver, a visiting X-band TWSTFT station, and the Timetrace receiver. Currently two Loran C receivers are being evaluated.

6.1 Report of the CCTF Working Group on TWSTFT

The president invited Dr Klepczynski to report on the work of the CCTF WG on TWSTFT.

Dr Klepczynski began by noting that TWSTFT was independent of GPS and was affected by different systematic effects. Signals are sent through a geosynchronous communications satellite and the precision achieved was between 200 ps and 500 ps. However, because of costs, relatively few laboratories participated. The technique is amenable to automation. TWSTFT is used to link stations in North America, AMC, NIST, and two belonging to the USNO. In Europe, eight stations are linked: BNM-SYRTE, IEN, NPL, OCA, PTB, ROA, SP, and VSL. Five laboratories around the Pacific Rim are linked: AUS, CRL, NMIJ, NTSC, and TL. The regional leaders are Dr Parker, Mr de Jong and Dr Imae, respectively. Meetings of participating stations are held as the opportunity arose to discuss such operational matters, as scheduling, hardware, and software.

At present, observing time on INTELSAT is free but there is still no formal agreement in place. Links are established seven days per week, though not all stations participate in the seven-day schedule. Some stations operate routinely for four sessions each day (at 00 h, 08 h, 14 h and 16 h). Most stations are automated and some laboratories do continuous observation, for special experiments, from time to time.

Dr Klepczynski then moved to the topic of calibration of TWSTFT. In the relative calibration, one station is the reference. Other stations are calibrated relative to it using a transportable Earth station. For absolute calibration, it was necessary to measure delays through components by using signal injection. It would also be necessary to calibrate the satellite transponders (which has to be done before launch). However, calibration of transponders was not necessary if the same transponder was used for transmit and receive.

Dr Klepczynski continued with a list of planned work:

A calibration campaign within Europe will take place, starting summer 2004 using a transportable station.

A USNO-NIST calibration will be performed in November 2004 (using a transportable station).

A USNO-PTB X-band calibration is planned (using the Fly-away Transportable Station).

The Pacific Rim area is developing a transportable station.

Two additional laboratories are joining the group (SP and METAS).

Dr Klepczynski concluded by noting that the BIPM website has TWSTFT reports showing data; and remarking that TWSTFT was in “reasonably good shape”.

The president thanked Dr Klepczynski and congratulated the WG for their efforts to schedule meetings in line with other meetings. He proposed the continuation of the WG on TWSTFT.

6.2 Report on the pilot experiment on the utilisation of GPS P3 code dual frequency measurements and their introduction in the time links for TAI

The President invited Dr Petit to give a brief outline of the GPS P3 Pilot Project.

Dr Petit began by recalling that the work started in the Spring of 2002. The goal was to study time links computed with GPS P3 data obtained from geodetic-type dual-frequency receivers. Starting June 2003, some such time links were introduced into the TAI computation. The findings of the pilot experiment and some conclusions for the future use of these links in TAI are contained in CCTF/04-18.

Twelve laboratories participated and time transfer by GPS CA, TWSTFT and GPS P3 were evaluated using the three-cornered hat technique. The P3 stability was found to be 0.6 ns over one to thirty days. The standard deviation of the difference data between P3 and TWSTFT was found to be around 1 ns, over several months. Dr Petit presented a list of the calibration trips made by the BIPM using the Ashtech Z12-T receiver. The uncertainty in the P3 link was conservatively put at 5 ns (the accuracy of differential calibration was 3 ns). Dr Petit concluded that the study was continuing with the current involvement of three laboratories.

The President thanked Dr Petit and noted that there are now two microwave time transfer techniques that agree at the nanosecond level or better.

Dr Bauch noted that the Ashtech Z12-T receiver was no longer manufactured. He wondered if calibrations of other makes of P3-type receivers are planned. Dr Petit said that the intention, for the time being, was to continue the work with the Ashtech, but other receivers are available. Javad, Septentrio and Novatel receivers may be of use in the future.

6.3 BIPM GPS calibration trips

The President invited Dr Lewandowski to report on GPS calibration trips. Dr Lewandowski presented the report CCTF/04-26. For almost 20 years, the BIPM has conducted differential calibrations of GPS equipment located in time laboratories contributing to TAI. Usually the uncertainty of such differential calibrations estimated for the period of comparison, is 3 ns (1 σ). Since the last CCTF in 2001, the BIPM has conducted seven calibrations trips involving twenty of the 54 laboratories contributing to TAI. There was now considerable historical data on the GPS links' stability. Dr Lewandowski highlighted the stability of the OP-NIST link. Over the years, the OP GPS time receiver has been compared many times with the NIST absolutely-calibrated reference GPS time receiver. The difference between these two has never exceeded a few nanoseconds. It was planned to continue the trips with the temperature-stabilized receiver, beginning with a new trip to the Americas involving ten laboratories. Dr Lewandowski ended by noting that the BIPM is willing to help in the organization of calibration round-robins within RMOs.

The President asked whether the same receiver was used throughout the ten year span. Dr Lewandowski replied that, as round trips achieved a closure error of 3 ns or less, it did not matter whether the same receiver was used. It was possible to conclude that large changes between trips to the same laboratory are due to changes at that laboratory. Dr Lewandowski listed a number of causes of such changes.

Dr Palacio, noting that the uncertainty arising from a calibration trip is between 1 ns and 4 ns, enquired whether the BIPM has identified the source of the uncertainty. Dr Lewandowski replied that the uncertainty, indicated by the closure error, was usually about 3 ns.

The President thanked Dr Lewandowski for his report.

