Bureau International des Poids et Mesures

Consultative Committee for Time and Frequency (CCTF)

Report of the 18th meeting
(4–5 June 2009)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Note:

Following a decision of the International Committee for Weights and Measures at its 92nd meeting (October 2003), reports of meetings of the Consultative Committees are now published only on the BIPM website and in the form presented here.

Full bilingual versions in French and English are no longer published.

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 also available on the website.

A.J. Wallard,
Director BIPM

Corrected version including the texts of the Recommendations, Nov. 2010

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR TIME AND FREQUENCY
as of 4 June 2009

President

L. Érard, Member of the International Committee for Weights and Measures, Laboratoire National de Métrologie et d'Essais, Paris.

Executive Secretary

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

Members

Centro Nacional de Metrología [CENAM], México.

Federal Office of Metrology [METAS], Wabern.

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

Instituto Nazionale di Ricerca Metrologica [INRIM], Turin.

International Astronomical Union [IAU].

International GNSS Service [IGS].

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

International Union of Geodesy and Geophysics [IUGG].

International Union of Radio Science [URSI].

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 Metrology Institute of South Africa [NMISA], Pretoria.

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-INMS], Ottawa.

Observatoire Cantonal [ON], Neuchâtel.

Observatoire Royal de Belgique [ORB], Brussels.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

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

Technical University [TUG], Graz.

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

VSL [VSL], Delft.

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

Observers

Agency for Science Technology and Research [A*STAR], 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 18th meeting at the International Bureau of Weights and Measures (BIPM) headquarters, at Sèvres on 4 and 5 June 2009.

The following were present:

J. Achkar (LNE-SYRTE), A. Bauch (PTB), R. Beard (ITU-R), J.C. Bergquist (NIST), C. Boucher (IUGG), F. Cordara (INRIM), J. Davis (NPL), P. Defraigne (ORB), E. Dierikx (VSL), L. Erard (LNE), F.J. Galindo Mendoza (ROA), X. Gao (NIM), P. Gill (NPL), A. Godone (INRIM), F.-L. Hong (NMIJ/AIST), M. Hosokawa (NICT), T. Ikegami (NMIJ/AIST), M. Imae (NMIJ/AIST), N. Koshelyaevsky (VNIIFTRI), Y. Koyama (NICT), T.Y. Kwon (KRISS), P. Lemonde (SYRTE), J. Levine (NIST), T. Li (NIM), J.M. López-Romero (CENAM), A. Madej (NRC-INMS), L. Marmet (NRC-INMS), D. Matsakis (IAU and USNO), C. Matthee (NMISA), J. Mc A. Steele (URSI), D. McCarthy (USNO), T. O'Brian (NIST), J. Nawrocki (SRC), V. Palchikov (VNIIFTRI), T.E. Parker (NIST), D. Piester (PTB), F. Riehle (PTB), K. Senior (IGS), A. Stefanov (METAS), P. Tavella (INRIM), P. Tuckey (LNE-SYRTE), B. Warrington (NMIA), E. Zagirova (VNIIFTRI), A.J. Wallard (Director of the BIPM).

Observers: R. Hamid (UME), S.-L. Tan (A*STAR).

Guests: T. Bartholomew, W. Klepczynski (USNO), S.-Y. Lin (TL).

Also present: E.F. Arias (Executive Secretary of the CCTF), R. Felder, A. Harmegnies, Z. Jiang, M. Kühne (Deputy Director BIPM), W. Lewandowski, L. Mussio (JCRB Executive Secretary), G. Panfilo, G. Petit, T.J. Quinn (Director Emeritus BIPM), L. Robertsson, C. Thomas (Coordinator of the KCDB), L. Tisserand,

Sent regrets: P. Banerjee (NPLI), Y.S. Domnin (VNIIFTRI), P. Fisk (NMIA), K. Johnston (USNO), I. Kuselman (INPL), I.M. Mills (CCU President, University of Reading), R. Nelson (Satellite Engineering Research Corporation).

The President opened the meeting at 9 am and welcomed the delegates and observers. He thanked the Head of the BIPM Time, Frequency and Gravimetry section, Dr Felicitas Arias, for preparing the agenda and invited the Deputy Director of the BIPM, Prof. Michael Kühne, to add his welcome to the delegates.

The President noted that Dr Bruce Warrington 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 PTB, Germany, presented by Dr Bauch (CCTF/09-02)

The caesium fountain CSF1 has continued to submit data for the measurement of the scale unit of TAI, with a number of recent improvements including newly developed microwave frequency synthesis. The first evaluation of the second fountain CSF2 has been performed, with publication expected soon in *Metrologia*. The comparison between CSF1 and CSF2 has demonstrated agreement within the uncertainties of the standards, at a level below 1×10^{-15}.

The thermal beam standards CS1 and CS2 have continued operation. After an interruption for maintenance in 2008, CS1 now has a higher signal level and the value for u_A in *Circular T* is an even more conservative estimate. CS2 has continued operation with one beam only since one oven became depleted in 2008, with a long break for refurbishment expected when the second oven is depleted.

The $^{171}Yb^+$ single-ion optical frequency standard at 688 THz based on the $^2S_{1/2}$ (F = 0) – $^2D_{3/2}$ (F = 2) electric quadrupole transition was remeasured against CSF1 in late 2008, with a statistical uncertainty $u_A \leq 8 \times 10^{-16}$ and a systematic uncertainty u_B estimated at 5×10^{-16}. Statistical uncertainties are essentially dominated by the instability of CSF1 and the averaging time (up to 90 h). The measured transition frequency agrees with previous values within the uncertainty, with a final combined uncertainty of 0.8 Hz.

Other activities under development include high-resolution spectroscopy of the 642 THz electric octupole transition of $^{171}Yb^+$ and an optical frequency standard based on neutral Sr in a horizontal optical lattice.

Report from CENAM, Mexico, presented by Dr López-Romero (CCTF/09-03)

The optically pumped Cs thermal beam standard CsOP-1, under development since 1998, is undergoing continued improvement including a longer Ramsey cavity and better magnetic shielding. The standard has been renamed CsOP-2. An uncertainty $\leq 3 \times 10^{-14}$ is expected, and it is planned to submit data from this standard to the BIPM for inclusion in TAI.

Development of the Cs fountain CsF-1 is continuing, using a low-phase noise local oscillator based on whispering gallery sapphire resonators developed at CENAM. First Ramsey fringes are expected in late 2009.

