Bureau International des Poids et Mesures

Consultative Committee for Time and Frequency (CCTF)

Report of the 17th meeting
(14 –15 September 2006)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Bureau international des poids et mesures	Organization intergouvernementale de la Convention du Mètre

Note:

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

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

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

A.J. Wallard

Director BIPM

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR TIME AND FREQUENCY
as of 14 September 2006

President

S. Leschiutta, member of the International Committee for Weights and Measures.

Executive Secretary

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

Members

Federal Office of Metrology [METAS], Wabern

Institute for Physical, Technical and RadioTechnical Measurements, Rostekhregulirovaniye 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 Nazionale di Ricerca Metrologica [INRIM], Turin.

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

Laboratoire National de Métrologie et d'Essais, Observatoire de Paris, SYstèmes de Référence Temps-Espace [LNE-SYRTE], Paris.

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.

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

Observatoire Cantonal [ON], Neuchâtel.

Observatoire Royal de Belgique [ORB], Brussels.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

Technical University [TUG], Graz.

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

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

Observers

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

Space Research Center of the Polish Academy of Sciences [SRC], Warsaw.

Standards, Productivity and Innovation Board [SPRING Singapore], 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 17th meeting at the International Bureau of Weights and Measures (BIPM), at Sèvres. Four sessions took place, on 14 and 15 September 2006.

The following were present: J. Achkar (LNE-SYRTE), P. Banerjee (NPLI), A. Bauch (PTB), R. Beard (ITU-R), C. Boucher (IUGG), J.-S. Boulanger (NRC), A. Clairon (LNE-SYRTE), J. Davis (NPL), P. Defraigne (ORB), G. de Jong (NMi VSL), E. Dierikx (NMi VSL), Y.S. Domnin (VNIIFTRI), G. Dudle (METAS), P. Fisk (NMIA), X. Gao (NIM), P. Gill (NPL), A. Godone (INRIM), Y. Hanado (NICT), M. Hosokawa (NICT), T. Ikegami (NMIJ/AIST), Y. Ilyasov (VNIIFTRI), M. Imae (NMIJ/AIST), N. Koshelyaevsky (VNIIFTRI), E. Kroon (NMi VSL), T.Y. Kwon (KRISS), H.S. Lee (KRISS), S. Leschiutta (President of the CCTF), J. Levine (NIST), T. Li (NIM), A. Madej (NRC), L. Marmet (NRC), D. Matsakis (USNO), J. Mc A. Steele (URSI), D. McCarthy (IAU, USNO), G. Mileti (ON), T. O'Brian (NIST), S. Ohshima (NMIJ/AIST), J. Palacio (ROA), T.E. Parker (NIST), F. Riehle (PTB), P. Tavella (INRIM), P. Tuckey (LNE-SYRTE), A.J. Wallard (Director of the BIPM).

Observers: R. Hamid (UME), C. Matthee (CSIR-NML), J. Nawrocki (SRC), G. Xu (SPRING Singapore).

Guests: J. Dow (IGS, ESOC/ESA), W.J. Klepczynski (USNO), C.-S. Liao (NTFSL), K. Senior (IGS, NRL).

Also present: E.F. Arias (Executive Secretary of the CCTF), R. Felder, Z. Jiang, W. Lewandowski, G. Petit, L. Robertsson, C. Thomas (Coordinator of the KCDB), L. Vitushkin, P. Wolf (BIPM).

Sent regrets: T. Fukushima (IAU), K.J. Johnston (USNO).

The President opened the meeting at 10 am and welcomed the delegates and observers. He thanked the Head of the BIPM Time, Frequency and Gravimetry section, Dr Arias, for preparing the agenda and invited the Director of the BIPM, Prof. Wallard, to add his welcome to the delegates.

The President noted that Dr Fisk had agreed to serve as Rapporteur.

2 PROGRESS IN FREQUENCY STANDARDS

2.1 Currently operating primary frequency standards and new primary standards under development

The President invited each laboratory representative to present a brief report on developments related to primary frequency standards.

Report from INRIM, Italy, presented by Dr Godone (CCTF/06-02)

Ten comparisons between TAI and the INRIM Cs fountain (IENCsF1) have been completed with total uncertainties as small as 1.3 parts in 10^{15}, including uncertainties due to the TWSTFT frequency transfer method. Frequency comparisons via TWSTFT and GPS carrier-phase techniques yielded agreement within 4 parts in 10^{15}, limited by frequency transfer uncertainty. The type B uncertainty of IENCsF1 is calculated to be 6 parts in 10^{16}.

A second Cs fountain is under construction.

Report from NIM, China, presented by Prof. Gao

NIM's first Cs fountain was completed in 2004 and its type B uncertainty was initially evaluated as 9 parts in 10^{13}. By 2005, the uncertainty had improved to 5 parts in 10^{15}, but recent airconditioning problems in the laboratory have delayed further progress. A second Cs fountain is presently under construction and will be known as NIM 5.

Other frequency standard work at NIM included comparisons between 532 nm lasers with agreement demonstrated within 2 parts in 10^{14}.

Work on NIM's first optical frequency standard, based on Sr atoms, started in 2006.

Report from NICT, Japan, presented by Dr Hosokawa (CCTF/06-09)

NICT's first thermal Cs beam primary frequency standard NICT01 commenced operation in 2000 and ceased operation in June 2006. The type B uncertainty of NICT01 was estimated as 5.4 parts in 10^{15}, and comparisons with TAI were transmitted to the BIPM approximately twice per year.

The NICT is presently testing a new Cs fountain known as NICT-CsF1. The type B frequency uncertainty has initially been estimated as less than 2 parts in 10^{15}, and work on refining the accuracy evaluation is continuing. Comparisons between the frequencies of NICT-CsF1 and TAI are expected in 2006.

An optical frequency standard based on single Ca^+ ions is also under development. The clock transition has been observed with a linewidth of several hundred kHz, and work on reducing this linewidth is in progress.

Report from NMIJ, Japan, presented by Dr Ohshima (CCTF/06-05)

Operation of the Cs fountain NMIJ-F1 commenced in 2005. The type B uncertainty of this standard is presently estimated as 4 parts in 10^{15}, and the reasons for the larger than expected statistical frequency fluctuations are being investigated. Frequency comparisons with TAI are expected to be reported to the BIPM soon.

The NMIJ has measured the frequency of a Sr atom lattice clock, developed by the University of Tokyo, with an uncertainty of 1 part in 10^{14}. The result is in good agreement with measurements made by other laboratories.

The NMIJ is developing a Yb atom lattice clock in collaboration with the University of Tokyo.

Report from NPL, United Kingdom, presented by Dr Gill (CCTF/06-25)

The type B uncertainty of the Cs fountain standard NPL-CsF1 has been recently reassessed as 2 parts in 10^{15}, whereas in 2004 a value of 1 part in 10^{15} was published. The increased uncertainty is due to microwave leakage.

NPL-CsF1 has been run for four periods in excess of 30 days, and has been compared with two other European Cs fountains. The fountains agreed within 4 parts in 10^{15}.

A second fountain, NPL-CsF2, was completed in 2005, and evaluation is in progress.

A rubidium fountain is under construction, and the cooling, launching and detection systems are being tested. Completion is expected in 2006.

Work on optical standards based on $^{88}Sr^{+}$ and $^{171}Yb^{+}$ is continuing. The frequency of the 674 nm transition in $^{88}Sr^{+}$ has been measured with an uncertainty of 3.9 parts in 10^{15}, and is in excellent agreement with earlier measurements and with results from NRC. This transition has been recommended as a secondary representation of the second (Recommendation CCTF 2 (2006)). Recent improvements to the stability of the 674 nm laser have reduced the observed linewidth of the clock transition to 9 Hz with 100 ms interrogation times.

The frequency of the 467 nm transition in $^{171}Yb^{+}$ has been measured with an uncertainty of 1 part in 10^{12}. The uncertainty is presently determined by the relatively large observed linewidth (200 Hz) of the clock transition, which is due to trap vibrations. Work is in progress to reduce this linewidth.

The NPL is planning to commence work on an optical lattice clock, probably based on Sr atoms.

Report from VNIIFTRI, Russian Federation, presented by Prof. Koshelyaevsky (CCTF/06-11)

The VNIIFTRI has for many years operated a thermal beam primary Cs standard with a type B uncertainty of less than 3 parts in 10^{14}. A Cs fountain is presently under development, and Ramsey fringes have been observed. Completion is expected in 2007.

The Government of the Russian Federation has recently decided to improve the time standard infrastructure that supports the GLONASS system. A work programme extending to 2011 will involve realizing a time scale whose frequency accuracy will be maintained via a Cs fountain with a type B uncertainty of less than 5 parts in 10^{16}. The time scale will be maintained within 10 ns of UTC, and will be disseminated nationally with an uncertainty of less than 6 ns. New hydrogen masers, time transfer systems and other related infrastructure will be installed in primary and secondary laboratories.

Report from LNE-SYRTE, France, presented by Prof. Clairon (CCTF/06-20)

The type B uncertainties of the Cs fountain F01 and the Cs-Rb double fountain F02 were estimated as 7.5 parts in 10^{16} and 6.6 parts in 10^{16} (for Cs), respectively, in 2004. The frequency difference between the two fountains was 4 parts in 10^{16}.

The optical cooling systems and magnetic field control of F01 and F02 have recently been upgraded. Improved control of temperature gradients has reduced the uncertainty contribution of the blackbody shift to 6 parts in 10^{17}.

The mobile Cs fountain F0M has been modified to allow higher launching of the atoms, and will be moved to CNES (Toulouse, France) to contribute to the evaluation of the PHARAO space clock engineering model.

The LNE-SYRTE provides scientific leadership and test facilities for the PHARAO/ACES project, and has been testing the PHARAO space clock engineering model. Test results are very promising, and optical detection exhibiting excellent signal to noise ratios has been demonstrated.

Development of a compact Cs clock (HORACE) that uses laser cooling within the microwave cavity has continued and a frequency stability of $3.5 \times 10^{-12}\ \tau^{-1/2}$ has been demonstrated.

The frequency of the 461 nm transition in Sr atoms in a lattice clock has been measured with an uncertainty of 1.2 parts in 10^{14}, in excellent agreement with the result from the Joint Institute for Laboratory Astrophysics (JILA) in Colorado, United States. Another lattice clock, based on the 265.6 nm transition in Hg atoms, is under development, with the first probing of the clock transition expected in 2007.

An optical frequency standard based on a transition in Ag atoms probed by two photons of wavelength 661 nm is under development. The clock transition was observed in a thermal beam for the first time in 2004 and a magneto-optical trap is currently being developed.

Report from NIST, United States, presented by Dr O'Brian (CCTF/06-23)

The Cs fountain primary frequency standard NIST-F1 has been in operation since 1998 and 18 formal comparisons between its frequency and TAI have been reported to the BIPM since November 1999. Upgrades to NIST-F1 implemented since 2004 include improved magnetic field control and improvements to the molasses optics. The overall uncertainty of the latest comparison was 9.4 parts in 10^{16}, and the type B uncertainty in the frequency of NIST-F1 was 3.1 parts in 10^{16}.

A new Cs fountain standard, NIST-F2, is under construction. A novel feature will be a cryogenic drift tube to reduce the contribution of the blackbody shift to the type B uncertainty. The new standard will also launch 10 "balls" of atoms, of lower density than those launched by NIST-F1, to different heights. The balls will reach the detection region simultaneously, resulting in a reduced uncertainty contribution from the collision shift without sacrificing signal to noise ratio.

Work continues on an optical clock based on a single $^{199}Hg^{+}$ ion. The frequency of the 282 nm clock transition has been compared with NIST-F1 with a total uncertainty of 9.1 parts in 10^{16}.

The highly forbidden 578 nm clock transition in ^{174}Yb atoms confined in a one-dimensional optical lattice has been observed. The use of an even isotope reduces linear magnetic field sensitivity and other undesirable effects. On the other hand, in the even isotope a small magnetic field is required to induce sufficient state mixing to give the clock transition a weak electric dipole moment, without which it could not be observed. The usefulness of this system as a frequency standard will depend on the ability to stabilize this magnetic field.

The use of the forbidden 267 nm transition in $^{27}Al^{+}$ ions as a frequency standard has been explored by sympathetically cooling the $^{27}Al^{+}$ ions via quantum entanglement with $^{9}Be^{+}$ ions. This cooling technique was required because of the relative inaccessibility to current lasers of the 167 nm Al^{+} resonance transition. Preliminary results indicate a type B frequency uncertainty of 6 parts in 10^{17}.

Preliminary results have been obtained from a Ca atom optical frequency standard. This standard is expected to have a type B uncertainty of less than 3 parts in 10^{15}.