6.4 Report of the IGS Working Group on Clock Products

The President invited Dr Senior to report on the work of the WG. Dr Senior began by noting that the IGS/BIPM pilot project concluded in December 2002 and had moved to the operational phase. The project's goal was to develop strategies to exploit geodetic techniques for improved global time and frequency comparisons. The work began in March 1998 with the participation of more than 35 groups. The IGS contributions were a global dual-frequency tracking network, standards for operating geodetic stations, an efficient data delivery system, and state-of-the-art analysis. The BIPM contributions were high-accuracy metrological standards/measurements, timing calibration methods, timescale algorithms and independent comparisons, and the formation and dissemination of UTC.

Dr Senior continued by highlighting the advantage offered by the geodetic method: dual-frequency provides pseudo-range and carrier phase data; it is possible to model all effects explicitly and accurately; there is efficient processing of large global networks; sub centimetre positioning at one day intervals implies sub-nanosecond time transfer and frequency transfer at the 10^{-15} level. The IGS Combined Clock Products were listed, including the two IGS timescales, "final" and "rapid". The international distribution of clocks used in the IGS Combined Clock Products was displayed. Information on the IGS Kalman Filter Ensemble was presented. Dr Senior explained that one task of the NRL is to monitor and analyse GPS clocks in space vehicles. He presented stability data for the classes of clocks. Day boundary time steps in clock data were discussed. The frequency and time stability achieved by a geodetic station is very dependent on such factors as the thermal control and the view of the sky, within a particular installation. A variation of a factor of ten is possible; final error ranges from 115 ps to 1150 ps.

Dr Senior exampled the USNO and AMC2 as well-controlled stations. These stations show a diurnal temperature sensitivity of 2 ps/C. Detailed accuracy and stability conclusions from the study were presented, including the dominant noise types and noise floors (details can be found on NRL web pages).

Dr Senior then spoke about the transition to the operational phase. Those IGS stations which are co-located with timing laboratories were listed. It was anticipated that there will be further improvements in IGS clock products. Densification of analysis solutions to include all external clocks will continue (stations with H-masers and those of timing laboratories are the most critical). Timescale improvements will include better stability beyond one day, and closer linkage to UTC. Station operators could improve local clock performance in many cases; they can use the observed clocks as a diagnostic tool, thermally isolate receivers, and use phase-stabilized cables. The present status of the IGS clock products and IGS timescales was then summarized. Details of IGS timescales were given together with historical stability data. Station calibration bias was introduced. A new steering reference has been developed.

Dr Senior concluded by noting that an *in situ* method to transfer a laboratory calibration to a co-located IGS geodetic receiver system has been demonstrated. No cable, connector, or configuration changes are required. The precision (RMS) is about 1 ns. The IGS rapid and final results are consistent to 1 ns or better. The accuracy, compared to absolute instrumental calibration, was exampled for the laboratories AMC2 and USN1. It is possible to continuously monitor intra-laboratory calibration stability and this is being used to improve the steering of the IGS timescales to UTC.

The President thanked Dr Senior for his report.

6.5 Report of the Working Group on GNSS Time Transfer Standards

At the President's invitation, Dr Levine presented the report of the Working Group on GNSS Time Transfer Standards. The group has been meeting on the occasion of the PTTI conferences but suggestions are welcome for alternative timing. The report had two main themes. The first was to suggest a change to the data format of the GNSS systems to support additional constellations, such as Galileo. The suggestion was discussed at the last PTTI meeting and a proposal was sent to timing laboratories. Dr Levine continued by presenting some ideas about the problem of multipath in GNSS time transfer. The effect can contribute a peak-to-peak bias of about 10 ns. Calibrations of customers' receivers are achieved by short baseline common view. The short baseline exposes the two receivers to similar multipath bias, not averaged out by the thirteen-minute track (as the satellite position repeats every 24 hours plus four minutes, the four-minute daily advance on the track converts the multipath into a bias). The technique of repeating the track for the same position in the sky, creates a type-B uncertainty. The WG believes that the effect could be the underlying reason behind the change in time offset of laboratories between repeated BIPM calibration trips. Dr Levine suggested that collecting data over sub-tracks within a track could give more information about multipath bias. Calibrations can also be improved by making measurements with several different short baseline (a few metres). It is adequate to complete all the measurements in one day.

The president asked whether there was also an advantage in using tracks longer than 13 minutes. Dr Levine replied that longer tracks are no longer an advantage, now that selective availability has been turned off. The route to identifying systematic shifts was via less averaging. Dr Matsakis suggested that carrier phase data might be used to estimate multipath in dual frequency receivers. Dr Levine agreed that the approach is worthy of study. Dr Klepinsky enquired whether Dr Levine knew of any studies on the relation between carrier modulation and the multipath effect.

Dr Fisk asked what stage had the suggested revised formatting reached. Dr Levine replied that the “formal suggestion” stage had been reached. Regarding the multipath issue, these are only ideas. Dr Fisk commented that there is the possibility of changing the software used in the receivers in the Asia-Pacific region. Dr Levine added that he has seen “illuminating” data from a network of receivers operating with “15 second” clocks.

The President thanked Dr Levine for the presentation.

6.6 High precision time transfer

Dr Dimarcq was invited to make a presentation on high precision time transfer. He began by recalling the ACES mission. A microwave link is planned. The completion of the payload’s engineering model is scheduled for the end of 2004 with the flight scheduled for 2007. There are to be three categories of users: developers; laboratories with clocks; and other laboratories. Regarding the issue of the cost of the specialized modem for ACES and the limited mission length, there is now a possibility of a microsatellite having both compatible microwave, and T2L2 (optical link) capability.