Report from USNO, United States, presented by Dr Matsakis (CCTF/09-04)

An ambitious upgrade plan is in progress to prepare for GPS III. A new clock building was formally opened in November 2008, delivering temperature stability to 0.1 °C and humidity stability to 3 % throughout the building even during planned maintenance.

In order to improve time-scale operations, USNO is continuing the development of rubidium fountains. Two prototype Rb fountains agree within an instability of 2×10^{-13} at 1 s and 2×10^{-16} at ten days.

USNO has been participating in discussions involving the interoperability of GPS, Galileo, QZSS (Quasi-Zenith Satellite System), and GLONASS. A Galileo monitoring station was installed in December 2006, and detailed plans have been made to monitor the GPS to Galileo Time Offset (GGTO) in parallel and in concert with the Galileo Precise Timing Facility (GPTF).

*Report from VSL, the Netherlands, presented by Mr Dierikx (CCTF/09-05)**

Mr Dierikx reported staffing changes at VSL since the previous meeting of the CCTF. A programme to improve maintenance of UTC(VSL) is continuing, including upgrades to TWSTFT and GPS time-transfer equipment.

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

The Cs fountain NICT-CsF1 is currently operational with a frequency uncertainty of 1.9×10^{-15} and accuracy evaluations have been submitted to the BIPM for the determination of TAI since 2006. A 9.2 GHz synthesis chain has been introduced based on a cryogenic sapphire oscillator (CSO) developed at the University of Western Australia, with instability $<2 \times 10^{-15}$ at 1 s. A second Cs fountain is under development, with completion expected in approximately one year.

Development of an optical frequency standard based on an electric quadrupole transition in a single $^{40}Ca^{+}$ ion is continuing. A measurement of the transition frequency in 2008 achieved an uncertainty of 1.7×10^{-14}, and is in good agreement with a result obtained at Innsbruck.

A neutral Sr optical frequency standard is also under development, with two-stage magneto-optical trapping of both bosonic and fermionic isotopes demonstrated as well as 1D confinement of ^{88}Sr in an optical lattice. A frequency measurement is expected in the near future.

Dr Riehle asked if the most recent $^{40}Ca^{+}$ frequency measurement had been published. Dr Hosokawa confirmed that a value was published last year, and that the lower uncertainty of 1.7×10^{-14} had so far been reported in presentations and proceedings for the Asia-Pacific Time and Frequency Workshop (ATF) and the Precise Time and Time Interval (PTTI) Systems and Applications Meeting.

Report from NRC, Canada, presented by Dr Marmet (CCTF/09-07)

The Cs fountain NRC-FCs1 has produced Ramsey fringes for the first time, with launch and state preparation currently being optimized prior to the first evaluation. The target uncertainty is 1×10^{-15}.

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Development of an optical frequency standard at 445 THz based on an electric quadrupole transition in a single Sr^+ ion is continuing, with a number of subsystems including a new endcap trap and new laser systems built to improve trapping times and interrogation efficiency. Design and construction of laser systems for a neutral Sr lattice clock have also begun. Fibre-based frequency combs developed in partnership with the University of British Columbia have been used for a number of optical frequency measurements, including that of the Sr^+ transition frequency, showing agreement with previous values to (0.4 ± 4.5) Hz.

GPS common-view time and frequency transfer has been improved with a new Ashtech Z12T receiver, including participation in TAIPP and SIM comparisons. The CHU shortwave radio broadcast service has also been refurbished, including a change to one of the broadcast frequencies.

The President asked when submission of fountain evaluation data to the BIPM was planned. Dr Marmet estimated that the first evaluation would require at least one year.

Report from NMISA, South Africa, presented by Mr Matthee (CCTF/09-08)

An ensemble of 5071A commercial Cs standards has been extended and the monitoring and comparison system upgraded in preparation for development of a local time scale.

Work on optical frequency standards is in its infancy but is progressing. The intention is to develop a robust portable standard based on the two-photon transition in Rb, for a range of metrological applications including support of developing Economies in the region.

Report from KRISS, Republic of Korea, presented by Dr Kwon (CCTF/09-09)

The optically-pumped Cs beam standard KRISS-1 submitted data to the BIPM in December 2008 for contribution to TAI, with an evaluated uncertainty of 1×10^{-14}. Operation restarted this month after an interruption for maintenance and regular reporting is planned in future.

Because effort has been concentrated on KRISS-1, the KRISS Cs fountain has made limited progress since the previous CCTF meeting, but new laser systems and a new optical RF generation system are currently under development.

Work is continuing on a neutral Yb lattice optical frequency standard, with second-stage magneto-optical trapping demonstrated and optimization in progress in preparation for loading the optical lattice. Narrow lasers for the 578 nm clock transition are also under development.

The President asked if future development at KRISS would concentrate on optical frequency standards in preference to the Cs fountain. Dr Kwon replied that the current intention is to continue development of both microwave and optical standards.

Report from NMIJ/AIST, Japan, presented by Mr Imae (CCTF/09-10)

The Cs fountain NMIJ-F1 is in regular operation with eight evaluations reported to the BIPM over the last year. The current uncertainty is 4×10^{-15} with further improvements planned. Construction of a second Cs fountain NMIJ-F2 has begun, to realize a projected uncertainty below 4×10^{-15}.

Work has continued on the development of neutral atom optical lattice clocks with both Sr and Yb. The frequency of the $^1S_0 - {}^3P_0$ clock transition in an ^{87}Sr 3D lattice clock was measured in a collaboration between NMIJ, the University of Electro-communication and the University of Tokyo, using a phase-stabilized 120 km optical fibre link between Tokyo and Tsukuba. The result shows very good agreement with values from JILA and SYRTE, with a standard deviation of 0.27 Hz (6×10^{-16}). The first frequency evaluation for the ^{171}Yb 1D lattice clock was also obtained recently, with an uncertainty of approximately 1×10^{-14}. A number of improvements are planned.

The President noted the strong collaboration with the University of Tokyo.

*Report from ROA, Spain, presented by Dr Galindo (CCTF/09-11)**

An ensemble of 5071A commercial Cs standards has been extended by the addition of a hydrogen maser since April 2006. A new algorithm has been developed to realize UTC(ROA), using the maser and an Auxiliary Output Generator and replacing use of a single Cs clock since 26 February 2009.

Report from NIM, China, presented by Dr Li (CCTF/09-12)

The first NIM Cs fountain has continued operation at an uncertainty of 5×10^{-15}, with the second fountain NIM5 demonstrating uncertainty of 2×10^{-15} in preliminary evaluations. A comparison shows agreement between the two standards at a level of 5×10^{-15}, dominated by the first fountain. NIM anticipates reporting evaluations to the BIPM within a few months.