Report from NMIA, Australia, presented by Dr Fisk (CCTF/06-32)

There are no significant new results from the NMIA optically-cooled ytterbium ion frequency standard, which has been under development for more than ten years. Work is in progress to replace all vacuum components in the vicinity of the Paul trap with non-magnetic components, but this has been delayed by other demands on the Time group, including taking over the national "Speaking Clock" service and the provision of improved time services to various commercial and government organizations.

Report from PTB, Germany, presented by Dr Bauch and Dr Riehle (CCTF/06-07)

The long-running thermal Cs beam primary standards Cs1 and Cs2 continue to operate and a new evaluation of their uncertainties has been carried out. The results (type B uncertainties of 7 parts in 10^{15} and 12 parts in 10^{15}, respectively) are consistent with previous evaluations. PTB plans to continue operation of the clocks unless major failures occur. In view of the superiority of Cs fountain clocks, operation of the vertically oriented thermal beam standard Cs4 has been terminated, and the clock has been shipped to a museum. The similar clock Cs3 continues to operate, but no further uncertainty evaluations will be made.

The Cs fountain standard CsF1 has been in use for the past five years and 15 reports on comparisons between its frequency and TAI had been sent to the BIPM by 2004. In early 2004 the type B uncertainty of CsF1 was estimated to be less than 1 part in 10^{15}, however in November 2004 frequency differences of 1 part in 10^{14} were observed during a comparison campaign between CsF1 and several European fountains. The source of this discrepancy has been traced to Majorana transitions in CsF1 caused by unintended changes in the properties of the magnetic shielding, and a microwave power dependence which is presently not completely understood.

A new Cs fountain primary standard CsF2 has recently been completed and its performance and uncertainty will be evaluated over the next two years.

The PTB has been operating optical frequency standards based on the 436 nm transition in single $^{171}Yb^{+}$ ions for five years. Two such standards have been compared and agreement within 3.8 parts in 10^{16} has been demonstrated. The type B uncertainty of the standard is estimated as 3.1 parts in 10^{15}.

The PTB operates an optical standard based on the 657 nm transition in Ca atoms. The atoms are prepared in a 15 μK ballistically expanding cloud, and continuous operation for more than two weeks has been demonstrated. A type B uncertainty of 2 parts in 10^{15} is predicted, and improvements beyond this point using expanding clouds will require much greater effort. Future work will therefore be directed at the development of a Sr atom optical lattice clock, for which the first frequency measurements are expected later in 2006.

Report from NRC, Canada, presented by Dr Boulanger, Dr Marmet and Dr Madej (CCTF/06-21)

The NRC does not intend to send the BIPM further reports on comparisons between TAI and the three thermal Cs beam primary frequency standards CsV, CsV1A and CsV1C. NRC will instead concentrate on comparisons between TAI and more accurate NRC clocks.

A Cs fountain, NRC-FCs1, is under construction. Its design is based on results from an earlier prototype. All parts of the fountain are now complete with the exception of the microwave cavity. First operation is expected in 2007.

The frequency of the 674 nm transition in a single trapped $^{88}Sr^{+}$ ion has been determined with a type B uncertainty of 3.4 parts in 10^{12}. This is expected to improve to 3 parts in 10^{14} as a result of recent improvements in the spectral resolution of the clock transition due to improved stability of the laser sources. A new ion trap system is also being built, with a goal of reducing the systematic uncertainties to the 10^{-17} level. Results from the new ion trap system are expected in two years.

Report from METAS, Switzerland, presented by Dr Dudle (CCTF/06-24)

Work continues on the development of FOCs-1, a primary Cs standard based on a slow continuous fountain of atoms. A short-term stability of 2 parts in 10^{13} at an averaging time of 1 s has been demonstrated, limited by the signal to noise ratio determined by the atomic flux. No accuracy evaluation of the standard is available yet due to reliability problems.

A second slow Cs fountain, FOCs-2, has been constructed. Optical pre-cooling followed by an optical lattice is used to reduce the transverse temperature of the slow beam, resulting in an increase in the atomic flux and an improved short term frequency stability. Observation of Ramsey fringes is expected before the end of 2006.

Report from KRISS, Korea, presented by Dr Lee (CCTF/06-03)

Several further improvements had been made to the optically-pumped thermal Cs beam primary frequency standard KRISS-1. The type B uncertainty is estimated to be 1.2 parts in 10^{14} and this is thought to be the limit of development. The results of frequency comparisons with TAI are expected to be reported to the BIPM in 2007.

Development of a Cs fountain standard continues, but has been limited recently by lack of staff. Ramsey fringes of 1 Hz linewidth have been observed, and the rate of progress is expected to increase with the appointment of new staff in 2006.

Work has commenced on an optical lattice clock based on Yb atoms. Detection of the first signals from the lattice is expected before the end of 2007.

An optical femtosecond comb has been developed and used to measure the frequency of the 950 nm Cs D2 line with an uncertainty of 2.5 parts in 10^{13}.

The President remarked that 12 laboratories are engaged in Cs fountain development, and many of these laboratories are building more than one. He said that he would present this to the CIPM as an indication of the very strong activity in primary frequency standard development in NMIs. He also noted that evaluation of the optical frequency standards with type B uncertainties in the 10^{-16} range is generally limited by the performance of the Cs fountains used as frequency references. He concluded the session by thanking the BIPM for supporting these developments.

2.2 Frequency standards in TAI

The President invited Dr Petit to present a report entitled “High Accuracy Frequency Standards in TAI”.

Dr Petit said that during the period 1999-2005 the BIPM had received 69 measurements of the frequency of TAI with respect to Cs fountains. The BIPM had studied the data from these measurements and sought to answer three questions:

1) What are the effects of Cs fountains on the uncertainty of TAI?

Cs fountains have improved the uncertainty in the frequency of TAI by about a factor of 2, with the present uncertainty being 1 part in 10^{15}. This improvement is smaller than the improvements (a factor of between 5 and 10) in the uncertainties of Cs fountain standards over Cs beam standards. The reasons for this are thought to be:

- noise contributed by the intermittent nature of the comparisons between Cs fountains and TAI,
- noise contributed by the comparison methods themselves, and
- instability of EAL from other sources.

These issues are being worked on and improvements are expected.

2) How self-consistent are the measurements from individual Cs fountains?

Due to limited data, this question could be studied in the context of only four Cs fountains. For each of these fountains the chi-squared statistical indicator showed good self consistency, particularly for more recent data.

3) How do measurements from individual Cs fountains compare with others?

Again, due to limited data this question could be studied in the context of only four Cs fountains. The frequency of each of these four Cs fountains was compared in turn with the frequency of TAI, calculated without steering input from the fountain in question. The result was that none of the frequency measurements from the four Cs fountains agreed within the stated uncertainties, with discrepancies ranging from 1.8 σ to 4.6 σ. These discrepancies may increase as comparison methods are improved.

Dr Madej asked about the causes of the inconsistencies between Cs fountains. Dr Petit replied that the BIPM cannot determine this, and said that the matter should be referred to the CCTF Working Group on Primary Frequency Standards.

The President thanked Dr Petit for the report and commented that greater improvements in the accuracy of TAI could be expected in future as more Cs fountains come on-line and comparison methods improve.

2.3 Report of the CCTF Working Group on Primary Frequency Standards

The President invited Dr Parker to present this report (CCTF/06-13).

Dr Parker began by saying that the CCTF Working Group on Primary Frequency Standards was established in 2005 to address the issues arising from the introduction of data from many new Primary Frequency Standards (PFSs) into TAI, and in particular, to study the algorithms used and the associated accuracy calculations. The working group consists of 20 individuals from 13 metrology organizations, including the BIPM Time, Frequency and Gravimetry section.

The terms of reference of the working group are to:

- develop and propose standards for the documentation of frequency biases and uncertainties, operational details, and frequency transfer uncertainties for a PFS,
- develop and propose standards for the reporting of the results of a PFS evaluation to the BIPM,
- provide a forum to evaluate and discuss consistency among primary frequency standards,
- provide a forum to discuss and assess overall knowledge of the accuracy of the SI second for use in establishing the frequencies of secondary standards (microwave and optical) and possibly an eventual redefinition of the second,
- interact with the BIPM on issues related to PFS contributions to the accuracy of TAI, particularly in the process of integration of the first reports of a standard,
- encourage and facilitate direct comparisons between primary frequency standards, and
- encourage and support laboratories with new standards under construction.

The working group has met twice: in August 2005 and March 2006, and a one-day workshop is planned for May 2007 adjacent to the European Frequency and Time Forum meeting.

Dr Parker reported that the formula used to calculate the uncertainty of frequency transfers into TAI has been updated to incorporate the time uncertainties for UTC that are now published in *Circular T* and to take account of the fact that flicker phase noise now dominates data from modern high accuracy time transfer technologies (ie: TWSTFT, GPSCP, GPS P3, etc). The old formula was based on the characteristics of GPS common view time transfer. The new formula yields reductions in uncertainties by a factor of between 2 and 3 for most laboratories. Dr Parker noted that frequency transfer uncertainty remains as a significant, and often dominating, factor in the total frequency comparison uncertainty budget, and that in order to take advantage of frequency comparison data in steering TAI, prompt submission to the BIPM of a complete report on each frequency comparison is essential.

Dr Parker said that 73 comparisons between PFSs (including thermal beams) and TAI had been made between 2000 and mid-2006. Seven Cs fountains contributed to these comparisons. A chi-squared statistical indicator for these comparisons of 1.3 indicates an error in PFS uncertainties of only 14 %, which is considered very satisfactory.

Dr Parker pointed out seven instances where data points from the same Cs fountain standard were not self consistent. Most of these came from the first three comparison reports from the standard, possibly indicating that experience improves the quality of reports. This led to a recommendation (included in Recommendation CCTF 3 (2006)) that when a new PFS comes on line the operators consider its long-term stability with respect to TAI before submitting a formal report. The working group concluded that there is evidence of systematic inconsistencies between some PFSs and that additional direct comparisons between Cs fountains are needed in order to properly evaluate their consistency.

Dr Parker concluded by saying that there is a need for a global assessment of the uncertainty in the SI second, and for consideration of alternative realizations of the second.

Dr McCarthy asked about the possibility of an organized campaign to compare PFSs. Dr Parker replied that the problem with this idea in the past has been unreliability of the PFSs making it difficult to maintain a comparison schedule, but reliability is improving dramatically, and comparisons following a schedule may be possible soon.

The President thanked Dr Parker for the report and reminded the CCTF of the previous activities of the CCTF Working Group on Uncertainties in Primary Frequency Standards led by Dr Douglas, and noted that that this work is continuing under the present working group.

2.4 Report of the CCL-CCTF Working Group on Secondary Representations of the Second

The President invited Dr Riehle to present this report (CCTF/06-15).

Dr Riehle began by saying that the Working Group on Secondary Representations of the Second was established in 2001 as a working group of the CCTF when it was clear that the accuracy of optical frequency standards would soon equal or exceed the accuracy of microwave frequency standards and that the establishment of optical frequencies as secondary realizations of the second would therefore be beneficial. In 2003, discussions between the CCTF and the CCL led to the formation of a Joint Working Group because the CCL *Mise en Pratique* had for some years listed recommended optical frequencies as secondary representations of the metre. In 2005, the Joint Working Group recommended to the CCL that a single list of optical frequencies be established as secondary realizations of the second, and consequently the metre, and that the *Mise en Pratique* Working Group be merged with the Joint Working Group. The CCL agreed to these proposals, which will be recommended to the CIPM (Recommendation CCTF 1 (2006)).

In 2006, the Joint Working Group selected five frequencies as secondary representations of the second. In order to be selected, the frequency was required to have an uncertainty that has been evaluated and documented to the same level as that is required for the inclusion of primary frequency standard data in TAI. Further, the uncertainty was required to be no more than about a factor of 10 greater than the primary frequency standards of the day. The selected frequencies are:

- the unperturbed ground-state hyperfine transition of ^{87}Rb with a frequency of $f_{^{87}\mathrm{Rb}}$ = 6 834 682 610.904 324 Hz and an estimated relative standard uncertainty of 3×10^{-15},
- the unperturbed optical 5s $^2S_{1/2}$ – 4d $^2D_{5/2}$ transition of the $^{88}Sr^+$ ion with a frequency of $f_{^{88}\mathrm{Sr}^+}$ = 444 779 044 095 484 Hz and a relative standard uncertainty of 7×10^{-15},
- the unperturbed optical 5d^{10} 6s $^2S_{1/2}$ (F = 0) – 5d^9 6s^2 $^2D_{5/2}$ (F = 2) transition of the $^{199}Hg^+$ ion with a frequency of $f_{^{199}\mathrm{Hg}^+}$ = 1 064 721 609 899 145 Hz and a relative standard uncertainty of 3×10^{-15},
- the unperturbed optical 6s $^2S_{1/2}$ (F = 0) – 5d $^2D_{3/2}$ (F = 2) transition of the $^{171}Yb^+$ ion with a frequency of $f_{^{171}\mathrm{Yb}^+}$ = 688 358 979 309 308 Hz and a relative standard uncertainty of 9×10^{-15}, and
- the unperturbed optical transition 5s^2 $^1S_0$ – 5s5p $^3P_0$ of an ^{87}Sr with a frequency of ensemble with a frequency of $f_{^{87}\mathrm{Sr}}$ = 429 228 004 229 877 Hz and a relative standard uncertainty of 1.5×10^{-14}.