The President noted that a combination of the two techniques of PRN coded and carrier phase were predicted (in the presentation) to realize a precision of 10 ps. Concerning the planned chip rate, Dr Dimarcq said that 100 Mchip was planned for Ku-band and 10 Mchip for S-band.

Dr Bauch noted that TWSTFT is immune to the rapid movement of the satellite due to it being geostationary. He wondered how the precision could be achieved by the ACES system. Dr Dimarcq responded that the ACES link is not a true two-way system. The signals passing each way will have to be re-correlated with a precision of about 10^{-5}.

Dr Bauch asked what frequency standard was planned for the microsatellite, Dr Dimarcq replied that the payload is not yet decided; a good quartz crystal or a rubidium clock are possibilities. Dr Dimarcq added that it should be noted that common view possibilities for ACES are limited by the comparatively low altitude of the vehicle.

The President thanked Dr Dimarcq for his contribution.

7 SPACE-TIME REFERENCES AND GENERAL RELATIVITY: REPORT ON THE IERS CONVENTIONS PRODUCT CENTRE

The President invited Dr Petit to present the report (CCTF/04-16) of the IERS Conventions Product Centre. Dr Petit began by noting that a collaboration between the BIPM and the USNO has been providing these products since 2001. The *IERS Conventions (2003)* is a 128-page book defining the standard reference systems realized by the IERS along with the models and procedures used for this purpose. The tasks are to edit the IERS conventions and to maintain the software so as to be compatible with these conventions. The most significant changes from previous *IERS Conventions (1996)* are due to the incorporation of the recommendations of the 24th IAU General Assembly held in 2000.

The BIPM arranged for a visiting scientist to conduct studies on the consistency of the Conventions and IERS products. Jim Ray, from the U.S. National Geodetic Survey, has been in this one-year position since 1 September 2003.

The IERS conventions are available on the website of the USNO. The BIPM website is being developed to include the IERS conventions together with a user forum.

The President thanked Dr Petit.

Dr Boucher expressed his satisfaction in noting the stronger interaction between the BIPM and the IUGG and IAU via the IERS. He said that the work is a valuable reference, used beyond the scientific community, and is strengthened by the contribution of the BIPM. The President thanked Dr Boucher and the IUGG for supporting the work of the BIPM.

8 CLOCKS IN SPACE

The President began the next agenda item by noting the contribution from Dr Dimarcq during the discussion on high precision time transfer (at item 6 of the agenda). He then invited Dr Thomann to present a summary of the work on space clocks, of the ON (CCTF/04-02).

Dr Thomann explained that the ON is providing the H-maser for the ACES experiment. The maser is the 3rd generation of masers developed at the ON; it has a very compact, sapphire-loaded, microwave cavity, enabling the same performance level as state-of the-art, ground masers to be achieved at a weight of only 35 kg. The ON is also involved in clock development for the Galileo system. The satellites of the first generation would each be equipped with two lamp-pumped Rb-cell clocks and two Space Passive Hydrogen Masers (SPHM). The Rb clock was initially developed at the ON and is now in industrial development at TEMEX Neuchâtel Time (TNT). Work on the SPHM dated from the year 2000. An engineering model of the SPHM (physics package developed by ON and electronics package by Galileo Avionica in Italy) was delivered to the European Space Agency in 2003. The clock achieved an instability of 8×10^{-13} $\tau^{-1/2}$ and 10^{-14} in one day. A qualification model is planned for testing in the second GSTB satellite. ON is completing the first phase of the development of a laser-pumped Rb-cell clock for ESA, for the second generation of Galileo satellites. This demonstration has established the constraints on the pumping laser frequency stability, demonstrated efficient techniques of light-shift reduction (a factor of 40), determined optimum buffer gas composition for laser-pumped operation, and developed a compact, frequency stabilized, extended-cavity diode laser system for space applications. The ON has also recently resumed the development of a space-qualified, optically pumped thermal Cs beam clock with short-term instability 3×10^{-12} between 1 s and one day. The goal for the mass of the entire clock is 7 kg, intermediate between the 3 kg Rb-cell clock and the 17 kg SPHM.

The President thanked Dr Thomann for his report and invited Dr Morikawa to report on developments at CRL.

Dr Morikawa began by introducing the new name for his institution, the National Institute for Information and Communication Technologies (NICT). He then presented a progress report on the development of a space-borne H-maser (CCTF/04-12). The instrument is being developed for use on board the Quazi-Zenith Satellite System (QZSS) (CCTF/04-11), which is to be compatible with GPS. It is planned to launch the maser, in 2008, on board one of the three QZSS vehicles. Development of the maser dates back to 1997. The device benefited from modelling of the electromagnetic field in the sapphire-loaded cavity and exhibited fractional frequency sensitivities of 2×10^{-14} per Gauss at 1 mG and 3×10^{-14} per Celsius. In 2003, at the inception of the QZSS project, some engineering problems were identified. The maser required: longer lifetime and higher reliability; better performance in space; further reduction in weight and size; and higher proof against mechanical shock at launch. A breadboard model was developed in order to overcome these problems. The model benefited from a novel vacuum pump, improved thermal insulation and magnetic shielding. Work on the engineering model is planned for 2004.

The President thanked Dr Morikawa and remarked on the important scientific contribution made by space-borne H-masers. He gave as examples the tests of gravitation and relativity, led by Dr Vessot, on the SAO/NASA 1976 Gravity Probe-A experiment.

The President invited Dr Morikawa to summarize the Quazi-Zenith Satellite System project (CCTF/04-11).