Preparations are under way to relocate most NIM facilities to a new campus 45 km from the current site. An optical fibre link is under development to connect the two sites, with laboratory evaluations complete and the link under construction.

Development of a neutral Sr optical lattice clock began in 2007. First-stage magneto-optical trapping has been demonstrated, with second-stage cooling and trapping in preparation. This standard will also be moved to the new campus in approximately one year.

The President thanked NIM for their planned contribution to TAI and asked for the length of the fibre link. Dr Li reported that the physical distance is 45 km, but the actual fibre length may be longer.

Report from INRIM, Italy, presented by Dr Godone (CCTF/09-13)

The Cs fountain IT-CsF1 has contributed evaluations to the determination of TAI over the last three years, with frequency accuracy evaluated at $5–8 \times 10^{-16}$ and a combined uncertainty including the link to TAI in the range $1–1.8 \times 10^{-15}$. Improvements include improved evaluation of the frequency shift due to microwave leakage and the density shift. A second fountain IT-CsF2 is being developed in cooperation with NIST, operating at cryogenic temperatures to reduce the blackbody shift. A preliminary evaluation of IT-CsF2 shows an uncertainty of 1×10^{-15}, with a full evaluation to be completed later in 2009. The aim is to submit evaluation

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data to the BIPM in 2010, and to continue improvements to reach the low 10^{-16} level in the longer term.

A neutral Yb optical lattice clock is also under development. First-stage magneto-optical trapping has been demonstrated, with second-stage cooling and trapping in preparation. A reference cavity has also been completed for the narrow laser for the clock transition.

Report from NPL, United Kingdom, presented by Dr Davis and Dr Gill (CCTF/09-14)

The national time scale UTC(NPL) is realized using an ensemble of masers and commercial Cs standards, and was relocated to the new NPL building in October 2006. A Dicom GTR50 is now the primary receiver used for GPS time transfer. NPL is actively involved in reference timing systems for Galileo, as a major contributor to development of the Galileo Time Service Provider and by developing time-scale algorithms for one of the two Galileo Precise Time Facility.

The MSF 60 kHz radio broadcast service was relocated from Rugby to Anthorn in 2007 and is still in operation.

NPL currently operates three fountains, two Cs and one Rb. NPL-CsF1 was first evaluated in 2004, and contributed to the determination of TAI a number of times before its relocation to the new building in November 2007. The fountain is currently being upgraded before being returned to service. NPL-CsF2 has been back in operation since late 2008, following redesign to operate in a configuration where frequency shifts due to variations in state populations are greatly reduced; an accuracy evaluation is currently in progress. The Rb fountain was developed as a secondary representation of the second, and to assist in evaluation of other standards. It has been in operation since 2008 and is currently under evaluation.

NPL has continued development of optical frequency standards based on single trapped ions and on a neutral Sr optical lattice, although relocation of these standards to the new building has been a significant disruption. The 445 THz electric quadrupole transition in $^{88}Sr^+$ has been remeasured using an optical frequency comb referenced via a hydrogen maser to TAI, obtaining an uncertainty of 4.6 Hz. The transition frequency obtained is in good agreement with previous values obtained at NPL (at larger uncertainty, as the earlier measurement was referenced to a Cs fountain) and also at NRC. The probe laser linewidth has been reduced, and a second Sr^+ trap has been constructed to assist with evaluation of systematic shifts.

The 642 THz electric octupole transition in $^{171}Yb^+$ has been studied at NPL for some time. A recent measurement of the transition frequency made in the same way as for Sr^+ obtained an uncertainty of 12 Hz (1.9×10^{-14}), limited by maser instability and AC Stark shift. A preliminary measurement of the 688 THz electric quadrupole transition in the same ion has been made again in the same way with an uncertainty of 9 Hz (1.3×10^{-14}), in good agreement with values obtained at PTB within this uncertainty.

A neutral Sr optical lattice clock is currently under construction, aiming for a small footprint and incorporating a novel Zeeman slower.

Three optical frequency combs are in operation. Experiments in frequency transfer over optical fibre have begun, obtaining stability in the 10^{-16} range at an averaging time of approximately 30 s.

Report from METAS, Switzerland, presented by Dr Stefanov (CCTF/09-15)

FOCS-1, a primary Cs standard based on a continuous beam of laser-cooled atoms, has been under development in collaboration with the University of Neuchatel. The uncertainty of this standard is currently under evaluation, with results expected in approximately one year. A second continuous fountain standard FOCS-2, an improved version of FOCS-1, is also under construction with observation of Ramsey fringes expected soon.

The time scales UTC(CH) and TA(CH) are maintained using a small ensemble of commercial Cs standards and a hydrogen maser, with a new real-time master-clock definition adopted for UTC(CH) in November 2007. These time scales are linked to TAI and UTC via a TWSTFT link to PTB.

The President looked forward to the first evaluation of the continuous fountain standards for contribution to TAI.

Report from LNE-SYRTE, France, presented by Dr Tuckey (CCTF/09-22)

Three fountains are in regular operation with improved reliability, contributing about half of TAI fountain evaluations. Internal comparisons within the fountain ensemble with statistical uncertainty in the low 10^{-16} range support systematic uncertainty evaluations.

The Cs fountain FO1 has an accuracy of 4.4×10^{-16} and an instability of 3×10^{-14} at 1 s. The dual-species fountain FO2 is functioning, achieving similar performance with both Rb and Cs. A new measurement of the Rb hyperfine interval obtained a value consistent with previous measurements, with an improved uncertainty of 6.4×10^{-16}. The mobile Cs fountain FOM was transported to the University of Innsbruck to participate in a measurement of the $4s\ ^2S_{1/2} - 3d\ ^2D_{5/2}$ electric quadrupole transition in $^{40}Ca^+$, with an uncertainty of 2.4×10^{-15}. The FOM is now in operation at CNES, Toulouse, for testing of the PHARAO cold-atom space clock. Funding has been confirmed for the PHARAO/ACES mission with launch scheduled for 2013, and construction of the PHARAO flight model has begun.

Development of neutral atom lattice clocks has continued, with an Sr standard currently demonstrating an accuracy of approximately 1 Hz (2.6×10^{-15}) and achieving 1 Hz statistical uncertainty within 15 min. A neutral Hg lattice clock is also under development, with laser cooling demonstrated using the $^1S_0 - {}^3P_1$ transition at 254 nm. The $^1S_0 - {}^3P_0$ clock transition at 265.6 nm has been observed for the first time with cold atoms of both ^{201}Hg and ^{199}Hg isotopes, and a preliminary measurement of the transition frequency has been performed with an uncertainty of approximately 4×10^{-12}.