These frequencies will be recommended to the CIPM as secondary realizations of the second (Recommendation CCTF 2 (2006)).

Dr O'Brian asked how additional secondary optical representations of the second beyond the existing four recommended optical frequencies should be proposed. Dr Riehle replied that the Joint Working Group studies proposals in response to a questionnaire circulated prior to the Joint Working Group meetings. He noted that it is the responsibility of the CCTF to recommend secondary representations of the second.

The President asked Prof. Wallard if he was comfortable with the proposals in the Recommendations CCTF 1 (2006) and CCTF 2 (2006). Prof. Wallard replied that these Recommendations were timely and that he endorsed them.

Dr Riehle said that current long-distance time and frequency transfer methods are not good enough to take advantage of the accuracy of optical frequency standards, and consequently time scales are not yet able to benefit. New methods will have to be developed, including transportable standards, optical fibre links, optical satellite links and improved microwave links. Coordinated international activity will be needed for this work, together with interdisciplinary expertise in geophysics, gravitation and general relativity. Dr Riehle therefore proposed that the CCTF consider whether a recommendation to the CIPM is needed on this issue.

Dr de Jong commented that the performance of TWSTFT is improving, for example via higher chip rates on current modems, at the expense of using more bandwidth. Although these improvements increase the cost of TWSTFT, they are being driven by the demanding task of comparing Cs fountain standards. Dr de Jong said that it is premature to conclude that TWSTFT cannot be developed to meet the requirements of comparing optical frequency standards.

Dr Klepczynski remarked that since the TWSTFT community is now paying commercial rates for satellite time and bandwidth, realizing improvements by increasing bandwidth usage will be limited by cost. Dr Arias responded that the Joint Working Group realizes that it lacks the expertise to analyse fully the frequency transfer problem and believes that all possibilities should be studied.

Dr Levine pointed out that time and frequency comparisons are not the same. In particular, portable clock trips for time comparisons are difficult due to accumulated errors resulting from transport. Consequently, time transfer modes involving exchanging signals at a distance will be required for the foreseeable future.

Dr Tuckey said that in 2008 the European Space Agency is planning to fly, on a satellite called JASON, an experiment on laser time and frequency transfer called “T2L2”.

The President reminded the CCTF that Dr Riehle was asking for guidance on how to proceed, and opened a discussion regarding whether a recommendation should be made to the CIPM, and whether a working group should be established to address this time transfer problem.

Dr Arias expressed the view that instead of adding this problem to the list of tasks of existing working groups, it would be better to form a new working group to ensure that a clear focus on the desired outcomes is maintained.

Dr Bauch pointed out that comparisons of fountains have been carried out very successfully without a dedicated working group. He put forward the alternative proposal that the Working Group on TAI form a study group for this purpose. Prof. Wallard spoke in support of Dr Arias, saying that the challenge is clear but the solution is not. Prof. Wallard said that this is a new initiative that requires strong driving, and that a dedicated working group would be more effective. Prof. Wallard also proposed a recommendation to encourage laboratories to address the problem of comparing optical frequency standards and disseminating their results, since this may help these laboratories secure budgets.

Dr Klepczynski proposed that the recommendation also mention the need for increased satellite bandwidth, so that it could be presented to INTELSAT in support of a request to make bandwidth available for testing new TWSTFT technologies.

Dr Riehle agreed with Prof. Wallard and Dr Arias, and with the proposal for a recommendation.

Dr Boucher offered to propose a suitable expert from the IAU to join this working group. Dr de Jong suggested that the Working Group on TWSTFT should be involved and Dr Klepczynski agreed.

Dr Beard said that the ITU would like to be involved because it had been considering issues related to time and frequency transfer, and was particularly interested in whether frequency comparisons with uncertainties of 1 part in 10^{15} could be achieved over comparison intervals of 1 day.

The President said that after listening to the discussion he was satisfied that the CCTF should establish a new working group on improving comparison methods for frequency standards. There was general agreement, and Dr Levine proposed that the working group should not be focussed exclusively on optical frequency standards, but should consider issues related to time and frequency transfer in general. The President agreed and asked Dr Bauch, Dr de Jong, Dr Ikegami, Dr Klepczynski, Dr Ohshima, Dr Riehle, Dr Robertsson and Dr Tuckey to meet and prepare a draft recommendation.

Later in the meeting the draft recommendation (Recommendation CCTF 6 (2006)) addressing the need of coordinating the development of advanced time and frequency transfer techniques was presented and accepted; a CCTF Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques was established. The President asked the BIPM to contact the chairs of the other CCTF working groups and request that they provide representatives on the new working group. He also proposed that Dr Tuckey be appointed Chair of the new working group.

In accepting the President's proposal, Dr Tuckey said that LNE-SYRTE has a long history of microwave standard development and has now moved into the field of optical frequency standards. The organization has also had a long involvement in GPS time transfer and TWSTFT activities.

The President thanked Dr Riehle and the Joint Working Group for the report, and complimented them on the consultative way in which they did their work.

2.5 Report on the realization of Terrestrial Time

The President invited Dr Petit to present a report entitled "TT(BIPM): A realization of Terrestrial Time".

Dr Petit began by explaining that Terrestrial Time (TT) is a coordinate time in the relativistic sense and is defined by IAU2000 Resolution B9 to be related to Geocentric Coordinate Time by a scale factor. TT is therefore equal to proper time as realized by primary frequency standards on the geoid. TT is intended to be the most stable and accurate time scale available. This stability and accuracy is achieved by calculating TT once per year, using post-processed and smoothed monthly estimates of EAL and data from primary frequency standards. During the period 1993-2006, the frequency uncertainty of TT has improved from 6 parts in 10^{15} to 1 part in 10^{15}. The present frequency accuracy of TT is significantly better than that of TAI because TAI is produced in semi-real time and consequently with less available data and knowledge. TT reaches a maximum stability of 4 parts in 10^{16} at averaging times of one month.

Dr Petit said that all frequency transfers from primary frequency standards to TT will use the new formula developed by the Working Group on Primary Frequency Standards, and that data from secondary realizations of the second may also be used.

The President thanked Dr Petit for the report and commented that the advantages of TT are being highlighted by the improving accuracy of optical frequency standards.

3 PRESENT STATUS OF TAI

3.1 Report of the BIPM Time, Frequency and Gravimetry section

The President invited Dr Arias to present this report (CCTF/06-26).

Dr Arias said that as part of the integration of frequency and gravimetry activities into the BIPM Time section, four new staff members had been appointed since the last CCTF meeting in 2004, and the name of the section had been changed accordingly.

The frequency stability of EAL is now 4 parts in 10^{16} at an averaging time of 40 days, and the frequency accuracy of TAI is estimated as a few parts in 10^{15}. EAL is calculated post-real time, and 58 laboratories in NMIs and observatories contribute data from about 300 clocks each month. Of these clocks, 65 % are high performance HP5071A Cs standards and 21 % are hydrogen masers. The hydrogen masers contribute to the stability of EAL and TAI, but not to the frequency accuracy of TAI.

In 2000 the weighting algorithm for incorporation of clocks into EAL was changed, and since that time the fraction of clocks at maximum weight has dropped from 50 % to 13 %. The total number of contributing clocks has increased by 20 % since 1995.

The frequency accuracy of TAI is derived mainly from 11 primary frequency standards, of which seven are Cs fountains. The accuracy and stability of TAI has been improved by changes to the algorithm used to steer its frequency, and since July 2004 the maximum monthly steer has been reduced from 1 part in 10^{15} to 0.7 parts in 10^{15}.

Dr Arias noted that in the period 2004 to 2006 the time transfer techniques used to supply data for incorporation in EAL/TAI had improved significantly. The number of laboratories with calibrated receivers has increased, and type A uncertainties have been reducing, particularly as a result of introducing new GPS techniques such as P3, based on geodetic receivers.

Dr Arias stressed that there was still much work to be done through calibration campaigns and other means to reduce further the type B uncertainties*.

The Time, Frequency and Gravimetry section has been cooperating with several other organizations, including:

- IERS – on conventions and space-time references,
- OMP and other observatories – on pulsar time,
- LNE-SYRTE – on atom interferometry,
- LNE-SYRTE – on high accuracy time transfer,
- ITU-R – on the future of UTC and participation in the Special Rapporteur Group of Study Group 7,
- IAU – on Commissions 19 (Rotation of the Earth) and 31 (Time), and
- IUGG – as a member.

In concluding, Dr Arias said that the BIPM Time, Frequency and Gravimetry section has established a Quality Management System for the process of preparing *Circular T* and for its work in the timing laboratory. The Quality Management System has been externally audited. In addition, since the last CCTF meeting in 2004 the staff of the Time, Frequency and Gravimetry section have published 60 papers.

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* See Recommendation CCTF 5 (2006).

The President thanked Dr Arias for the report, and remarked that he was impressed with the amount and quality of work of the Time, Frequency and Gravimetry section.

3.2 Report of the CCTF Working Group on TAI

The President invited Dr Tavella to present this report (CCTF/06-34).

Dr Tavella began the report by saying that 71 delegates representing 25 laboratories and 27 countries attended the 7th meeting of laboratories contributing to TAI at the BIPM on 13 September 2006. The meeting noted the possibility of correlated frequency drifts in commercial Cs clocks which may be affecting EAL. As yet there is no clear evidence of electronic or physical effects which could explain these drifts.

Dr Tavella said that many laboratories are now operating geodetic receivers in time transfer applications, and that these receivers have produced promising results. These results have led to a draft recommendation (Recommendation CCTF 4 (2006)) that encourages timing laboratories to operate such receivers.

The 7th meeting of laboratories contributing to TAI also discussed the evaluation of the uncertainty in [$UTC - UTC(k)$]. It was agreed that correlation and comparison uncertainties within laboratories could be important and should be studied, but that the uncertainty in the internal delay of timing receivers was probably the most important factor. It was also clear that correct communication of data and timing system configuration to the BIPM is extremely important.

Dr Tavella said that the CCTF Working Group on TAI established two study groups in 2005: one on the use of the GPS All-In-View (AIV) time transfer technique in TAI, chaired by Dr Levine, and one on optimization of timing links for TAI, chaired by Dr Matsakis*.

The CCTF Working Group on TAI has a sub-group on algorithms, chaired by Dr Tavella. This sub-group will host the Fifth International Symposium on Time Scale Algorithms in March 2008 in San Fernando, Spain, co-sponsored by the BIPM, the INRIM, the ROA and the USNO.

Finally, Dr Tavella presented a draft declaration (Declaration CCTF 1 (2006)) for the reorganization of the CCTF Working Group on TAI, enlarging its membership to encompass other organizations with an interest in TAI and strengthening ties with other CCTF Working Groups. Dr Tavella also pointed out that her term as Chair of the Working Group has now covered two consecutive meetings of the CCTF and is therefore completed.

4 FUTURE DEVELOPMENTS FOR UTC AND TAI

4.1 Report of the Study Group on the GPS All-In-View (AIV) Time Transfer Technique

The President invited Dr Levine to present this report (CCTF/06-17).

Dr Levine began by saying that the GPS AIV technique takes advantage of the fact that all GPS satellites share a common reference time scale. This allows time transfers over baselines longer

* These study groups presented reports to the CCTF as part of this agenda item.

than can be achieved with a single common view (CV) link, since it is not necessary for both participating ground stations to receive signals from a particular satellite simultaneously. However, the AIV technique depends heavily on precise ephemerides for the whole constellation, which makes it less useful than CV for real time applications. The AIV and CV techniques converge over short baselines where the same satellites are in view of both ground stations.