Dr Morikawa began by summarizing the value and use of GPS receivers in Japan; there are now more than 1200 high-performance dual frequency receivers in use. Opportunities to expand the use further would be increased if the problem of screening of the GPS satellites by high buildings ("urban canyons") could be reduced. Dr Morikawa continued by outlining the organizational backing of QZSS. The private sector has established a joint company, the Advanced Satellite Business Corporation, which would develop and operate the communications and broadcasting system. Four government Ministries and their related research institutions are participating in the project. Dr Morikawa explained that the system comprised three vehicles in different orbital planes inclined at about 45 degrees to the equatorial plane. The orbits would ensure that one satellite is located above Japan at more than seventy degrees elevation, at all times, the elevation ensuring that satellites are visible in urban canyons. The extent of compatibility with GPS was outlined. The launch of the first vehicle is planned for 2008 and budget approval for the second development phase is imminent.

The President invited comment. Dr O'Brian offered an update on the PARCS project. (PARCS is a collaboration between the NIST, the JPL and the University of Colorado, to put a micro-gravity caesium clock on the International Space Station). He said that the future of the project is very unclear. There have been major changes of strategy in NASA; there is now greater emphasis on manned planetary exploration with a consequent de-emphasis on orbital flight.

The President thanked Dr O'Brian for his report and recalled the report of Dr Dimarcq on the (broadly equivalent) ESA-led project, ACES.

9 FUTURE SATELLITE NAVIGATION SYSTEMS

The President introduced the next item on the agenda. He recalled the letter (CCTF/04-20) from Dr Hahn, of the Galileo Project Office, ESA (discussed at item 5 of the agenda).

The President invited Dr Boucher to comment on this agenda item. Dr Boucher said his main concern is the interface between the time community and the astronomical community. The benefit from the science being undertaken by these communities is being felt in a much wider field. A current issue concerns the contribution toward the new GNSS systems (GPS, GLONASS and Galileo) which could come from the IUGG. The working group (BIPM/IAU) on

Relativity for Celestial Mechanics, Astrometry and Metrology (RCMAM) addressed this issue, but the contribution of the CCTF WG on GNSS Time Transfer Standards was also noted. Interested timing institutes are welcome to contribute to the work of these groups. There is an interest in having a forum for discussing the various navigation systems that are open to a wider sphere of contributors and a more general range of issues. It is proposed that such a forum could be linked to the United Nation Scientific and Technical Sub-committee of the Committee on the Peaceful Use of Outer Space.

Dr Boucher then raised the subject of the imminent Second Call within Framework Six of the EC's research funding, for work on the specification of the Galileo timing system.

He concluded by noting the importance of the contribution of the time community to Galileo. The IGS and the CCTF is the appropriate interface between the science community and the future users of Galileo.

The President thanked Dr Boucher. He remarked that Dr Boucher's comments about the usefulness of the work of the timing laboratories to those outside the timing community (e.g. the geodesy community) are valuable.

10 KEY COMPARISONS AND THE MUTUAL RECOGNITION ARRANGEMENT IN THE TIME AND FREQUENCY DOMAIN

10.1 Report of the CCTF Working Group on the MRA

The President invited Mr de Jong to present the work of the CCTF Working Group on the MRA. Mr de Jong said that he would present a report (CCTF/04-07) and a view of future work. He reviewed the history of the MRA and named the WG members. The WG reported to the 15th CCTF where key comparisons (KC) were proposed as being provided by the contribution to *Circular T*. The task of the WG was to coordinate the RMOs, to coordinate the list of calibration and measurement capabilities (CMCs), and to achieve the practical execution of comparisons. Mr de Jong detailed the process by which the WG arrived at guidelines (detailed in (CCTF/04-07) for the construction of CMCs. Under the title "Status and possible implementations of procedures", Mr de Jong listed eight items:

a) identification of the KCs;

b) execution of KCs;

c) review the results of CIPM KCs;

d) approve the final report of CIPM KCs for publication by the BIPM;

e) examine and confirm the results of RMO key and supplementary comparisons;

f) examine and confirm the results of bilateral key comparisons;

g) coordinate the CIPM and the RMO KCs through consultations with the RMOs; and

h) discuss disputes from MRA and KCs.

The first item was dealt with as a recommendation (CCTF-K2001) at the 15th meeting of CCTF. The second item was achieved by the publication of *Circular T*. Regarding the third item, this is done well by the Time section but although the WG noted that the uncertainties for time links are now in *Circular T*, the uncertainties in [*UTC* - *UTC(k)*] are not. Items *d*), *e*), and *f*) are not done. Item *g*) is done, in part, and the last item, *h*) is not at issue as there have been no disputes. However, KC results were not in the BIPM key comparison database (KCDB). It is for the CCTF to identify and list the KCs, to organize the execution of the KCs and to review the results of the KCs. The action now required for CCTF was to adopt the guidelines as recommendations. Discussions at CCTF, to define a procedure to put the KCs in the KCDB, could result in a further recommendation, and the WGMRA and the BIPM should also be the subject of one or more recommendations. Mr de Jong offered an action list: for *c*) and *d*) a workable solution could be found at the CCTF meeting; in the next 3 years *e*), *f*), *g*), *h*) should be accommodated. The WGMRA might again accept this task between two CCTF meetings.

The President thanked Mr de Jong for a "very comprehensive" report. He noted that a long list of actions had been proposed and invited discussion.

Professor Wallard asked Mr de Jong to comment on the NMIs' approaches to applying quality systems, noting that Clause 7 stated that RMOs are responsible, not the CCs. He added that part of the work could fall under IEC 17025 and part under ISO 9000.

Mr de Jong stated that in EUROMET, an NMI must have external review of its Quality System. The CMC list had been reviewed by external (to that NMI) experts. Some NMIs had done self declaration but it was desirable to have a degree of peer review.