The French ensemble atomic time scale TA(F) has been steered from time to time to cancel long-term frequency drift. By using correction data from the laboratory primary frequency standards, TA(F) has remained within approximately 2×10^{-15} of the SI second over the past two years.

The link between EGNOS and UTC passes through LNE, with broadcast data for ENT – UTC obtained through UTC(OP). These data have been declared compliant to specification by CNES.

The laboratory now has two operational TWSTFT stations: OP01 on the Europe-Europe and Europe-USA networks, and OP02 on the Europe-Asia network. Colocation experiments obtain a common-clock deviation below 200 ps over more than one day. Improvements to frequency references and distribution have enhanced the performance of the NIST-OP link, with a frequency instability now just below 1×10^{-15} at one day.

Optical fibre links are under development in collaboration with the Laboratoire de Physique des Lasers, achieving a frequency instability over 86 km of 2×10^{-16} at 1 s and reaching the 10^{-19} level after a few hours. Recently, it has been demonstrated that this transfer link can be shared with internet traffic over an operational fibre network.

The Time Transfer by Laser Link (T2L2) experiment, developed by CNES in partnership with the Observatoire de la Côte d'Azur (OCA), was launched on Jason-2 in June 2008. The design goal is a stability of 1×10^{-16} at one day in common view.

*Report from ORB, Belgium, presented by Dr Defraigne (CCTF-09/21)**

The time laboratory of the Royal Observatory of Belgium currently operates an ensemble of three HP5071A Cs standards and two active hydrogen masers. A new version of the R2CGGTTS software has been made available on the BIPM FTP server. In addition, new software for time and frequency transfer called Atomium has been developed based on combined code and carrier analysis, including processing of GLONASS data and the ability to form a least-squares combination of GPS and TWSTFT observations.

*Report from A*STAR, Singapore, presented by Ms Tan (CCTF-09/25)**

The laboratory operates an ensemble of four HP5071A Cs standards, and added a hydrogen maser in 2007. Time transfer for contribution to TAI uses a TTR-3 dual-frequency GPS/GLONASS receiver, to be replaced by two Septentrio geodetic GPS receivers. The laboratory also participated in TWSTFT networks until March 2009.

Report from VNIIFTRI, Russian Federation, presented by Dr Koshelyaevsky (CCTF-09/45)

Development of Cs fountain primary frequency standards is continuing. The current goal is to achieve an uncertainty below 3×10^{-15} by the end of 2009, with full evaluation and submission to TAI expected subsequently. The design goal for the next prototype fountain standard is an uncertainty below 1×10^{-16}, planned for the end of 2011.

Report from NIST, United States, presented by Dr O'Brian (CCTF-09/34)

The Cs fountain primary frequency standard NIST-F1 has contributed approximately 35 evaluation reports to the determination of TAI since 1999. Recently, some shorter but more frequent evaluations have been undertaken, slightly increasing the statistical uncertainty (to $2–3 \times 10^{-16}$) but allowing more frequent steering.

Developed in collaboration with INRIM, the next-generation Cs fountain NIST-F2 incorporates both a drift tube at cryogenic temperatures to reduce the blackbody shift and a multiple-launch

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system to reduce collisional shifts. Initial operation of NIST-F2 at 77 K has been demonstrated, with a full evaluation in progress until early 2010.

An optical frequency standard based on the 1.06 THz (282 nm) electric quadrupole transition in $^{199}Hg^+$ has achieved an uncertainty of 1.7×10^{-17}. A 'logic clock' optical frequency standard also continues to improve, based on the $^1S_0 - {}^3P_0$ transition at 267 nm in a single $^{27}Al^+$ ion coupled to a $^9Be^+$ in a linear Paul trap for sympathetic cooling and readout. This standard has demonstrated an uncertainty of approximately 2×10^{-17} with an instability of $7 \times 10^{-15}\,\tau^{-1/2}$.

Development of neutral Yb and Sr optical lattice clocks has also continued in collaboration with JILA, achieving uncertainties at the low 10^{-16} level.

*Report from UME, Turkey, presented by Dr Hamid (no written report)**

UME maintains an ensemble of three Cs atomic clocks, with time distribution and time stamping systems disseminating accurate time to end users. The laboratory also maintains a number of wavelength standards, including HeNe/I_2, Nd:YAG/I_2 and HeNe/CH_4 stabilized lasers as well as diode laser systems locked to D2 transitions in Rb and Cs. Research activities include the use of Ti:Sa and Er fibre optical frequency combs for frequency stabilization and frequency measurement.

The President gave a short summary of these presentations, as follows: contributions to TAI from two to three new fountain standards are expected; fountain standards are still developing, with cryogenic operation expected to yield further improvement; there is significant development of optical clocks, with Yb and Sr lattices and Yb^+ and Sr^+ single ions the most used, and Hg^+ and Al^+/Be^+ currently the most accurate; and optical fibre links are under development, with operation demonstrated over several tens of kilometres and active work in progress.

2.2 TT(BIPM) and primary frequency standards

The President invited Dr Petit to present a report entitled 'TT(BIPM) and primary frequency standards'.

Dr Petit reported that TT(BIPMxx) is an annual realization of the 'ideal' Terrestrial Time TT using post-processing of all available data from primary frequency standards (PFS). The latest such realization, TT(BIPM08), was released in January 2009, with details available through the BIPM FTP server.

The uncertainty in f(TT(BIPM)) has decreased from more than 2×10^{-15} before 2000 to about 5×10^{-16} since 2007, due to the increased number of PFS evaluations. Over the last five years, 125 evaluations have contributed to f(TT), with $\chi^2 \approx 1.3$ for f(PFS) – f(TT).

TT(BIPM) provides a reference to assist in estimation of the accuracy and stability of TAI. Currently, f(TAI) – f(TT(BIPM)) is approximately 4×10^{-15}, and TAI – TT(BIPM07) shows long-term instability of approximately 2×10^{-15} at an averaging time of two years. This implies

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that TT(BIPM) is better than TAI as a reference for long-term analysis, for example of millisecond pulsars.

The full accuracy of primary frequency standards is currently not transferred to TT(BIPM), owing to frequency transfer noise and some slightly inconsistent PFS evaluations. It would be possible to use (or at least analyse) reports from secondary representations of the second, if these were provided by laboratories, and a protocol could be developed in future.