Compared with the CV technique, AIV has demonstrated reductions of typically 1.5 ns in the type A uncertainties of long baseline time transfers. In some cases, this represents a 100 % improvement. Of 30 timing links studied, all but two showed an improvement when AIV processing was used. Dr Levine pointed out that for most laboratories the type B uncertainties are much larger than the type A uncertainties, so much of the benefit of the AIV processing technique will only be realized in TAI when calibration uncertainties are reduced.

Dr Levine concluded by pointing out that separate AIV processing will be required for the GPS, Galileo and GLONASS systems due to their different time references.

4.2 Report of the Study Group on the Optimization of Time Transfer Links

The President invited Dr Matsakis to present this report (CCTF/06-06).

Dr Matsakis summarized a detailed report in which the uncertainty analysis of time transfer links was reviewed in the light of present understanding of the theory and practice of time transfer.

The study group defined two types of uncertainties: site-based uncertainties and link-based uncertainties. Site-based uncertainties (eg: uncertainties in receiver delays) affect only the site (laboratory) in question, are independent of link topology and are not reduced by averaging redundant links. Link-based uncertainties (eg: delays introduced to GPS CV time transfer by the ionosphere), on the other hand, are dependent on link topology and are reduced by averaging redundant links. A complication arises at so-called “crossover” sites, where two different time transfer modes are in use (eg: GPS CV and TWSTFT). When crossover sites are used in multi-step timing links, the site-based uncertainties of each time transfer mode do not always cancel, but instead propagate into link-based uncertainties.

The outcome of these considerations is that link-based uncertainties have a greater impact on TAI than site-based uncertainties, and that the number of crossover sites used in links between laboratories should be minimized. Furthermore, although the algorithm for calculating TAI rejects data from laboratories with unstable local timescales (site-based noise) by allocating low or zero weighting, such laboratories can still degrade TAI if they are “pivots”, that is, if they form part of a multi-step timing link, due to conversion of site-based noise to link-based noise. This can occur at crossover sites, or at sites where time transfers are not continuous or simultaneous along each arm of the link. Sites with low or zero weighting in the TAI algorithm, but which nevertheless form part of timing links, are known as “virtual pivots”.

The AIV processing method was recommended for GPS data by the working group since the concept of virtual pivots does not arise.

Finally, Dr Matsakis said that the study group had found that averaging of redundant links between laboratories was not promising for either the GPS or TWSTFT time transfer modes, since it does not reduce the site-based noise which can, in turn, propagate into link-based noise. The study group recommended instead that the GPS carrier-phase technique be further developed.

4.3 Use of PPP for TAI links

The President invited Dr Petit to present this report.

Dr Petit said that although the BIPM has been using data from geodetic GPS receivers for calculating TAI links for several years, only the code portion of the data has been used. It is clear that it would be beneficial to make use of the carrier-phase portion of the data.

Several approaches for processing carrier-phase data for timing purposes are available, and it is considered that the technique known as Precise Point Positioning (PPP) is the most promising.

The PPP technique uses IGS satellite ephemerides and clock products to calculate the difference between each station clock and the IGS time reference, and is already in general use for contributing data to the IGS time scale. The PPP technique is consequently similar to the AIV time transfer method, except that PPP uses carrier-phase data in addition to code data.

The BIPM has been using software (known as GPSPPP) which has been developed by the geodetic group at NRC Canada to process RINEX data from geodetic receivers operated by several timing laboratories around the world. The clock epoch solutions calculated by the BIPM for these laboratories using GPSPPP agree with the IGS final clock products within 200 ps, giving confidence in the integrity of the software and the technique.

A comparison between four months of PPP data and data from a TWSTFT Ku-band link has demonstrated RMS differences of between 0.4 ns and 1 ns. Diurnal signatures and long term trends of up to 2 ns were also observed, but are not yet understood.

A 3-cornered-hat comparison using PPP, a Ku-band and an X-band TWSTFT link showed that each mode of time transfer was stable within about 300 ps over averaging times of up to 10 days, and that PPP is generally the most stable over these averaging times. A long term trend of about 2 ns was also observed. This trend appeared to be in the PPP link but is not yet understood.

Dr Petit concluded by saying that the BIPM has found the NRC package to be reliable, that the PPP results are satisfactory, and that calibration information needs to be transmitted separately or included in the RINEX format. Finally, more workers are needed, particularly in the current development and testing phase.

Dr Arias pointed out that Recommendation CCTF 4 (2006) concerns the use and study of GPS carrier-phase techniques for time transfer and that this encompasses the PPP technique.

5 REDEFINITION OF UTC: PRESENT SITUATION

The President invited Dr Beard to present this report.

Dr Beard said that in 2000 the ITU formed the Special Rapporteur Group on UTC (SRG) to address issues related to the definition and uses of UTC. The SRG considered a range of issues, including:

- proliferation of *ad hoc* system time as time scales (eg: GPS Time),
- use of TAI, and
- interfacing of multiple systems with different time scales.

The SRG compiled a report for publication on the ITU website in 2006 and, having completed its tasks, was disbanded in September 2006.

The SRG sent a questionnaire to 12 international bodies in 2005 to obtain information related to the impact and implementation of leap seconds. It was expected that the insertion of a leap second in December 2005 would help bring these issues into focus.

Ten responses were received, of which six were from timing laboratories and two were from agencies operating satellites. There was no response from the agency responsible for the Galileo GNSS system.

Of the responses received, only three expressed satisfaction with UTC in its present form. Some agencies also reported minor problems related to GPS-driven equipment, NTP time servers and related networking equipment.

The responses from timing centres regarding the implementation of the 2005 leap second indicated few or no problems. There was, however, a lack of uniformity in how the 2005 leap second was accommodated, with some agencies reporting that this was accomplished by effectively changing the length of a second at the time of the leap second.

Media interest around the leap second highlighted the confusion of the general public regarding time scales and their purposes, and it appears that the purpose and utility of UTC has become unclear. Particular issues included confusion over the relationship between UTC and UT1, and the reasons for leap seconds.

The SRG concluded that the majority of system operators are coping with the time irregularities introduced by leap seconds, but that the elimination of leap seconds from UTC would facilitate many applications requiring a continuous time reference.

ITU Working Party 7A has confirmed that any changes in the definition of UTC would have to be accepted at the World Radio Conference (WRC), and that clarifying information would be required for the briefing of WRC delegates. Working Party 7A further determined, at its 2006 meeting, that further analysis and dissemination of information would be required before a formal recommendation on the subject of leap seconds in UTC could be agreed.

The points needing to be emphasized to the WRC included:

- the proliferation of internal time scales due to a lack of a standard continuous time scale,
- UTC is the only time realized in time laboratories and disseminated with time signals, and
- TAI is the basis for UTC and provides a frequency reference.

Dr Beard said that the introduction of a new continuous time scale as an alternative to removing leap seconds from UTC would be very disruptive and confusing. Furthermore, following this path would be inconsistent with the original motivation for the introduction of UTC, which was intended to be a common time scale for broadcast coordination.

Finally, on behalf of the ITU, Dr Beard asked for the assistance of the CCTF in the following tasks:

- establishing how leap seconds are accommodated,
- providing clarification of time scales, their realization and their uses,
- clarification of the dangers of *ad hoc* system time scales,
- clarification of the relationship between UTC and UT1 and the definition of UT1,
- determination of the impact of the radiocommunications community transitioning to another time scale, and
- reviewing standards for timing systems and their use.

The President suggested that each member of the CCTF write to Dr Beard regarding these issues, and proposed to Prof. Wallard that the BIPM should express an opinion. The President then asked about the responses from the technical unions. Dr Steele said that URSI had not yet arrived at a formal view. Dr Boucher said that he was not aware of IUGG having formed a view. Dr McCarthy said that the IAU had written to the ITU in response to the request for organizations to report their experiences with the most recent leap second. The letter said that the IAU experienced no major problems, but was concerned about the effort required to accommodate the leap second.

Dr Boulanger suggested that TAI should serve the purpose of a continuous time scale, and noted that NRC broadcasts TAI via NTP servers. Dr Arias responded that TAI is not a disseminated time scale, it is not defined or endorsed for broadcast by the ITU, and the ITU would need to take action to change this. Dr Beard said using TAI as a new broadcast time scale would create difficulties and instead many organizations have established their own internal time scales (eg: IGS uses IGS time for data collection). Significant problems would arise if the ITU abandoned UTC because UTC was originally intended to be, and is widely accepted as, the timescale for broadcast purposes.

Dr McCarthy said that USNO is planning to establish an NTP server disseminating UT1. The server will become available in January 2007.

The President pointed out that TT is another candidate for a continuous time scale, and asked Dr Petit to comment. Dr Petit said that like TAI, TT is not a disseminated time scale, and that it is not yet used by the general public.

The President proposed that the CCTF should form a view on the issue of leap seconds, and that the BIPM should write to the ITU on this subject and that the content of the letter should be developed by a working group established for this purpose. Prof. Wallard agreed with the proposal, and added that the BIPM had received a formal request from ITU for information on this issue.

The President proposed that the working group should consist of:

- Dr Arias representing the BIPM,
- Dr Boucher representing the IUGG,
- Dr McCarthy representing the IAU,
- Dr Beard representing the ITU,
- Dr Koshelyaevsky representing the laboratories contributing to TAI,
- Dr Steele representing URSI, and
- Dr Boulanger.

The President requested that the draft letter be prepared for Prof. Wallard's consideration within one month.

Dr Levine pointed out that the issue of leap seconds is mainly political, not technical, and said that this should be taken into account. Prof. Wallard responded that he was well aware of the political issues, but he believes that a letter from the BIPM addressing the technical issues is nevertheless valid and useful.

6 TIME AND FREQUENCY TRANSFER METHODS

6.1 Report of the CCTF Working Group on TWSTFT

The President invited Dr Klepczynski to present this report (CCTF/06-22).

Dr Klepczynski began by saying that the Working Group had met 14 times, the most recent meeting occurring on 10-12 September at the Observatoire de Paris. The continued interest in TWSTFT is an indication that it is complementary to the other time transfer modes, including GPSCV, P3, GPS carrier-phase, and others. The TWSTFT mode is particularly important to the new GNSS systems and augmentations under development, such as Galileo, GAGAN and QZSS. In particular, TWSTFT is important because it independent from the GNSS-based modes, and is an essential cross check of their performance.

The international cooperation in TWSTFT activities consists of three regions: North America, Europe and the Pacific Rim, with two, eight and seven active stations respectively, as in September 2006.

Calibration of the stations is obviously critical and to date there have been five campaigns using a portable Ku-band calibration system in Europe and North America, but none in the Pacific Rim region. An X-band calibration system, which uses military satellites, has been circulated seven times in the European and North American regions. The BIPM has been circulating a GPS-based calibration up to three times per year in recent years.

The TWSTFT cooperation is now at a critical stage because of a notification received from INTELSAT in March 2006 saying that further TWSTFT activity on INTELSAT satellites must be on a fully commercial basis. Dr Parker of NIST has negotiated a five year contract with INTELSAT giving the North American and European regions access to three satellite transponders on a non-pre-emptible basis. The cost of this contract has been met by NIST and PTB, and these organizations are discussing an appropriate basis for sharing these costs with participating stations.

Future tasks for the working group include the establishment of improved links between the TWSTFT regions, in particular with the Pacific Rim region. In addition, there is scope for improving the performance of TWSTFT using carrier-phase techniques.

The President thanked Dr Klepczynski and the working group for their contributions, and for their part in the negotiation of the new contract with INTELSAT.

6.2 Calibration of GPS equipment at the BIPM

The President invited Dr Lewandowski to present this report.

Dr Lewandowski began by saying that the BIPM Time, Frequency and Gravimetry section is now using new combined geodetic/timing systems for its calibration campaigns. These systems were developed by the Astrogeodynamical Observatory of Poland in collaboration with the BIPM, and generate CA, P1, P2, P3, CGGTTS and RINEX output products.

Six calibration campaigns have been completed since 2004 and, to date, the GPS equipment of 20 out of the 50 laboratories contributing to TAI has been calibrated. In the remainder of 2006 10 more laboratories are scheduled for calibration.

Some of the above laboratory calibrations have involved a differential (GPS-TWSTFT) calibration of TWSTFT equipment, in which 1 σ uncertainties of less than 1 ns have been achieved.

The results of these calibration campaigns are presented in Section 6 of BIPM *Circular T*.

Dr Lewandowski concluded by saying that the BIPM will continue GPS/GLONASS calibration campaigns, and will also continue to assist Regional Metrology Organizations (RMOs) in organizing regional campaigns.

Dr Palacio commented that the BIPM campaigns are not key comparisons, but are instead key calibrations. He suggested that the BIPM should encourage RMOs to conduct these calibrations, and that the BIPM should give the RMOs guidance on procedures for these campaigns to ensure comparability of the results.