Dr Dudle noted that the only KC in place referred to the annual report of 2001. He asked if *Circular T* was to be taken to be a KC. Mr de Jong replied that the WG would like to see a monthly update of a file of those KCs that are being done continuously. The BIPM Time section would check this. Criticisms of the KCs should be taken to the BIPM in the first instance. The WG might try to resolve disputes, but a small deviation from the MRA would be inherent. It would be necessary to obtain the approval from the JCRB.

Professor Wallard, in his position as the chair of the JCRB, undertook to have the issue considered at the upcoming meeting.

Dr Bauch noted that the KC in 2001 was [*UTC* - *UTC(k)*]. He would like this to be kept. Mr de Jong replied that the WG concurred but that a laboratory's participation in the MRA would lead to comparison data being placed in the KCDB.

Dr Tavella introduced the requirement of the quality-conscious industrial user. She offered her help in structuring the data record.

The President, noting that the WG had produced a complex document, invited Mr de Jong to indicate specifically, without going into detail, what input the WG required from the CCTF at this stage.

Mr de Jong indicated that the CCTF should accept the guidelines 1, 2 and 3 (detailed in CCTF/04-07).

The President, noting the suggestion, and also that a procedure was required for incorporating the KC into the KCDB, invited Dr Thomas to make a presentation on the KCDB.

Dr Thomas began by saying that the KCDB is needed to support the CIPM MRA. The overall coordination for the MRA is done by the BIPM with the authority granted by the CIPM. KCs are selected by CCs to test the principle techniques and methods; this is the basis for mutual recognition of national standards. The CCs are required to select what should be done as KCs.

The KCDB has four appendices. Results of KCs are analysed and approved by the CCs. The degree of equivalence to the reference value is represented by two values, an offset and an uncertainty. The measure [*UTC* - *UTC(k)*] is deficient in that the uncertainty is absent. 547 KCs are recorded, of which CCTF has only one. KCs are normally conducted by RMOs to serve the needs of industry. They are normally current for a fixed period. The CCTF KC is unique in being "ongoing". The JCRB and the RMO should approve CMCs. The purpose of the CMCs is to reduce technical barriers to trade. They are there to serve industry. Dr Thomas demonstrated the use of the database on the BIPM website (www.bipm.org/kcdb). It is possible to distinguish the best capability (the uncertainty in the KC) and the usual service available. Dr Thomas concluded by noting that it was not apparent, when the CCTF KC for 2001 was entered, that a continuous update was intended.

The President invited questions of Dr Thomas.

There followed an extensive discussion. The issues raised included: what activities constitute a KC; how the timing of the calibrations of time transfer links can impact the frequency of declared KCs; how the data from KCs might be represented on the KCDB; whether the [*UTC* - *UTC(k)*] offset or its evolution is the useful quantity; the resource required by the KCDB office to maintain some of the suggestions in the database; whether the KC is a continuous process and whether this is the best approach; the complications inherent in having a continuous update of the KC (the offset and the uncertainty both varying with time); the problem of UTC(*k*) laboratories that are not participants of the MRA; how to arrive at uncertainties for CMCs in the absence of uncertainties for [*UTC* - *UTC(k)*]; and the potential dependence on the period of measurement of the CMC's uncertainty? There was concurrent discussion on the best approach to be taken to resolve these issues.

The President chose to adjourn the discussion at this point. Guideline 1 had been accepted. However, it had been agreed that the other recommendations of the CCTF WG on the MRA should be revised and presented later in the meeting.

Professor Wallard offered some introductory comment. The MRA WG had worked on the guidelines but had not examined their terms of reference. There was still a need to look at the process by which the CCTF could approve the KCs. The CCTF should determine the terms of reference by correspondence between the President and the MRA WG. It was not clear that the present terms of reference are ideal; they should be compared with those used by other CCs.

Mr de Jong continued the discussion. He proposed that the guidelines G1, G2, and G3 (CCTF/04-07) remain unchanged. The CMCs should refer to the hypothetical case of an ideal device under test and state that the uncertainty depends on the performance of the device under test (DUT). It should not be necessary to change the uncertainties in the CMCs, but it should be made clear that customers should expect larger uncertainties.

Dr Bauch asked whether the uncertainty would refer clearly to the measurement. Mr de Jong confirmed this. Professor Wallard noted that Guideline 2 clarified the relation between the uncertainty stated in the database and that to be expected by the customer. Guideline 2 was accepted.

Discussion then moved to Guideline 3, which, together with Annex 6, clarifies how to extrapolate the uncertainty from the KC results for shorter averaging times than the five days interval of the BIPM *Circular T*.

Dr Tavella suggested that the example given in Annex 6 was misleading due to the assumption made about noise types. The example should be removed or clarified. Dr Thomann, supported by Dr Boulanger, agreed, noting that the example was only valid for standards exhibiting white frequency noise.

The President noted the agreement to drop the example from Annex 6.

Mr de Jong raised the issue of the BIPM not being able to give a date for the provision of uncertainties for [*UTC* - *UTC(k)*], in *Circular T* . He suggested that the uncertainties given for CMCs be based on the uncertainties shown in *Circular T* for the time transfer links. However, he added that these uncertainties might lead to over optimistic values in the case for a laboratory where the clock noise, rather than the link, dominates.

Dr Petit noted that this approach is not logically satisfactory as there are "*n*" laboratories and "*n*-1" links. Dr Bauch added that some laboratories have more than one link; PTB has three links and it would not be clear which to use. Dr Arias pointed out that only one link is used to calculate *Circular T* and that link's uncertainty is reported.