The President thanked Dr Petit for the report, and asked what would be the effect on TT(BIPM) of additional PFS evaluations given the current level of frequency transfer noise. Dr Petit replied that further evaluations improve accuracy in two ways: first, by reducing the effect of transfer noise, and second by reducing the contribution due to instability in EAL, which is used as a ‘flywheel’ between evaluations.

2.3 Report of the CCTF Working Group on Primary Frequency Standards

The President invited Dr Parker to present this report (CCTF/09-01).

Dr Parker began by explaining that the Working Group, established in 2005, serves as a group of experts on primary frequency standards (PFS) for consultation by the BIPM or national laboratories. The Working Group has held three meetings since 2005, and a one-day workshop in Geneva in May 2007. Eight presentations were made at the workshop, from six laboratories operating primary frequency standards and from the BIPM, with the main theme of ‘lessons learned’ intended to assist laboratories developing new standards.

A new formula for estimating frequency transfer uncertainty recommended by the Working Group was implemented by the BIPM for contribution to TAI in September 2006.

According to CCTF Recommendation CCTF/06-08, the first report of a new primary frequency standard, as well as reports from standards whose uncertainties have changed appreciably, is circulated to the Working Group for comments before the report is accepted by the BIPM. The Working Group was consulted twice regarding the Cs fountain NICT-CsF1 (in July 2007, on first operation, and in October 2008, for a significant decrease in uncertainty) and once regarding the thermal beam standard KRISS-1 (in January 2009). All reports were approved with minor changes.

Discussions were held by email on two topics. First, the group did not assign a specific threshold for reduction in uncertainty at which consultation of the Working Group would be required, instead leaving this decision to the discretion of the BIPM. Second, noting that Type B uncertainties in *Circular T* sometimes differ significantly from referenced peer-reviewed journal articles, the Working Group encourages all PFS laboratories to update uncertainties published in peer-reviewed journals when appropriate, but again did not support a specific threshold. The group also recommended that a clarification be added to Section 4 of *Circular T* to make this difference explicit.

Currently, nine fountains and four thermal beam standards from eight laboratories report evaluations to the BIPM. At least one fountain report has been included in each publication of *Circular T* for the last two years, with an average of 3.6 per month. There have been 181 fountain reports in *Circular T* since November 1999.

Dr Parker presented graphs comparing Cs fountains to TAI, and individual fountains to a weighted mean. The latter includes nine operating fountains, with only one outside the weighted mean by greater than the reported uncertainty – despite the intention that this uncertainty be the combined standard uncertainty, corresponding approximately to a 68 % confidence interval. The comparison nevertheless supports the conclusion that these fountains are consistent within evaluated uncertainties, with additional details presented by Dr Parker.

Dr Matsakis asked how many fountains are in continuous operation, and which report most often. Dr Parker replied that no fountain is in continuous operation; LNE-SYRTE undertakes the most frequency evaluations; NIST is present every month in *Circular T*, but typically with a shorter evaluation period; and NMIJ also reports consistent operation.

Dr Tuckey reported that the mobile fountain has the highest operational reliability of the LNE-SYRTE ensemble, operating continuously for a period of weeks. LNE-SYRTE is still working to improve the level of reliability, in part to meet the stringent operational requirements of the ACES mission.

Dr Ikegami reported that NMIJ-F1 is also operating almost continuously.

The President enquired whether the workshop exchanged ‘tricks’, ‘secrets’ or both. Dr Parker replied that one of the most common problems with any primary frequency standard, particularly fountains, is instrumental effects synchronous with pulsed operation; one example from experience with NIST-F1 was pulsed operation of drift tube heaters. Many laboratories reported similar issues to avoid based on their own experience, which was particularly valuable.

The President asked which fountain was next to be reviewed by the Working Group, and Dr Parker replied that this may be any of a number currently in preparation.

Dr Arias commented that, following discussion with the Working Group chair, implementation of the revised wording in Section 4 of *Circular T* should be implemented as soon as possible. Dr Parker agreed that this increases transparency, and encourages laboratories to update publications regularly.

Dr Gill noted that an incremental improvement in performance may not be sufficient for a new peer-reviewed publication. Dr Parker agreed that small changes may not be sufficient, but noted that a series of these changes can accumulate to a more significant improvement, and referred to a BIPM study which found that unpublished improvements could reduce uncertainty by up to a factor of two. Such an accumulated improvement may merit publication if the reduction is significant.

2.4 Report of the CCL/CCTF Frequency Standards Working Group

The President invited Dr Riehle to present this report.

Dr Riehle began by explaining that the CCL/CCTF Frequency Standards Working Group (FSWG) was established in 2006, following a recommendation to CIPM by the CCTF. The Frequency Standards Working Group (FSWG) has the responsibility to maintain a single List of Recommended Frequencies (LoR), by making recommendations to the CCL regarding radiations to be used for the realization of the definition of the metre and to the CCTF for radiations to be used as secondary representations of the second. Dr Riehle noted that the FSWG was confirmed at the CCL meeting in 2007, with amended terms of reference including responsibility for key comparisons of standard frequencies (such as CCL-K11) and to respond to future needs of both CCL and CCTF concerning standard frequencies relevant to the respective communities.

The FSWG was invited by the CCU to make a report 'On a new definition of the second', in preparation for a possible redefinition as early as 2015. A presentation was prepared by Dr Riehle and Dr Gill, in discussion with Dr Erard and Dr Arias. The presentation covered Cs clocks as the primary realization of the second, the concept of secondary realizations of the second, the List of Recommended Frequencies, and options and constraints for a new definition.

The presentation summarized work currently in progress in the frequency standard community, noting that optical clocks are now superior to the best primary Cs clocks in both accuracy and stability. Different optical transitions are under investigation in different institutes, with strategic cooperations including external agencies, and novel concepts of time and frequency transfer suitable for optical clocks are currently being explored. The CCTF is closely monitoring these developments.

It was noted that the existing SI definition of the second based on Cs will serve the needs of industry for some time, with secondary representations serving the needs of the scientific community. It is not yet clear whether the best approach is to adopt standards based on single trapped ions or on neutral atoms in an optical lattice, with further work required for consensus. The time will be right for a new definition when the current progress in optical standards slows, and when the current limitations of frequency transfer have been solved: 2015 may be too early, but 2019 may be possible.