The President asked for comments on Dr Palacio's views. Dr Arias said that there is an ongoing discussion within the CCTF Working Group on the MRA regarding whether a calibration campaign should have the status of a supplementary comparison. Dr de Jong added that one of the tasks of that working group is to establish methods for incorporating the results of RMO calibration activities into BIPM processes.

Dr Fisk drew the attention of the CCTF to the report from NMIA (CCTF/06-32), which has as an appendix a report on an APMP calibration campaign coordinated by NMIA and TL Chinese Taipei.

The President remarked on the large amount of work required to evaluate* the uncertainties listed in *Circular T* and thanked the BIPM Time, Frequency and Gravimetry section and contributing laboratories for this effort.

The President then asked Dr Petit to continue the BIPM GPS/GLONASS calibration report with a presentation on the calibration of geodetic receivers.

Dr Petit said that 25 laboratories are operating dual-frequency geodetic GPS receivers. Most of these receivers are of the Ashtech Z12T type, but an increasing number of Septentrio PolaRx2 and Topcon Euro-80 receivers are in use.

The BIPM Time, Frequency and Gravimetry section mainly uses an Ashtech Z12T receiver as a travelling P3 calibration system, and is starting to use a Septentrio PolaRx2 receiver since the Ashtech receiver is no longer commercially available.

Both receivers produce C/A, P1, P2, L1 and L2 output data, and can synchronize their internal time scales to an external 1 pps input signal. They also accept an external 10 MHz or 20 MHz reference frequency.

Several years of experience with the Ashtech Z12T as a travelling calibration receiver has shown that a consistency of between 1 ns and 2 ns is possible, but that care must be taken to ensure that the same internal setup of the receiver is maintained throughout the calibration campaigns.

The other, non-Ashtech, systems operated by several laboratories are also being used for calculating timing links but, due to possible internal operational differences in these receivers, further tests are needed to check the consistency of these links.

Dr Petit concluded by emphasizing the importance of laboratories operating geodetic receivers maintaining consistent internal setups.

* The algorithm for calculating the uncertainties has been published in *Metrologia* (CCTF/06-31).

The President remarked that it is expensive for the BIPM to maintain a range of state-of-the-art geodetic receivers for study and calibration, and congratulated the BIPM Time, Frequency and Gravimetry section for this work.

Dr Matsakis asked if the results from GPS C/A calibration campaigns were consistent with results from P3 campaigns. Dr Petit replied that calibration results are generally consistent regardless of the equipment used. Dr Lewandowski added that in the past there were some consistency problems but these have reduced as understanding of the receivers improved.

6.3 Report of the IGS activities and Working Group on Clock Products

The President invited Dr Dow to present this report.

Dr Dow began with an overview of the activities of the IGS. The IGS became an official service of the International Association of Geodesy in January 1994. The IGS facilitates the pooling of the limited resources of many (now about 200) organizations recording GNSS data to establish an independent GNSS ground segment which generates high accuracy products. This work is done on a "best effort" basis, achieving reliability through redundancy.

The IGS product set includes precise space vehicle orbits, clock corrections, sub-centimetre ground positioning, input to the ITRF reference frame, ionospheric maps and tropospheric corrections.

The IGS Working Group on Clock Products arose from the very successful joint IGS/BIPM Pilot Project on GNSS timing observations which operated between 1998 and 2002. The IGS ground network now includes a considerable number of Cs clocks and hydrogen masers, allowing the creation and maintenance of a timescale (IGS Time) more stable than that provided by the GPS satellites. Both final and rapid time scale products are now being generated by the IGS Clock Product Coordinator.

The IGS has been pursuing three key strategic goals between 2002 and 2007:

- delivery of world class GPS and other GNSS products,
- pursuit of new opportunities, including real time products, exploitation of Low Earth orbit satellites and new GNSS developments, and
- continuous improvement of the effectiveness of the IGS organization.

A new strategic planning exercise for 2008-2012 is in progress.

Dr Dow concluded by saying that the IGS looks forward to continuing its fruitful collaboration with the global timing community represented by the CCTF.

Dr Levine said that it would be helpful if the IGS could develop systems to help timing laboratories evaluate GNSS data processing software. Possible examples could include provision of test data sets. Dr Dow replied that diversity of software is one of the strengths of IGS and he would be glad to discuss this possibility further.

The President then invited Dr Senior to continue the IGS report with a presentation entitled "Report of the IGS Clock Products Working Group" (CCTF-06/35).

Dr Senior began by saying that there are presently seven IGS analysis centres contributing to clock products and 175 stations contributing data referenced to a total of 54 hydrogen masers, 32 Cs standards and 27 Rb standards. Twenty-five of these stations are co-located with timing laboratories.

Data from these co-located stations has been used to calculate IGS Time since 2001, which has a stability of 1 part in 10^{15} at averaging times of one day. The stability degrades over longer averaging times due to steering to GPS time. IGS Time was officially adopted in 2003 as the reference time scale for IGS rapid and final clock products.

A new timescale planned for 2006-2007 and its calculation algorithm will take better advantage of the performance of the Cs standards and hydrogen masers in the IGS network.

At present, the geodetic receivers at IGS stations co-located with timing laboratories are calibrated by estimation based on IGS clock products and BIPM's *Circular T*. The results are considered good to within about 2 ns.

Dr Senior said that Version 3 of the RINEX clock data format is now being developed and invited input from the timing community regarding ways to make it better serve its needs.

Dr Senior concluded by saying that software for processing timing data, known as Clock Analysis Visualisation and Archiving Software (CANVAS), is available on the IGS website and invited interested workers to contribute to its further development.

Dr Tavella asked if the new IGS time scale would be steered to UTC instead of GPS time. Dr Senior replied that it would be steered to UTC, and said that the IGS plans to improve the calibration of IGS stations co-located with timing laboratories to achieve this. He added that all historical data would be reanalyzed using the new time scale.

The President thanked Dr Dow and Dr Senior for the IGS reports. He then reminded the CCTF of the recent passing of Dr Len Cutler and referred to his many technical contributions and proposed that the BIPM prepare a letter of appreciation to be sent to Mrs Cutler, signed by members of the CCTF. This was agreed and done.

6.4 Report of the Working Group on GNSS time transfer standards (CGGTTS)

The President invited Dr Levine to present this report (CCTF-06/18).

Dr Levine began by saying that several proposals for the consideration of the CCTF were finalized by the working group at its most recent meeting on 10 September 2006.

The first two proposals were for minor changes to the CGGTTS data reporting format. These changes are intended to facilitate the inclusions of GNSS systems other than GPS in the reporting format, and to accommodate 3 digit space vehicle identification numbers. The changes were designed to maintain maximum compatibility with existing data processing software.

The working group has also been studying the type B uncertainties of CGGTTS data, since the recent successful receiver calibration campaigns have reduced the type A uncertainties to levels typically below the type B uncertainties.

Dr Levine said that multipath effects on GPS signals result in timing variations which repeat from day to day, with the normal 4 minute shift due to the precession of the GPS satellite orbits. The traditional 13 minute track averaging time is not always sufficient to average out the multipath variations, resulting in an apparent time bias which can easily be confused with a shift in the receiver delay calibration.

Dr Levine has developed an algorithm to identify and remove these multipath-related biases, and a reduction of the type B uncertainty in the GPS link between the NIST Boulder and Fort Collins facilities from about 3 ns to 1.5 ns was demonstrated. The algorithm uses short satellite track averaging times, among other innovations.

Dr Levine reminded the CCTF that the 13 minute track length was chosen in the 1980s due to limitations of contemporary GPS receivers, and proposed that shorter track lengths be considered, perhaps 15 s or 30 s. He noted that while 15 s is compatible with existing technical directives, 30 s is compatible with current geodetic receivers.

The working group also proposed that:

- the CCTF encourage stability in the definitions of the signals to be transmitted by the Galileo system, since changes in signals cause difficulties for receiver designers,
- the CCTF encourage studies of the statistics of Galileo signals in order to develop directives for processing of timing data, and that the reporting format should be the same as for other GNSS systems, and
- the CCTF encourage the use of the most recent ionospheric model in single frequency timing receivers, since different ionospheric models may be transmitted simultaneously by different GNSS systems.

Dr Levine concluded by proposing that, due to the increasing number of GNSS systems becoming available in the next few years, the existing CGGTTS should be replaced with short term working groups to study specific questions, and that these working groups should have specific membership and terms of reference. These proposals are combined in a draft recommendation to the CIPM (CCTF/06-29).

Dr Lewandowski said that although he agreed that specific issues could be addressed effectively by small groups, he believes that these should be overseen by the CGGTTS. Dr Arias supported Dr Lewandowski and proposed that appropriate study groups be established as is done by the CCTF Working Group on TAI.

Dr Levine accepted these views, but stressed the need for clear and updated terms of reference for the CGGTTS. The President commented that formation of study groups is appropriate and is at the discretion of working group chairs. He then asked Dr Levine to continue as Chair of the CGGTTS and to ensure that its activities encompass frequency transfer. Dr Levine agreed to this request.

6.5 High precision time transfer

The President asked Dr Tuckey to report on recent developments in high precision time transfer.

Dr Tuckey said that ESA and OCA have jointly developed a two-way time transfer method known as T2L2, which is based on optical signals. The method will be tested using the JASON satellite, to be launched in 2008. The satellite horizon-to-horizon transit time will be about 1000 s and in the common-view mode the projected stability using JASON is between 1 ps and 2 ps, with an accuracy of 100 ps. The performance in the non-common view mode will be limited by the stability of the clock on board the satellite. The time transfer signal structure is not yet well defined, but proposals will be presented at the EFTF meeting in Geneva in 2007, with the objective of setting up collaborations.

7 REPORT ON SPACE-TIME REFERENCES AND GENERAL RELATIVITY

Report on the IERS Conventions Product Centre

The President asked Dr Petit to present this report.

Dr Petit began by saying that since 2001 Dr Arias and Dr Petit of the BIPM, and Dr Luzum and Dr McCarthy of the USNO, have been serving as the Conventions Centre of the IERS.

In 2004 Dr McCarthy and Dr Petit published a 128 page book entitled "*IERS Conventions* (*2003*)" and they also maintain related web pages and a discussion forum on the BIPM website.

Dr Petit and Dr McCarthy are working with the Advisory Board for the *IERS Conventions* Update, chaired by Dr Ray, to keep the book up to date. An editorial board will be established when the next edition, which will include explanatory supplements, is closer to publication.

Dr Petit concluded by announcing the possibility of a workshop on conventions being held at the BIPM towards the end of 2007.

8 CLOCKS IN SPACE

The President invited Prof. Clairon to report on the latest developments in the PHARAO cold atom Cs space clock project.

Prof. Clairon said that the PHARAO engineering model is now complete and was delivered to the French space agency CNES at the beginning of 2006. Delivery of the complete Atomic Clock Ensemble in Space (ACES) engineering model is expected in 2007 and launch of the ACES package for installation on the International Space Station is scheduled in 2010.

9 FUTURE GLOBAL NAVIGATION SATELLITE SYSTEMS

The President said that no contributions under this agenda item had been proposed.

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

Report of the CCTF Working Group on the MRA

The president invited Dr de Jong to present this report (CCTF/06-16).

Dr de Jong said that the Working Group on the MRA was established by the 14th CCTF in 1999, and in 2001 the 15th CCTF decided to define the computation of TAI and UTC as the key comparison for time, designated CCTF-K2001.UTC, with UTC as the reference value. The

CCTF Working Group on the MRA worked closely with the BIPM with the result that uncertainties were included in *Circular T* for the first time in 2005.

Dr de Jong said that about 40 laboratories now have [*UTC* - *UTC*(*k*)] published in Appendix B of the BIPM key comparison database (KCDB), and that there are 19 fully accepted Calibration and Measurement Capabilities (CMCs) for time and frequency in the KCDB (Appendix C). More are in preparation. He noted that not all laboratories steer their UTC(k) timescales within the recommended 100 ns tolerance of UTC.

Dr de Jong requested that the BIPM publish the guidelines prepared by the working group (guidelines 1, 2 and 3) regarding the classification of measurements and estimation of uncertainties. Dr Thomas suggested that these should be published on the JCRB website, since this is where people look for guidance on CMCs. It was agreed that this would be done.

Dr de Jong noted that the working group has several tasks in the immediate future, including developing guidelines and procedures to support RMO calibration activities and to transform the results into formal supplementary comparisons.