Dr Matsakis suggested that the discussion be postponed at this stage. More work was required and he offered that USNO could contribute.

There ensued further discussion on the purpose and utility of the uncertainty in the CMC.

Dr Wolf, noting that the uncertainty in [*UTC* - *UTC(k)*] depended on all the links between clocks, said that there is not yet practical solution as to how the link uncertainties should be combined to produce the uncertainty in [*UTC* - *UTC(k)*].

Dr Arias said that she was aware of the suggestion that an interim solution for the purpose of CMCs and especially for the KCDB was to multiply the link uncertainty by a factor of two.

The President, noting that the text suggested by the MRA WG demonstrated real progress, invited the WG to continue their work.

Mr de Jong said that the terms of reference would need to be discussed before the WG could make further progress.

Professor Wallard offered some information about how the MRA issue is dealt with by other CCs. Most CCs have a WG on KCs. There has been a significant effort, devoted to discussion of the role and responsibilities of these WGs, by the JCRB. CCTF should, if possible, be consistent with the guidelines offered by the JCRB and by the CIPM. It was unfortunate that the WG had not adopted these terms of reference for their work, but they could now be agreed by correspondence.

Mr de Jong said he was unaware of these unified terms of reference, and he would welcome the clarity on offer. However, he would not be content with a prolonged delay in adopting the revised terms of reference.

The President summarized the agreement arising from the discussion: the expanded terms of reference would be agreed, by correspondence, after the meeting. In the meantime, the existing ones would remain; the chairman and membership should remain unchanged; the nine points in the report should be reviewed for alignment with the MRA WGs of the other CCs.

11 THE BIPM WORK PROGRAMME

The President invited Dr Arias to present the proposed work programme for the BIPM Time section.

Work on the task of attributing uncertainties to [*UTC* - *UTC(k)*] would begin this year. There would be a study to ascertain the optimum utilisation of links in the case where an NMI operated more than one. The possibility of using these multiple links, with weightings, would be studied. In addition, there would be a study of how to enhance the steering of TAI, to improve the accuracy of the step interval.

The BIPM provides access to other timescales: GPS and GLONASS. It will provide in the future access to the Galileo time scale.

The President thanked Dr Arias for her proposed work programme.

Following an opportunity for discussion, Professor Wallard thanked the members for their input in prioritizing the proposed work.

12 RECOMMENDATIONS

The President introduced the next agenda item and began with (CCTF/04-28). He continued by reviewing the background to the recommendation of the CCL/CCTF Joint WG on Secondary Representations of the Second. The JWG had reviewed the present state of frequency standards both microwave and optical. The CCTF supported the work of the JWG.

Dr Riehle thanked the President for his accurate summary.

Dr Koshelyaevsky offered a correction to the text regarding the standard uncertainty attributed to the ^{87}Rb transition.

The recommendation was approved.

Dr Petit presented the revised recommendation concerning the reporting and use of primary frequency standards. He pointed out that the recommendation was now that each evaluation should be accompanied by a report, and that all reports should contain elements specific to the particular evaluation.

Dr Parker said that the last part of the recommendation was too vague. He suggested that the Working Group on the Expression of Uncertainties in Primary Frequency Standards (CCTF/99-09 and Recommendation S 3 (1999)), or a more general working group on primary standards, could evaluate the performance of standards and give guidance to the BIPM.

Dr Petit thought that it might be impractical to seek month-by-month guidance from the WG.

Dr Wolf suggested a form of words such that the CCTF Working Group on the Expression of Uncertainties in Primary Frequency Standards might be mandated by the recommendation to advise the BIPM on steering the of TAI.

There was a debate about whether even a sub-set of the WG could be expected to advise in a sufficiently timely manner. Dr Parker maintained that the WG could contribute to the longer-term issues.

There was some discussion on the value of the word “desirable” within the considerations.

Dr Bauch undertook to re-address the CCTF Working Group on the Expression of Uncertainties in Primary Frequency Standards.

The President, having invited some improved punctuation, for the purpose of clarity, noted that the recommendation was accepted.

Dr Petit then presented the revised recommendation (draft 02-04-2004) concerning the steering of International Atomic Time, the text having been modified following Dr Fukushima’s comment regarding the geoid.

Dr Parker believed that the second part of the recommendation, to achieve the steering goal before the next CCTF meeting, had the potential to introduce a constraint conflicting with the first and third parts.

Dr Henderson noted that the third part, requiring that "optimal stability" be ensured, could conflict with the first part, requiring that the TAI scale unit conform to its definition within 3 σ. Dr Levine said that optimal stability is achieved if a frequency steer is smaller than can be distinguished from noise processes. Dr Petit added that the process is more complicated; there is leeway due to the drift on EAL. Dr Tavella suggested that a choice has to be made between stability and accuracy; the word "ensure" should be dropped; the WG should be consulted (cf. "in collaboration with").

It was agreed that the recommendation should be modified so as to minimize the impact on stability, and the recommendation was approved.

13 OTHER BUSINESS

The President indicated that the tasks that were proposed, by the BIPM Time section, at item 11 of the agenda were accepted.

The President then closed the meeting and thanked the delegates.