In its response, the CCU strongly encourages laboratories to continue work on optical frequency standards towards a new definition of the second, potentially in 2019, and encourages the CCL/CCTF FSWG to evaluate optical frequency ratios, as these may offer higher stability and reproducibility than comparisons involving the Cs microwave frequency. The response also notes that a potential redefinition of the SI base units the kilogram, ampere, mole and kelvin in 2011 will also lead to a new phrasing of the definition of the metre and the second: for example, 'The metre as the base unit of length is defined such that the speed of light is 299 792 458 m/s', and 'The second as the base unit of time is defined such that the (ground-state) hyperfine transition of 133Cs has the frequency 9 192 631 770 Hz'.

Dr Riehle summarized recommendations to be brought to the CCTF from the meeting of the Frequency Standards Working Group held on 2 June 2009 at the BIPM:

- In response to a request from the CIPM that the procedure for appointment of the chair of each Working Group should be defined in the terms of reference, the FSWG recommended that the chair be appointed jointly by the CCL and CCTF chairs with the possibility of a second term.
- After extensive discussion, the JWG recommended a series of amendments to the List of Radiations:
  - the unperturbed optical transition $5s^2\ {}^1S_0 - 5s5p\ {}^3P_0$ of the ^{87}Sr atom, a secondary realization of the second with an uncertainty of 1.5×10^{-14}, be updated to reflect recent measurements made at JILA, SYRTE and the University of Tokyo/NMIJ;
  - the unperturbed optical transition $5s^2\ {}^1S_0 - 5s5p\ {}^3P_0$ of the ^{88}Sr atom be added, combining measurements made at SYRTE and at the University of Tokyo;

  - the unperturbed optical transition 4s $^2S_{1/2}$ – 3d $^2D_{5/2}$ of the $^{40}Ca^+$ ion be added, combining measurements made at the University of Innsbruck and at NICT;
  - the unperturbed optical transition $^2S_{1/2}$ (F = 0) – $^2F_{7/2}$ (F = 3, mF = 0) of the $^{171}Yb^+$ ion be updated, to reflect the recent measurement made at NPL;
  - the frequency of the unperturbed $^1S_0$ – $^3P_0$ transition of the ^{171}Yb atom be added, to reflect the recent measurement made at NMIJ.
- The JWG did not recommend any additions to the list of secondary representations of the second or of realizations of the metre.

Dr Riehle also reported that a series of subgroups will be established to address other actions arising from the FSWG meeting:

- one subgroup will draft guidelines for the evaluation of new frequency measurements for inclusion in the LoR, with representation from BIPM, NMIA, NPL and PTB;
- a second subgroup will develop a draft protocol for establishing traceability to the metre directly from a Cs standard using an optical frequency comb, with representation from BEV, BIPM, INRIM, NMIA, NMIJ, NPL and NRC;
- a third subgroup will evaluate the implications of determining optical frequency ratios, for example for inclusion in the LoR, with representation from NIST, NRC, LNE-SYRTE, NMIJ, PTB and NPL;
- a fourth subgroup will draft a questionnaire regarding possible new BIPM activity to support validation of optical frequency comb measurements, with representation from BEV, NPL and BIPM.

Dr Tuckey asked about the implications of the potential rewording of definitions of the metre and second. Dr Riehle replied that this was not clear, and cited the example of the candela where no obvious problem was identified initially but objections were raised subsequently. At present there is no obvious problem for the metre and second, but these should be investigated in detail.

The President noted that the President of the CCU was invited to report to the CCTF but was not able to attend, so Dr Riehle had kindly reported on behalf of the CCU. The CCU objective is to have a consistent wording for the definitions of all base units, but this proposal is still under discussion.

Dr Thomas, executive secretary of the CCU, commented that only rewording is proposed at this stage. There are several proposals for how these definitions might be worded, occasioned by the possible redefinition of the ampere, mole, kelvin and kilogram. Overall, it was considered that it may be preferable to have a consistent wording in the definitions of the seven SI base units, and for these to be explicitly in terms of the fixed value of a fundamental constant. A Working Group has been set up to meet at the beginning of August 2009, including Dr Thomas as executive secretary, to draft the relevant section of the SI brochure including additional background on related physics.

The President noted that a CCTF Working Group on Strategy and Planning will be established, and recommended that this issue be referred to that group through its terms of reference. There is still time for further discussion, and for review of draft documentation when it has been prepared by the CCU Working Group.

Dr Madej enquired whether the FSWG had reached consensus on the values appearing in the list of reference radiations, and whether further discussion had taken place since the FSWG meeting. Dr Riehle replied that some questions had arisen in preparation of the report to the CCTF which the co-chairs would like to discuss again with the Working Group members, and explained that this discussion related only to uncertainties rather than to frequency values. For example, uncertainty in the realization of the second through a Cs primary standard remains a significant contribution to each of the three measurements for ^{87}Sr, which in principle requires a more careful combination to avoid inconsistencies from a simplistic statistical treatment. The President proposed that FSWG members meet to resolve this issue and finalize recommendations for the CCTF.

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/09-26).

Dr Arias began by outlining the present organization of the Time, Frequency and Gravimetry section, currently comprising twelve staff following the consolidation of laser, optical comb and gravimetry activities. A facility for the production of iodine cells was closed at the end of 2008, but cells will be filled and delivered to satisfy the needs of laboratories until the end of July 2009.

Achievements of the section since the 17th CCTF in 2006 include the continued timely production of TAI, UTC and TT, with an improvement of approximately one order of magnitude in frequency accuracy in the decade since 1998; continued improvement of the uncertainty of clock comparison through adoption of new methods, and characterization of delays for both GNSS and TWSTFT equipment; studies on improved frequency prediction for hydrogen masers in the ALGOS algorithm; increased accuracy of TAI through new evaluations of primary frequency standards, and coordination through the Working Group on Primary Frequency Standards; and a significant contribution to the CIPM MRA through regular updates of the key comparison CCTF-K001.UTC in the KCDB.

As of 2009, 68 laboratories in 51 nations (42 Member States and nine Associate States and Economies) are participating in TAI. About 350 clocks currently contribute, with 87 % either 5071A Cs standards or hydrogen masers, and on average about 15 % at maximum weight.

Continuing upgrades to time-transfer equipment at participating laboratories means that currently only 6 % of GPS links use a single-channel receiver, 54 % are GPS multi-channel (statistical uncertainty $u_A \approx 2.5$ ns in common view and 2 ns in all-in-view), 22 % are GPS P3 ($u_A \approx 0.7$ ns) and 15 % use TWSTFT ($u_A \approx 0.5$ ns). The systematic uncertainty u_B is 5 ns for most GNSS equipment, with 1 ns achieved for some TWSTFT.