Dr de Jong pointed out that the terms of reference for the working group have not changed since 2001, and proposed that the terms of reference be updated to include:

- authority to take all actions required by the MRA between meetings of the CCTF,
- authority to act as the point of contact for the BIPM and the JCRB on MRA matters relating to the CCTF,
- authority to coordinate activities related to the CCTF between RMOs and to develop guidelines and procedures necessary to implement key comparisons and supplementary comparisons, and
- a requirement to report on actions taken and decisions made to the next CCTF meeting so that the CCTF may then revise the decisions if it considers it necessary.

In conclusion, Dr de Jong said that since he is now retired from NMi VSL, he would step down as Chair of the working group, and he thanked its members and the CCTF for their support.

The President thanked Dr de Jong for the report and said that a new Chair would be appointed according to the rules of the CIPM. He remarked that the changes to the terms of reference are not major, and that the present activities of the working group already reflect the proposed changes. He asked Prof. Wallard and Dr Thomas for their opinions, and both agreed to the changes, which were confirmed by the CCTF.

Dr Dudle proposed that a key comparison in frequency should be established, with its reference value defined as the reciprocal of the scale unit of UTC. Dr de Jong replied that this task was well in hand, that algorithms have been developed, and that the degree of equivalence for the key comparison for frequency could be derived from the existing key comparison for TAI and UTC.

Dr O'Brian expressed concern that steering of UTC(k) would show up as a frequency offset. Dr de Jong replied that the frequency change corresponding to the steering should be included in the CMC frequency uncertainty and consequently the steering should not result in a significant frequency excursion.

Dr Parker asked if uncertainties will be published for the key comparison for frequency, and Dr de Jong said that they would be.

Dr Dudle said that the letters "K2001" in CCTF-K2001.UTC create confusion in that they are sometimes interpreted as a date, and that laboratories which were not contributing data to TAI in 2001 have been prevented by some reviewers from posting CMCs. Dr Thomas replied that removing the "2" from "2001" can be done if the CCTF wishes. It was agreed that this should be done, so that the key comparisons for time and frequency are now called CCTF-K001.UTC and CCTF.K002.FREQ, respectively.

Dr Arias observed that the CCTF had agreed in principle to the new key comparison for frequency, and said that the BIPM Time, Frequency and Gravimetry section would work with the working group to implement it.

11 BIPM WORK PROGRAMMES FOR THE YEARS 2007-2008 AND 2009-2012

The President invited Dr Arias to address the CCTF on this agenda item.

Dr Arias began by saying that the BIPM Time, Frequency and Gravimetry section had no major new activities to announce, and that the section is driven by the trends in time and frequency metrology and the wishes of the CCTF.

Dr Arias said that in 2006-2007 the section's activities would include:

- calibration of single and dual frequency GPS time transfer equipment,
- study of new equipment on the market and development of procedures for calibration,
- introduction of GLONASS links into TAI and the related calibration issues,
- implementation of the AIV data processing method endorsed by this meeting of the CCTF,
- inclusion of GNSS carrier-phase and Precise Point Positioning in TAI time links as a result of endorsement by this meeting of the CCTF,
- continuation of work on TWSTFT and continued inclusion of TWSTFT links in TAI time links,
- study of the problem of including Galileo links into TAI – this will need additional staff resources, or a reprioritisation of tasks to free up existing staff,
- continuation of work to improve the accuracy of TAI with assistance from the Working Group on Primary Frequency Standards, and by taking advantage of new standards as they become available,
- continuation of work to understand better the behaviour of atomic fountains,
- study of the manner in which data from the new secondary realizations of the second endorsed by this meeting of the CCTF should be reported to the BIPM and how the data will be included in TAI, and
- establishment of the key comparison for frequency endorsed by this meeting of the CCTF.

Dr Arias said that although she was not in a position to give specific details of the longer term (2009-2012) work plan to be presented to the CIPM by the section, the activities would be based on present activities with extensions to take advantage of future GNSS systems and an increasing number of highly accurate microwave and optical frequency standards.

The President thanked Dr Arias for the report and extended his best wishes to the section. He also asked Prof. Wallard to bear in mind the importance of these activities when planning the BIPM's budget.

In response, Prof. Wallard said that the BIPM is preparing three documents for the CGPM in November 2007:

- a document discussing the possibility of redefining a number of SI base units,
- the work programme of the BIPM approved by the CIPM,
- a document approved by the NMIs Directors' Meeting detailing all activities of the BIPM, their justification and their deliverables, and proposing corresponding resource increases. This document will be placed on the BIPM website so that NMI directors can encourage their governments to support the activities. Resource increases will be proposed. Prof. Wallard encouraged members of the CCTF to consider and support this document as it applies to CCTF activities.

12 RECOMMENDATIONS AND DECLARATIONS

The President noted that six recommendations (Recommendations CCTF 1 (2006) to CCTF 6 (2006)) and one declaration (Declaration CCTF 1 (2006)) were discussed during this meeting of the CCTF. These were discussed one further time under this agenda item, and after some minor amendments all were agreed. In some cases, the BIPM was asked to finalize the wording where this did not affect the intent of the recommendations.

DECLARATION CCTF 1(2006)
Re-organization of the CCTF Working Group on International Atomic Time (TAI)

The Consultative Committee for Time and Frequency (CCTF),

considering that

- in 1985 the Consultative Committee for the Definition of the Second (CCDS) formed a Working Group on TAI composed mostly of representatives of international organizations,
- the terms of reference and membership of this working group corresponded to the needs and expectations at that time,
- the practice for this working group has been to work in close collaboration with the laboratories contributing to TAI,
- this working group regularly organized meetings of the laboratories contributing to TAI, stimulating discussion and providing guidance for the improvement of TAI;

declares that the terms of reference for the Working Group on TAI be updated and the membership enlarged so that they become as follows:

The CCTF Working Group on TAI is composed of:

a) a representative of each of the following organizations:

- International Astronomical Union (IAU),
- International Committee for Weights and Measures (CIPM),
- International Union of Geodesy and Geophysics (IUGG),

- International Union of Radio Science (URSI),
- International Telecommunication Union, Radiocommunication Sector (ITU-R),

b) the Director of the BIPM,

c) the individual responsible for TAI at the BIPM, and

d) representatives of the laboratories contributing to TAI.

An expert from an organization or a laboratory contributing to TAI is appointed by the CCTF President as Chair of the working group. The period of this Chairmanship covers two consecutive meetings of the CCTF and may be renewed.

The mandate of the working group is as follows:

a) to examine the remarks and requirements expressed by the users of the service of TAI,

b) to prepare guidelines for the improvement of the service of TAI and to report on these to the CCTF, and

c) to establish temporary *ad hoc* study groups to analyse some specific problems, whenever necessary; these study groups should report to the working group.

The said mandate should extend equally to Coordinated Universal Time UTC, in respect of its metrological qualities but not in its definition nor in its astronomical content.

The working group should work routinely by correspondence addressed to its President, and it should meet, if possible annually, at the request of its President.

The Working Group on TAI should work closely with all the other CCTF working groups to harmonize the overall contributions to TAI.

The BIPM provides the permanent secretariat for the working group.

Dr Koshelyaevsky presented an additional draft recommendation concerning unification of the reference frames of GNSSs. The document recommended that authorities responsible for operating and developing GNSSs use internationally-adopted time and geodesy reference frames and methods for computation of corrections.

The President remarked that he was not sure that appropriate international standards existed. Dr Levine said that such standardization would be helpful but is presently impractical, since Galileo developers, for example, are unlikely to adopt GPS time as their reference time scale.

Dr McCarthy said that although he accepts the present impracticality of the proposal, the draft recommendation would nevertheless encourage motion in the right direction and would not be harmful.

Dr Steele said that although Galileo is likely to adopt a realization of ITRF he thought it unlikely that the operators of GLONASS would do so.

Prof. Wallard suggested that since the recommendation was presented so late in the present meeting, the CCTF should consider it at the next meeting.

The President summarized the discussion by saying that although there is a consensus that such a recommendation might be helpful, there is insufficient time to refine it at this meeting. He proposed that the CCTF ask the BIPM to work with Dr Beard and Dr Koshelyaevsky to produce a document and a covering letter addressing the issues in the proposed recommendation. Dr Beard suggested that the letter be sent to the ITU and similar organizations. This course of action was agreed.

13 OTHER BUSINESS

Dr Arias said that Dr Thomas had requested that the CCTF provide a small group of people to work with the BIPM in revising Appendix 2 (concerning time) of the SI Brochure, which is published on the BIPM website. The President and Dr Bauch volunteered for this task.

Prof. Wallard said that the BIPM Time, Frequency and Gravimetry section has had very successful collaborations with many laboratories, and encouraged laboratories to consider allowing a staff member to work with the BIPM for a period of time.

Prof. Wallard also reported that the BIPM had received a request that a semi-commercial laboratory in Sweden be allowed to contribute to TAI. He asked if the CCTF had any objections to the BIPM accepting this request.

Dr McCarthy asked if the laboratory in question was in full compliance with all requirements and previous recommendations regarding laboratories contributing to TAI. Dr Arias replied that she was doubtful since this is a private laboratory, and added that the BIPM does not accept requests for participation in TAI from laboratories other than NMIs unless the laboratory's request is supported by the NMI of the country concerned. Prof. Wallard said that he believed the request under discussion was fully supported by the Swedish NMI, but he would re-check this.

The President announced that following the upcoming meeting of the CIPM he would be retiring from his activities in the CIPM and the CCTF. Prof. Wallard thanked the President for his work, saying that he has made enormous contributions to the BIPM and metrology over many years. He invited the CCTF to join him in thanking the President for his contributions.

The President closed the meeting at 5:30 pm, thanking the delegates and wishing them a safe journey home. He warmly thanked the rapporteur, Dr Fisk, for his work.

P. Fisk, *Rapporteur*

November 2006

Recommandations du Comité consultatif du temps et des fréquences

présentées au Comité international des poids et mesures

RECOMMANDATION CCTF 1 (2006) :
Valeurs recommandées des fréquences étalons destinées à la mise en pratique de la définition du mètre et aux représentations secondaires de la seconde

Le Comité consultatif du temps et des fréquences (CCTF),

considérant

- la proposition exprimée dans la Recommandation CCL 2 (2005), lors de la 12e session du Comité consultatif des longueurs (CCL),
- la possibilité de réaliser des mesures de fréquence directes et exactes au moyen du peigne à impulsions femtosecondes,
- la réduction continue des incertitudes associées aux étalons de fréquence,
- qu'en matière d'exactitude requise, les besoins sont différents, tant pour la communauté de la métrologie des longueurs représentée par le CCL d'une part, que pour satisfaire aux critères de choix des représentations secondaires de la seconde définis par le CCTF d'autre part ;

recommande que

- le Groupe de travail du CCL sur la mise en pratique de la définition du mètre et le Groupe de travail commun au CCL et au CCTF sur les représentations secondaires de la seconde soient fusionnés en un seul groupe de travail commun au CCL et au CCTF sur les étalons de fréquence,
- la liste des radiations recommandées par le Groupe de travail du CCL pour la mise en pratique de la définition du mètre et la liste des représentations secondaires de la seconde du CCTF soient fusionnées dans une seule liste de « valeurs recommandées des fréquences étalons destinées à la mise en pratique de la définition du mètre et aux représentations secondaires de la seconde »,
- d'autres fréquences soient proposées, évaluées et ajoutées à la liste des fréquences étalons, par le groupe de travail commun au CCL et au CCTF sur les étalons de fréquence, sans qu'elles soient nécessairement approuvées comme radiations préférées par le CCL ou comme représentations approuvées par le CCTF,
- le CCTF examine et recommande les fréquences qu'il propose au CIPM d'approuver comme représentations secondaires de la seconde,
- le CCL examine et recommande les fréquences qu'il considère comme importantes pour la métrologie des longueurs d'exactitude élevée, et
- la liste des valeurs des fréquences soit maintenue sur le site Web du BIPM.