D. Henderson, *Rapporteur*

18 October 2004

revised March 2005

Recommandations du
Comité consultatif du temps et des fréquences

présentées au
Comité international des poids et mesures

RECOMMANDATION CCTF 1 (2004) :
Au sujet des représentations secondaires de la seconde

Le Comité consultatif du temps et des fréquences,

considérant que

- le Groupe de travail commun au CCL et au CCTF sur les représentations secondaires de la seconde a discuté, lors de sa réunion au Bureau international des poids et mesures du 30 mars 2004, des radiations candidates potentielles en vue de leur inclusion dans la liste des représentations secondaires de la seconde,
- ce groupe a recommandé une transition pour cette liste,

soutient cette action,

recommande que la transition quantique hyperfine non perturbée de l'état fondamental du ^{87}Rb pourrait servir de représentation secondaire de la seconde, à la fréquence de f_{Rb} = 6 834 682 610,904 324 Hz, avec une incertitude-type relative estimée (1 σ) de 3×10^{-15},

et **reconnaît** que plusieurs étalons de fréquence optique ont été examinés par ce groupe de travail. Bien qu'aucun d'entre eux ne soit recommandé pour le moment, le groupe estime que les progrès rapides des étalons de fréquence optique rendent nécessaire d'examiner à nouveau la possibilité de les utiliser comme représentations secondaires de la seconde.

RECOMMANDATION CCTF 2 (2004) :
Au sujet de l'utilisation des étalons primaires de fréquence et de la publication de leurs résultats

Le Comité consultatif du temps et des fréquences,

considérant que

- la Recommandation S 3 (1999) du CCTF fournit des directives pour rendre compte des résultats obtenus avec les étalons primaires de fréquence et de leurs incertitudes,
- il est fondamental de faire un usage approprié des résultats de mesure des étalons primaires de fréquence pour assurer une estimation correcte de l'unité d'échelle du Temps atomique international (TAI),
- il est souhaitable que cette estimation soit fondée sur un nombre suffisant de mesures de différents étalons primaires de fréquence,
- l'incertitude de chaque mesure doit être établie au moyen d'une documentation convenable et les méthodes utilisées pour son estimation doivent être décrites,
- il est souhaitable que toutes les valeurs des fréquences primaires soient archivées et rendues accessibles au public,

recommande que

- les laboratoires qui possèdent des étalons primaires de fréquence les utilisent de manière régulière afin de réaliser la seconde du Système international d'unités (SI) et fournissent au Bureau international des poids et mesures (BIPM) des résultats de comparaison entre ces étalons primaires de fréquence et une horloge qui contribue au TAI,
- pour chaque étalon primaire, l'incertitude déclarée fasse référence à une publication déjà existante décrivant toutes les corrections, les méthodes d'évaluation et la description de tous les instruments utilisés, ou qu'elle soit elle-même l'objet d'une telle publication [Recommandation S 3 (1999)],
- toutes les évaluations successives d'un étalon primaire de fréquence soient accompagnées d'un rapport décrivant les changements depuis la première évaluation complète publiée, ainsi que tous les éléments spécifiques à chaque évaluation,
- cette documentation soit archivée par le BIPM et rendue accessible au public,
- les évaluations soient utilisées pour le pilotage du TAI, à moins qu'elles ne soient considérées comme préjudiciables au TAI par décision mutuelle du laboratoire concerné et du BIPM,
- le Groupe de travail sur l'expression des incertitudes des étalons primaires de fréquence examine comment chacune des évaluations publiées des étalons primaires de fréquence est utilisée.

RECOMMANDATION CCTF 3 (2004) :
Au sujet du pilotage du Temps atomique international (TAI)

Le Comité consultatif du temps et des fréquences,

considérant que

- le TAI a été défini par la Conférence générale des poids et mesures en 1971, et que cette définition a été complétée par le Comité consultatif pour la définition de la seconde en 1980,
- le TAI est une réalisation du Temps terrestre (TT) tel qu'il a été défini récemment dans la Résolution B1.9 (2000) de l'Union astronomique internationale,
- l'unité d'échelle du TAI s'est écartée de façon significative de sa définition au cours des années passées,
- les nouveaux étalons primaires de fréquence permettent de déterminer cet écart avec une incertitude convenable,
- il est avantageux que le TAI établisse directement la traçabilité à la seconde du SI,

recommande que

- la procédure de pilotage de fréquence du TAI soit adaptée afin de s'assurer que l'estimation de l'unité d'échelle du TAI telle qu'estimée soit conforme à sa définition dans la limité de trois fois l'incertitude-type,
- cette procédure soit établie, en collaboration avec le Groupe de travail sur le TAI, afin de minimiser l'impact sur la stabilité du TAI.

Recommendations of the
Consultative Committee for Time and Frequency

submitted to the
International Committee for Weights and Measures

RECOMMENDATION CCTF 1 (2004):
Concerning secondary representations of the second

The Consultative Committee for Time and Frequency,

considering that

- the CCL/CCTF Joint Working Group (JWG) on Secondary Representations of the Second in its meeting at the BIPM on 30 March 2004 discussed possible candidates to be included in the list for secondary representations of the second,
- this group has recommended a transition for this list,

supports this action,

recommends that the unperturbed ground-state hyperfine quantum transition of ^{87}Rb may be used as a secondary representation of the second with a frequency of f_{Rb} = 6 834 682 610.904 324 Hz and an estimated relative standard uncertainty (1 σ) of 3×10^{-15},

and **recognizes** that several optical frequency standards have been reviewed by the JWG. Although none has been proposed at this stage, the JWG believes that the rapid progress with these optical frequency standards requires that they should again be reviewed at its next meeting for their possible use as secondary representations of the second.