As decided at the 17th CCTF in 2006, time links are now calculated using the GPS all-in-view method (instead of common view) and taking advantage of IGS products, leading to a reduction of time transfer noise by up to 30 % over long baselines. International time-transfer links all terminate at PTB, replacing the earlier network of pivot laboratories in continents. TWSTFT links are supported through the specification of data treatment protocols and support for characterization of equipment delays.

Studies of the GPS precise point positioning (PPP) technique have been undertaken, and following a recommendation of the 17th CCTF the TAIPPP pilot experiment has been established with over 20 laboratories participating. The performance of PPP, GPS P3 and TWSTFT techniques has been compared, with the possibility of combining link results across multiple techniques under investigation.

Relative characterization of GNSS receiver delays for both single and dual-frequency receivers has been completed for 65 % of laboratories contributing to TAI. This work is to be expanded in future, with new receivers dedicated for this purpose and through support for comparison campaigns undertaken within the regional metrology organizations. P3 comparison campaigns have been in progress since 2001, mostly using an Ashtech Z12T which will now be replaced by a GTR50 travelling receiver, and a global analysis of results has been started as part of a PhD thesis on GNSS calibration. Work on absolute characterization of delays has been started in collaboration with CNES and OP. A new GPS/GLONASS calibration campaign between OP and VNIIFTRI is ongoing, which will support a GLONASS Time Transfer Pilot Project currently in preparation.

Significant amounts of detailed information are now made available online through the FTP server and Web interface. This information includes data used for the computation of TAI, link comparison results, and results from comparison campaigns to characterize GNSS receiver delays.

In collaboration with the WGPFS, the uncertainty of frequency transfer to primary frequency standards has been refined. Over the period since the 17th CCTF in 2006, the quantity d reported in *Circular T* (the fractional frequency deviation between the scale unit of TAI and the SI second on the geoid) has evolved from $+1.0 \times 10^{-15}$ to $+5.7 \times 10^{-15}$. The steering policy for TAI has been maintained since CCTF 2004. Monthly steering corrections of up to 0.6×10^{-15} are applied, with a total correction since CCTF 2006 of 1×10^{-14}.

TT(BIPM) is computed in post-processing and updated every year, as reported by Dr Petit. It is used as a reference to evaluate f(EAL), f(TAI) and the performance of primary frequency standards. EAL shows a frequency drift of approximately -4×10^{-16} per month against TT(BIPM). To try to reduce this drift, tests were carried out to update the frequency prediction algorithm for masers in EAL to a quadratic model. Results indicate a 20 % reduction in drift, with work ongoing to improve the weighting model.

Results for the key comparison in time CCTF-K001.UTC have been published monthly in KCDB, with 46 participating laboratories. A proposal for a new key comparison in frequency, CCTF-K002.FREQ, has been prepared with the WGMRA, and submitted for adoption by CCTF (see discussion on this proposal under the report from the Working Group on the MRA).

The Time, Frequency and Gravimetry section has continued a well-established programme of international scientific coordination, both between NMIs and with international organizations such as IAG, ICG, IERS, IGS and ITU. These collaborations continue to be important to progress the activities of the section and for mutual benefit.

Dr Tuckey mentioned that a number of EURAMET laboratories had expressed a desire for improved information on GPS calibration campaigns, and thanked the BIPM for making this available online.

Dr Arias noted that ongoing characterization of GNSS receiver delays is necessary for the preparation of TAI and the dissemination of UTC. A proposal has been prepared to involve the regional metrology organizations more actively in supporting these campaigns, for discussion by the CCTF (CCTF/09-39).

Dr Boucher conveyed the thanks of the IUGG for efficient cooperation with the BIPM. The President thanked Dr Boucher for his comments and Dr Arias for the report.

3.2 Report of the CCTF Working Group on TAI

The President invited Dr Tavella to present this report.

Dr Tavella began by explaining that the terms of reference for the Working Group were changed at the 17th CCTF in 2006, to include a wider representation from participating NMIs as well as external agencies. The 8th meeting of representatives of laboratories contributing to TAI was held at the BIPM on 3 June 2009. No special issues or study groups required discussion, so the meeting was organized to present an overview across a variety of issues.

A total of 75 participants from 35 countries attended, including representatives from scientific unions, the CCTF president and BIPM staff. Approximately ten laboratories anticipate participation in TAI for the first time in the near future, including nations which are or expect to become Associate States and Economies of the CGPM.

Dr Tavella presented the agenda for the meeting, and highlighted some of the issues discussed:

- A number of participants requested further education regarding realization of time scales, laboratory practice and time scale algorithms, potentially at a future workshop (either regional or global). Further education and support could be a future responsibility of the Working Group.
- Characterization of receiver delays was identified as a key issue, with ongoing discussion regarding the limits of receiver performance and the need for future comparison campaigns.
- A common protocol for characterization of relative delay of GNSS receivers is to be developed by the BIPM together with RMO representatives. The BIPM also plans to draft guidelines covering the use of results for delay compensation.
- A view was expressed that current and future GNSS receiver manufacturers should be encouraged to ensure receivers accept external timing inputs, to facilitate time and frequency transfer.
- The ITRF coordinate frame was recommended as a standard when preparing data for time transfer from either GPS or GLONASS (and future GNSS systems).
- The BIPM presented results of a questionnaire conducted immediately after introduction of the most recent leap second, with several recommendations including that laboratories subscribe to the IERS for announcement of future leap seconds.

Dr Tavella also presented a short report on the Fifth International Symposium on Time Scale Algorithms, held at the Real Observatorio de la Armada in San Fernando (Spain) in 2008. A total of 70 participants attended, with about half from national metrology institutes and half from industry including telecommunication and navigation. Papers presented at the symposium are published in a special issue of *Metrologia* (**45**(6), 2008).

Dr Bauch noted the number of requests for training, and commented that several training programmes are already in place, for example the tutorials held prior to the IEEE Frequency Control Symposium and the NIST Time and Frequency Seminar.

Dr Tavella invited Dr Warrington to comment on training practices within the APMP region. Dr Warrington explained that training programmes were also in place in the Asia-Pacific, and that a two-day workshop in time and frequency had been held in conjunction with the APMP meetings in Sydney in 2007 that was well received by laboratories in the region.