RECOMMANDATION CCTF 2 (2006) :
Au sujet des représentations secondaires de la seconde

Le Comité consultatif du temps et des fréquences (CCTF),

considérant

- qu'une liste commune de « valeurs recommandées des fréquences étalons destinées à la mise en pratique de la définition du mètre et aux représentations secondaires de la seconde » est à établir,
- que le Groupe de travail commun au Comité consultatif des longueurs (CCL) et au CCTF sur les représentations secondaires de la seconde, lors de sa réunion au BIPM en septembre 2005, a discuté des fréquences des radiations candidates potentielles en vue de leur inclusion dans la liste des représentations secondaires de la seconde,
- que le Groupe de travail commun au CCL et au CCTF a examiné et mis à jour les valeurs des fréquences des transitions de l'ion de mercure (Hg), de l'ion de strontium (Sr), de l'ion d'ytterbium (Yb) et de l'atome neutre de strontium lors de sa session de septembre 2006,
- que le CCTF avait déjà recommandé dans sa Recommandation CCTF 1 (2004) la fréquence de la transition quantique hyperfine non perturbée de l'état fondamental de l'atome de ^{87}Rb comme représentation secondaire de la seconde,

recommande que les fréquences des transitions suivantes soient utilisées comme représentations secondaires de la seconde et soient intégrées à la nouvelle liste des « valeurs recommandées des fréquences étalons destinées à la mise en pratique de la définition du mètre et aux représentations secondaires de la seconde »

- la transition quantique hyperfine non perturbée de l'état fondamental de l'atome de ^{87}Rb, à la fréquence de $f_{^{87}\mathrm{Rb}}$ = 6 834 682 610,904 324 Hz, avec une incertitude-type relative estimée de 3×10^{-15},
- la transition optique non perturbée 5s $^2S_{1/2}$ – 4d $^2D_{5/2}$ de l'ion de $^{88}Sr^+$, à la fréquence de $f_{^{88}\mathrm{Sr}^+}$ = 444 779 044 095 484 Hz, avec une incertitude-type relative estimée de 7×10^{-15},
- la transition optique non perturbée 5d^{10} 6s $^2S_{1/2}$ (F = 0) – 5d^9 6s^2 $^2D_{5/2}$ (F = 2) de l'ion de $^{199}Hg^+$, à la fréquence de $f_{^{199}\mathrm{Hg}^+}$ = 1 064 721 609 899 145 Hz, avec une incertitude-type relative estimée de 3×10^{-15},
- la transition optique non perturbée 6s $^2S_{1/2}$ (F = 0) – 5d $^2D_{3/2}$ (F = 2) de l'ion de $^{171}Yb^+$, à la fréquence de $f_{^{171}\mathrm{Yb}^+}$ = 688 358 979 309 308 Hz, avec une incertitude-type relative estimée de 9×10^{-15},
- la transition optique non perturbée 5s^2 $^1S_0$ – 5s 5p $^3P_0$ de l'atome neutre de ^{87}Sr, à la fréquence de $f_{^{87}\mathrm{Sr}}$ = 429 228 004 229 877 Hz, avec une incertitude-type relative estimée de $1{,}5 \times 10^{-14}$.

RECOMMANDATION CCTF 3 (2006) :
Au sujet de l'utilisation des mesures de l'unité d'échelle du Temps atomique international (TAI)

Le Comité consultatif du temps et des fréquences (CCTF),

considérant que

- le nombre d'étalons primaires de fréquence délivrant des mesures de l'unité d'échelle du Temps atomique international (TAI) a augmenté de manière significative et devrait continuer à augmenter,
- dans l'avenir, les représentations secondaires de la seconde du SI devraient aussi délivrer des mesures de l'unité d'échelle du TAI,
- la Recommandation CCTF 2 (2004) fournit des directives pour déclarer ces mesures et recommande que le Groupe de travail pour l'expression des incertitudes des étalons primaires de fréquence (aujourd'hui nommé Groupe de travail sur les étalons primaires de fréquence) examine l'utilisation qui est faite de toutes les mesures déclarées provenant d'étalons primaires de fréquence,
- les premières mesures provenant d'un nouvel étalon primaire de fréquence peuvent montrer des écarts de fréquence excessifs qui tendent à disparaître quand on acquiert davantage d'expérience avec cet étalon et avec la procédure de transfert de fréquence,
- les étalons primaires de fréquence subissent parfois des modifications entraînant un changement significatif de leurs caractéristiques et des incertitudes correspondantes ;

recommande que

- le BIPM fournisse au Groupe de travail sur les étalons primaires de fréquence les premiers rapports de mesures des nouveaux étalons, ainsi que ceux des étalons de fréquence dont l'incertitude a changé de manière appréciable,
- l'utilisation et la publication consécutive de ces rapports dans la *Circulaire T* soit retardée afin de permettre au Groupe de travail sur les étalons primaires de fréquence de faire ses commentaires, et qu'ensuite la publication soit soumise à la décision mutuelle du laboratoire concerné et du BIPM, et
- la stabilité de fréquence à long terme d'un nouvel étalon de fréquence par rapport au TAI soit évaluée pendant plusieurs mois avant de soumettre le premier rapport et que les données correspondantes soient incluses dans ce rapport.

RECOMMANDATION CCTF 4 (2006) :
Au sujet de l'utilisation des techniques de mesure de la phase de la porteuse du Global Navigation Satellite System (GNSS) pour les comparaisons de temps et de fréquence du Temps atomique international (TAI)

Le Comité consultatif du temps et des fréquences (CCTF),

reconnaissant que

- les étalons atomiques de fréquence ont atteint une précision et une exactitude sans précédent et que de nouvelles et rapides avancées dans ce domaine sont prévisibles,
- la capacité à comparer ces étalons pour la réalisation du Temps atomique international (TAI) est déjà limitée par l'exactitude et la précision des systèmes actuels de comparaison de temps ;

comprenant la nature complémentaire des différentes techniques de comparaison de temps et de fréquence et les différentes formes sous lesquelles chaque technique peut fournir des données ;

notant que

- des techniques de mesure de la phase de la porteuse du GNSS ont été mises au point, qui sont utilisées de manière courante pour les comparaisons de temps et de fréquence avec une précision obtenue en moins d'un jour jamais encore atteinte par aucune autre technique à longue distance,
- les coûts associés à l'acquisition, à l'installation, à la mise en œuvre et à la maintenance des équipements sont inférieurs au prix d'achat d'un seul étalon primaire de fréquence à césium,
- plusieurs institutions sont volontaires pour traiter les données,
- de nombreux algorithmes prometteurs sont disponibles ou en cours de mise au point ;

considérant aussi que le manque de stabilité des équipements actuels pour les comparaisons de temps reste préoccupant à un niveau de précision de l'ordre de la nanoseconde,

recommande que

- les laboratoires participant au TAI envisagent d'acquérir des récepteurs géodésiques de pointe du temps du GNSS,
- les institutions qui produisent actuellement des solutions de routine établissent des programmes pour traiter les données de tous les laboratoires de temps qui veulent bien participer et qui répondent aux exigences exprimées dans la documentation,
- le Bureau international des poids et mesures (BIPM), dans un esprit très coopératif, produise ses propres solutions, les mette gratuitement à la disposition d'autrui, et les ajoute à sa base de données de mesures de temps,
- le BIPM commence à préparer des logiciels et des techniques pour l'introduction de ces résultats dans les calculs publiés dans la *Circulaire T*,
- le BIPM entreprenne de collecter toutes les informations disponibles sur les étalonnages des récepteurs géodésiques des laboratoires participants, et que

- le Comité international des poids et mesures assure les ressources nécessaires au BIPM pour mettre en œuvre ces recommandations.

RECOMMANDATION CCTF 5 (2006) :
Amélioration des comparaisons de temps utilisant le Global Navigation Satellite System (GNSS)

Le Comité consultatif du temps et des fréquences (CCTF),

considérant que

- les données des satellites du Global Positioning System (GPS) jouent un rôle important dans les comparaisons de temps et de fréquence,
- les autres systèmes satellitaires comme Galileo ou GLONASS prendront de plus en plus d'importance dans les comparaisons de temps et de fréquence dans l'avenir,
- les incertitudes actuelles dans l'étalonnage des équipements des laboratoires de temps limitent de manière significative les comparaisons internationales de temps en général et l'exactitude du calcul du Temps atomique international en particulier ;

recommande que

- les directives techniques pour présenter les données de ces systèmes soient modifiées afin d'inclure les données provenant de différents systèmes dans le même fichier, de la manière précisée en annexe,
- les laboratoires de temps travaillent à améliorer l'étalonnage des équipements de comparaison de temps et à réduire la contribution aux incertitudes de type B des récepteurs, ce qui comprend :
  - des équipements pour lesquels l'effet des fluctuations de la température ambiante et de l'humidité est réduit,
  - des antennes et des câbles pour lesquels l'effet des réflexions mulitples et des effets similaires est réduit.

Annexe :

Le changement minimal recommandé pour le moment est d'ajouter une lettre unique juste après le « PRN number » dans la colonne qui est actuellement vide. Cette lettre de l'alphabet en majuscule identifiera le type de système satellitaire. La lettre sera conforme aux spécifications de l'International GNSS Service (IGS). Si l'IGS n'a fait aucune recommandation, une lettre sera assignée par le Groupe de travail du CCTF sur la normalisation des comparaisons d'horloges utilisant le GPS et le GLONASS (CGGTTS), en consultation avec le BIPM. Les lettres recommandées à l'heure actuelle sont :

- G ou un espace pour le GPS,
- E pour Galileo,
- S pour un système à augmentation géostationnaire,
- R pour GLONASS.

RECOMMANDATION CCTF 6 (2006) :
Coordination de la mise au point de techniques avancées de comparaison de temps et de fréquences

Le Comité consultatif du temps et des fréquences (CCTF),

reconnaissant

- la disponibilité d'horloges, en hyperfréquence, à atomes refroidis, de haute qualité,
- l'amélioration rapide des étalons de fréquence optique dans les différents laboratoires,
- le besoin imminent de comparer, à distance, ces horloges à des niveaux d'exactitude et de stabilité impossibles à réaliser pour le moment, et

considérant que

- parmi les différents moyens techniques de comparaison, les liaisons par fibre optique, les étalons de fréquence optiques transportables, les liaisons optiques par satellite et les liaisons hyperfréquence ont été identifiés comme pouvant être utiles à cet effet,
- les améliorations des comparaisons de temps et de fréquence auraient des applications majeures pour l'évaluation des performances des étalons de fréquence actuels et contribueraient aux progrès des futurs étalons de fréquence primaires et des horloges,
- l'amélioration de la réalisation du Temps universel coordonné, qui en découle, serait bénéfique pour les applications à venir dans de nombreux domaines des sciences et des techniques ;
- un nouveau groupe de travail pour coordonner la mise au point de techniques avancées de comparaison de temps et de fréquences, composé d'experts de différents domaines, comme la métrologie des fréquences optiques, la génération des échelles de temps, et les comparaisons de temps et de fréquence, a été établi, afin de traiter et de coordonner ces questions ; et

recommande que

- la communauté du temps et des fréquences poursuive activement ces études de manière coordonnée,
- le BIPM continue à faciliter les activités des différents groupes de travail du CCTF et établisse les interactions nécessaires avec les autres organisations concernées, parmi lesquelles l'International GNSS Service (IGS), l'Union géodésique et géophysique internationale (UGGI), l'Union internationale des télécommunications (UIT), l'Union radioscientifique internationale (URSI),
- les organisations scientifiques nationales et internationales et les agences spatiales prennent en compte ces travaux comme il convient,
- les gouvernements nationaux et les organisations internationales assurent le financement nécessaire au développement de ces activités.

Recommendations of the Consultative Committee for Time and Frequency

submitted to the International Committee for Weights and Measures

RECOMMENDATION CCTF 1 (2006): Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second

The Consultative Committee for for Time and Frequency (CCTF),

considering

- the proposal expressed by the 12th Consultative Committee for Length (CCL) meeting in its Recommendation CCL 2 (2005),
- the realization of direct and accurate frequency measurements made possible by the femtosecond laser comb,
- the steady reduction in uncertainties associated with frequency standards,
- the differing accuracy requirements of the CCL length metrology community and the CCTF criteria for secondary representations;

recommends that

- the CCL *Mise en Pratique* Working Group and CCL/CCTF Joint Working Group be combined into a single CCL-CCTF frequency standards working group,
- the *Mise en Pratique*-CCL list of recommended radiations and CCTF secondary representation list be combined into a single new list of "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second",
- other frequencies may be proposed, evaluated and maintained on the frequency standards list by the CCL-CCTF Frequency Standards Working Group, not all of which are adopted as CCL-preferred radiations or CCTF-accepted representations,
- the CCTF consider and recommends those frequencies which it proposes the CIPM to accept as secondary representations of the second,
- the CCL consider and recommend those frequencies which it deems important for use in high accuracy length metrology, and
- the frequency values list is maintained on the BIPM website.