RECOMMENDATION CCTF 2 (2004):
Concerning the report and use of primary frequency standards

The Consultative Committee for Time and Frequency,

considering that

- CCTF Recommendation S 3 (1999) provides guidelines to report the results of primary frequency standards and their uncertainties,
- the proper usage of primary frequency standards measurements is essential to ensure a correct estimation of the scale unit of International Atomic Time (TAI),
- it is desirable that this estimation be based on a sufficient number of measurements from different primary frequency standards,
- the uncertainty of each measurement should be adequately documented and the methods of its estimation should be described,
- it is desirable that all primary frequency data be archived and made available publicly,

recommends that

- laboratories that develop primary frequency standards operate them on a regular basis to realize the SI second and provide to the International Bureau of Weights and Measures (BIPM) results of comparisons of the primary frequency standard with a clock contributing to TAI,
- the uncertainty statements of each primary standard either refer to the publication of all corrections, their methods of evaluation and descriptions of all instrumentation, or itself constitute such a publication [Recommendation S 3 (1999)],
- all successive evaluations of a primary frequency standard be accompanied by a report describing any changes since the first referenced full evaluation, as well as all elements which are specific to each evaluation,
- this documentation be archived by the BIPM and made publicly available,
- the evaluations be used for steering of TAI, unless deemed detrimental to TAI in a mutual decision by the concerned laboratory and the BIPM
- the Working Group on the Expression of Uncertainties in Primary Frequency Standards (PFS) reviews the use of all reported evaluations of PFS.

RECOMMENDATION CCTF 3 (2004):
Concerning the steering of International Atomic Time (TAI)

The Consultative Committee for Time and Frequency,

considering that

- TAI was defined by the General Conference on Weights and Measures in 1971, complemented by the Consultative Committee for the Definition of the Second in 1980,
- TAI is a realization of Terrestrial Time (TT) as defined, most recently, in Resolution B1.9 (2000) of the International Astronomical Union,
- the scale unit of TAI has significantly deviated from its definition over the past years,
- new primary frequency standards permit the determination of this deviation with adequate uncertainty,
- it is advantageous that TAI provides direct traceability to the SI second,

recommends that

- the procedure of TAI frequency steering be adapted with the aim of ensuring that the estimation of the TAI scale unit conforms to its definition within 3 σ uncertainty,
- this procedure be designed, in collaboration with the Working Group on TAI, to minimize the impact on TAI stability.

APPENDIX 1.
Working documents submitted to the CCTF at its 16th meeting

Open working documents of the CCTF can be obtained from the BIPM in their original version, or can be accessed on the BIPM website:

(http://www.bipm.org/cc/AllowedDocuments.jsp?cc=CCTF).

Document
CCTF/

04-00 Draft agenda, 1 p.

04-01 USNO (United States). — Time and Frequency Activities at the U.S. Naval Observatory, 16 pp.

04-02 METAS, ON (Switzerland). — Report to the 16th meeting of the Consultative Committee for Time and Frequency (CCTF), 3 pp.

04-03 NMIJ/AIST (Japan). — Research activities on time and frequency, 4 pp.

04-04 KRISS (Rep. of Korea). — Status Report to the 16th Session of the CCTF on Time and Frequency Activities at KRISS, 4 pp.

04-05 NIM (China). — Time and Frequency Research Activity in NIM, Gao Xiaoxun, 7 pp.

04-06 NML-CSIRO* (Australia). — Report to the CCTF from the National Measurement Laboratory CSIRO, 5 pp.

04-07 CCTF WG on the Consequences of the CIPM MRA. — Report from the CCTF WG, G. de Jong (Chairman), 10 pp.

04-08 NMi VSL (Netherlands). — Report of the VSL TF Section NMi Van Swinden Laboratorium, 2 pp.

04-09 PTB (Germany). — Report on Activities to the 16th Session of the CCTF, 6 pp.

04-10 CRL** (Japan). — Summary of time and frequency activities at CRL, 4 pp.

04-11 CRL (Japan). — Quasi-Zenith Satellite System – A new satellite positioning system of Japan, 2 pp.

04-12 CRL (Japan). — Development of a Spaceborne Hydrogen Maser, 2 pp.

04-13 ORB (Belgium). — CCTF 2004: Report of the Royal Observatory of Belgium, P. Defraigne, 3 pp.

04-14 IEN (Italy). — Report to the 16th session of the CCTF, 10 pp.

04-15 ROA (Spain). — Report of the ROA TF Section, 2 pp.

04-16 BIPM, USNO (United States). — IERS Conventions Centre, G. Petit (BIPM), D. McCarthy (USNO), 3 pp.

* Renamed NMIA.
** Renamed NICT.

Document CCTF/	
04-17	BIPM. — A new realization of Terrestrial Time, G. Petit, 6 pp.
04-18	BIPM. — Report of the TAI P3 experiment, G. Petit, Z. Jiang, 13 pp.
04-19	BIPM. — Report of the BIPM Time section 2002-2004, F. Arias, 7 pp.
04-20	ESA. — Letter, J. Hahn, 1 p.
04-21	NRC (Canada). — Report on activities to the 16th session of the CCTF, 4 pp.
04-22	NIST (United States). — Activities of the NIST Time and Frequency Division, 9 pp.
04-23	BNM-SYRTE (France). — Contribution to the 16th CCTF, A. Clairon, N. Dimarcq, P. Uhrich, 7 pp.
04-24	VNIIFTRI (Russian Fed.). — Time and frequency activity at the IMVP FGUP "VNIIFTRI", 8 pp.
04-25	NPL (United Kingdom). — Report to the 16th session of the CCTF, 5 pp.
04-26	BIPM. — BIPM GPS equipment calibration trips, W. Lewandowski, L. Tisserand, 3 pp.
04-27	ITU-R WP-7A Special Rapporteur Group. — UTC Transition Plan, 3 pp.
04-28	PTB (Germany). — Joint WG CCL/CCTF, F. Riehle (JWG co-chair), 19 pp.