RECOMMENDATION CCTF 2 (2006)
Concerning secondary representations of the second

The Consultative Committee for Time and Frequency (CCTF),

considering that

- a common list of "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second" shall be established,
- the CCL/CCTF Joint Working Group (JWG) on the *Mise en Pratique* of the Definition of the Metre and the Secondary Representations of the Second in its meeting at the BIPM in September 2005 discussed possible candidates to be included in this list for secondary representations of the second,
- the CCL/CCTF JWG reviewed and updated the values for the Hg ion, Sr ion, Yb ion, and the Sr neutral atom transition frequencies in its session in September 2006,
- the CCTF in its Recommendation CCTF 1 (2004) already recommended the unperturbed ground-state hyperfine quantum transition frequency of ^{87}Rb as a secondary representation of the second;

recommends that the following transition frequencies shall be used as secondary representations of the second and be included into the new list of "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second"

- the unperturbed ground-state hyperfine quantum transition of ^{87}Rb with a frequency of $f_{^{87}\mathrm{Rb}}$ = 6 834 682 610.904 324 Hz and an estimated relative standard uncertainty of 3×10^{-15},
- the unperturbed optical 5s $^2S_{1/2}$ – 4d $^2D_{5/2}$ transition of the $^{88}Sr^+$ ion with a frequency of $f_{^{88}\mathrm{Sr}^+}$ = 444 779 044 095 484 Hz and a relative uncertainty of 7×10^{-15},
- the unperturbed optical 5d^{10} 6s $^2S_{1/2}$ (F = 0) – 5d^9 6s^2 $^2D_{5/2}$ (F = 2) transition of the $^{199}Hg^+$ ion with a frequency of $f_{^{199}\mathrm{Hg}^+}$ = 1 064 721 609 899 145 Hz and a relative standard uncertainty of 3×10^{-15},
- the unperturbed optical 6s $^2S_{1/2}$ (F = 0) – 5d $^2D_{3/2}$ (F = 2) transition of the $^{171}Yb^+$ ion with a frequency of $f_{^{171}\mathrm{Yb}^+}$ = 688 358 979 309 308 Hz and a relative standard uncertainty of 9×10^{-15},
- the unperturbed optical transition 5s^2 $^1S_0$ – 5s 5p $^3P_0$ of the ^{87}Sr neutral atom with a frequency of $f_{^{87}\mathrm{Sr}}$ = 429 228 004 229 877 Hz and a relative standard uncertainty of 1.5×10^{-14}.

RECOMMENDATION CCTF 3 (2006)
Concerning the use of measurements of the International Atomic Time (TAI) scale unit

The Consultative Committee for Time and Frequency (CCTF),

considering that

- the number of primary frequency standards (PFS) reporting measurements of the TAI scale unit has significantly increased and is expected to continue doing so,
- in the future, secondary representations of the SI second are also expected to report measurements of the TAI scale unit,
- Recommendation CCTF 2 (2004) provides guidelines for reporting such measurements, and recommends that the Working Group on the Expression of Uncertainties in Primary Frequency Standards (at present the Working Group on Primary Frequency Standards) reviews the use of all reported evaluations of PFS,
- the first measurements from a new PFS might exhibit excessive frequency excursions that tend to disappear as more experience with the standard and the frequency transfer process is gathered,
- PFS sometimes undergo modifications leading to significantly changed characteristics and corresponding uncertainties;

recommends that

- the BIPM circulates to the Working Group on Primary Frequency Standards first reports of measurements from new standards, as well as those from frequency standards whose uncertainties have changed appreciably,
- the use and subsequent publication of those reports in *Circular T* be delayed to allow comments from the WG on PFS, following which, publication should be subject to a mutual decision by the concerned laboratory and the BIPM, and
- the long-term frequency stability of a new PFS relative to TAI should be evaluated over several months prior to the submission of a first report, and such data should be included in this report.

RECOMMENDATION CCTF 4 (2006)
Concerning the use of Global Navigation Satellite System (GNSS) carrier phase techniques for time and frequency transfer in International Atomic Time (TAI)

The Consultative Committee for Time and Frequency (CCTF),

realizing that

- atomic frequency standards have achieved unprecedented precision and accuracy, and that further rapid advances in this field are underway,
- the ability to compare these standards for the realization of International Atomic Time (TAI) is already limited by the accuracy and precision of current time transfer systems;

understanding the complementary nature of different time and frequency transfer techniques, and of different available manifestations of each technique;

noting that

- GNSS carrier phase techniques have been developed, which are used to routinely generate time and frequency transfer with a sub-daily precision unattained by any other long-distance technology,
- the costs associated with equipment acquisition, installation, operation, and maintenance are less than the purchase price of a single cesium frequency standard,
- several institutions have manifested their willingness to reduce the data,
- many promising software algorithms are either available or under active development;

and considering that instabilities of existing time transfer equipment remain a matter of concern at the nanosecond level;

recommends that

- the laboratories participating in TAI consider acquiring state-of-the-art geodetic GNSS time receivers,
- the several institutions currently generating routine solutions institute policies to reduce data from every timing laboratory that is willing to participate and can meet the documentation requirements,
- the International Bureau of Weights and Measures (BIPM), in a highly cooperative manner, generate its own solutions, make them freely available to others, and add them to its time transfer comparison database,
- the BIPM begin preparing software and techniques for introduction of the data into the computation of *Circular T*,
- the BIPM institute the operational collection of calibration information from the geodetic receivers of participating laboratories, and
- that the International Committee for Weights and Measures provide the required resources to the BIPM to carry out these recommendations.

RECOMMENDATION CCTF 5 (2006)
Improvement to Global Navigation Satellite System (GNSS) time transfer

The Consultative Committee for Time and Frequency (CCTF),

considering that

- data from the Global Positioning System (GPS) satellites play an important role in time and frequency transfer,
- other satellite systems such as Galileo and GLONASS will become increasingly important to time and frequency transfer in the future,
- present uncertainties in the calibration of equipment at timing laboratories place a significant limitation on international time transfer in general and on the accuracy of the computation of TAI in particular;

recommends that

- the technical directives for reporting data from these systems be modified to support including data from different systems in the same file, as described in the appendix,
- the timing laboratories work to improve the calibration of time transfer equipment, and to reduce the source of the type-B uncertainties of the receiving equipment including:
  - equipment that minimizes the impact of fluctuations in the ambient temperature and humidity,
  - antennae and cables which minimize the impact of multipath reflections and similar effects.

Appendix:

The minimal change recommended at this time is to add a single letter following the PRN number in the column which is now a space. This single upper case alphabetic character will identify the type of satellite system. The letter will conform to the IGS specifications. If there is no IGS assignment, one will be specified by the CGGTTS in consultation with the BIPM. Specifically:

- G or space for GPS,
- E for Galileo,
- S for a geostationary augmentation system,
- R for GLONASS.

RECOMMENDATION CCTF 6 (2006)
Coordination of the development of advanced time and frequency transfer techniques

The Consultative Committee for Time and Frequency (CCTF),

recognizing

- the availability of high performance cold atom microwave clocks,
- the rapid improvement of optical frequency standards in different institutes,
- the upcoming need to compare these remote standards at a level of estimated accuracy and stability which is not currently possible; and

considering that

- different technical possibilities for comparison that include optical fibre links, transportable optical frequency standards, optical satellite links and improved microwave links have been identified as possibly useful for the purpose,
- improvements in time and frequency transfer would have major applications to the performance assessment of current frequency standards and would support the progress of future primary frequency standards and clocks,
- the associated improvement of the realization of Coordinated Universal Time (UTC) would be beneficial for foreseeable applications in many fields of science and technology;
- a new Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques composed of experts from various fields, such as optical frequency metrology, time scale generation, and time and frequency transfer, to address and coordinate these issues is established;

recommends that

- the time and frequency community actively pursues this research in a coordinated manner,
- the International Bureau of Weights and Measures (BIPM) continue to facilitate the activities of the different working groups of the CCTF and establishes the necessary interactions with other relevant bodies such as the International GNSS Service (IGS), International Union of Geodesy and Geophysics (IUGG), International Telecommunication Union (ITU), International Union of Radio Science (URSI), etc.,
- national and international science organizations and space agencies give this development due consideration and weight, and
- national governments and international bodies provide funding to support the development of these activities.

APPENDIX 1.
Working documents submitted to the CCTF at its 17th 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/	
06-01	Draft agenda, 1 p.
06-02	INRIM (Italy). — Report to the 17th session of the CCTF, 14 pp.
06-03	KRISS (Rep. of Korea). — Status report to the 17th meeting of the CCTF on time and frequency activities at KRISS, 4 pp.
06-04	USNO (United States). — Time and frequency at the US Naval Observatory, D. Matsakis, 8 pp.
06-05	NMIJ/AIST (Japan). — Research on time and frequency at NMIJ/AIST, 7 pp.
06-06	USNO (United States), BIPM, LNE-SYRTE (France), PTB (Germany), NPL (United Kingdom), NICT (Japan). — Optimizing the configuration of time transfer links for TAI, D. Matsakis, F. Arias, A. Bauch, J. Davis, T. Gotoh, M. Hosokawa, D. Piester, 13 pp.
06-07	PTB (Germany). — Report on activities to the 17th session of the CCTF, 12 pp.
06-08	CCTF. — Proposed recommendation – Concerning the use of measurements of the TAI scale unit, 1 p.
06-09	NICT (Japan). — Summary of time and frequency activities at NICT, 7 pp.
06-10	NICT (Japan). — New generation system of Japan Standard Time at NICT, 3 pp.
06-11	VNIIFTRI (Russian Fed.). — Time and frequency activity at the IMVP FGUP “VNIIFTRI”, 8 pp.
06-12	CCTF. — Proposed recommendation – Concerning unification of the reference frames of global navigation systems, 1 p.
06-13	CCTF Working Group on Primary Frequency Standards. — Report to the 17th session of the CCTF – Working Group on Primary Frequency Standards, T. Parker, 5 pp.
06-14	ORB (Belgium). — CCTF 2006: Report of the Royal Observatory of Belgium, P. Defraigne, 2 pp.
06-15	CCL/CCTF Joint Working Group on Secondary Representations of the Second. — Report to the 17th session of the CCTF – CCL/CCTF Joint Working Group on Secondary Representations of the Second, F. Riehle, P. Gill, 8 pp.
06-16	CCTF Working Group on the Consequences of the Global MRA. — Progress Report from the CCTF Working Group on the Consequences of the Global MRA, G. de Jong, 11 pp.
06-17	NIST (United States). — Comparison of GPS all-in-view and common-view, J. Levine, 8 pp.
06-18	CGGTTS. — Report of the CGGTTS, J. Levine, 8 pp.
06-19	CCTF. — Proposed recommendation – Concerning the use of GNSS carrier phase techniques for time and frequency transfer in TAI, 1 p.
06-20	LNE-SYRTE (France). — Contribution to the 17th CCTF, September 2006, 11 pp.

Document CCTF/	
06-21	NRC (Canada). — Report on activities to the 17th session of the CCTF, 5 pp.
06-22	TWSTFT. — TWSTFT Annual Report 2006, B. Klepczynski, 13 pp.
06-23	NIST (United States). — Report to the 17th meeting of the CCTF – Activities of the NIST Time and Frequency Division, 17 pp.
06-24	METAS (Switzerland). — Report to the 17th session of the CCTF, 2 pp.
06-25	NPL (United Kingdom). — Report of the NPL to the 17th session of the CCTF, 6 pp.
06-26	BIPM. — Report of the BIPM Time section for the period 2004-2006, E.F. Arias, 11 pp.
06-27	CCL/CCTF Joint Working Group on Secondary Representations of the Second. — Proposed Recommendation 1 from CCL-CCTF Joint Working Group on Secondary Representations of the Second, 1 p.
06-28	CCL/CCTF Joint Working Group on Secondary Representations of the Second. — Proposed Recommendation 2 from CCL-CCTF Joint Working Group on Secondary Representations of the Second, 1 p.
06-29	CGGTTS. — Proposed recommendation – Improvement to GNSS time transfer, J. Levine, 1 p.
06-30	CCTF Working Group on TAI. — Proposed recommendation – Re-organisation of the CCTF Working Group on TAI, 1 p.
06-31	BIPM, USNO (United States), IEN* (Italy). — The evaluation of uncertainties in [*UTC* - *UTC*(*k*)], W. Lewandowski, D. Matsakis, G. Panfilo, P. Tavella, 9 pp. (*Metrologia*, 2006, **43**, 278-286)
06-32	NMIA (Australia). — Report to the CCTF from the National Measurement Institute, Australia, 20 pp.
06-33	NMi VSL (The Netherlands). — Report of the NMi VSL TF section, 2 pp.
06-34	CCTF Working Group on the International Atomic Time. — Report of the CCTF Working Group on the International Atomic Time – Presentation, P. Tavella, 9 pp.
06-35	NRL (United States). — Report of the IGS Clock Products Working Group – Presentation, K. Senior, 10 pp.
06-36	CCTF. — Declaration CCTF 1 (2006), Re-organization of the CCTF Working Group on International Atomic Time (TAI), 2 p.

* Renamed INRIM.