Dr McCarthy endorsed the recommendation to adopt the ITRF in GNSS systems, as more than simply a reference frame to express coordinates. Dr Boucher similarly endorsed this recommendation, to be discussed further by the CCTF.

The President encouraged laboratories and regional organizations to support educational activities, particularly to assist them to develop new capability, and also to continue to improve the timeliness and quality of data submitted to the BIPM.

Dr Arias conveyed the BIPM's appreciation for the participation of laboratories, and requested some attention to ongoing minor issues. An increasing number of smaller laboratories contribute to TAI, which promotes the wider dissemination of UTC but imposes a greater requirement for order and organization. The impact of minor items such as unreported discontinuities accumulates across a large number of laboratories. Additional effort by laboratories to address these issues allows the BIPM to concentrate on improving the quality and timeliness of TAI.

4 FUTURE DEVELOPMENTS FOR UTC AND TAI

4.1 Improving clock frequency prediction in TAI

The President invited Dr Panfilo to present this report (CCTF/09-24).

In the calculation of EAL, a clock prediction algorithm minimizes the effect on the time scale of adding or removing a clock from the ensemble or of adjusting clock weights. Using a linear prediction model assumes constant frequency of the clock during the month.

Based on real clock data over a three-year test period from 2006 to 2008, the difference between prediction and reality at 30 days has a mean near zero for 100 Cs clocks, but shows a typical systematic deviation of up to 10 ns for hydrogen masers. As expected, this indicates that the linear model does not account for maser frequency drift.

EAL shows a frequency drift with respect to TT(BIPM) of approximately -4×10^{-16} per month. Over the test period, the mean drift for 40 masers against TT is about -4×10^{-16} per day, and for 100 Cs clocks about -1×10^{-17} per day.

A trial calculation of EAL after removing masers from the ensemble reduces frequency drift against TT by about 40 %, to -2.4×10^{-16} per month.

A new prediction algorithm adopts a quadratic model for hydrogen masers, requiring continuity of both first and second time derivatives. Applying the new algorithm reduces the systematic deviation between prediction and reality for maser test data, and reduces the drift of EAL against TT to -3.2×10^{-16} per month. About 20 % of EAL frequency drift is therefore attributed to use of the linear prediction model.

EAL still shows a drift against TT(BIPM). Further improvements may be possible by optimizing the estimation of frequency drift or the weighting algorithm.

The President encouraged Dr Panfilo to continue work to reduce EAL drift.

4.2 The TAIPPP pilot experiment: precise point positioning for TAI

The President invited Dr Petit to present this report (CCTF/09-19).

Dr Petit began by explaining that the 17th CCTF recommended in 2006 that the BIPM prepare for the introduction of GNSS carrier-phase techniques into TAI. The BIPM therefore continued its investigation of precise point positioning, begun prior to the recommendation. This technique is a natural successor to P3 all-in-view, with each station processed independently using IGS products to obtain [*UTC*(*k*) – *IGS time*] with time links obtained subsequently by simple difference. The NRCan GPSPPP software was first implemented at the BIPM in 2004, with multi-technique comparisons presented at several international meetings. The TAIPPP pilot experiment was proposed in early 2008.

A call for participation was issued in January 2008; 30 laboratories have expressed interest, with 21 participating in the first computation (May 2008), and 25 in the most recent computation (May 2009). Several stations also participate in the IGS network, with five to six of them contributing to IGS clock solutions.

PPP processing at the BIPM uses GPSPPP software developed and supported by NRCan, which continues to provide support. This software uses IGS ephemerides and clocks directly, with updated models for station displacements (for example due to tides) and troposphere mapping. It allows batch processing over a continuous period of 35 or 40 days, and is therefore well adapted to the computation of TAI. Ionosphere-free L3/P3 measurements are used to solve for station clocks and the zenith tropospheric delay (both at 5 min intervals), as well as station coordinates (one set per month). Results are made available on the BIPM FTP server.

Discontinuities at month boundaries are typically 150 ps in phase and 3×10^{-16} in rate, comparable to discontinuities at day boundaries obtained by IGS analysis. The magnitude of these discontinuities provides information on the performance of the PPP technique as applied at individual stations, effectively through a comparison between code and phase solutions.

The difference between link results obtained from TWSTFT and PPP shows a typical RMS from 0.2–0.6 ns, generally towards the lower half of this interval and consistent with u_A <0.3 ns assuming nominal conditions. Previous three-way comparisons between PPP, Ku-band TWSTFT and X-band TWSTFT indicate that each of these techniques appears stable at the level of 100–300 ps up to an averaging time of ten days, with PPP generally more stable up to this time and Ku-band TWSTFT somewhat noisier than the other two techniques.

Site calibration information is not handled through standard RINEX data, but is relayed separately to the BIPM using a header format similar to standard CGGTTS data. BIPM calibration campaigns will continue to support the characterization of receiver delays at both L1 and L2 frequencies.

The routine use of PPP for TAI links appears satisfactory, and the BIPM intends to introduce PPP links into the calculation of TAI as soon as practicable. Suggested uncertainties are u_A ~0.3–0.5 ns, depending on the magnitude of monthly discontinuities, and u_B ~5 ns as for other GNSS techniques.

The President asked when the BIPM plans to introduce PPP links into the calculation of TAI, and Dr Petit replied that it was proposed to introduce these links before the end of 2009.

The President enquired whether it was necessary to decide formally on appropriate levels of uncertainty, but Dr Petit explained that these could be obtained directly by analysis of station data.

Asked how many stations were currently participating in the pilot experiment, Dr Petit confirmed that 25 laboratories contributed data to the most recent monthly calculation, with several additional laboratories expected in the near future.

Dr Levine commented that non-statistical or Type B uncertainties will dominate the overall link uncertainty, as they do for existing techniques, and asked whether the introduction of PPP would therefore lead to a significant improvement over these techniques. Dr Petit replied that the use of PPP does offer a significant improvement for frequency transfer, where Type B uncertainties do not enter, and noted that alternative calibration techniques may also be applicable for PPP transfer which may support lower Type B uncertainties.

Dr Levine pointed out that there is little evidence to argue that Type B uncertainties are constant over time, and some evidence to the contrary, which may still limit the performance of frequency comparisons. Dr Petit noted that any long-term variation in receiver delay should still appear in discontinuities at monthly boundaries, which would therefore increase the corresponding Type A uncertainty under the proposed analysis.

Dr Tavella asked whether these monthly discontinuities, and therefore the corresponding Type A uncertainties, vary from link to link and from month to month. Dr Petit explained that while these certainly vary from link to link, they should not vary significantly from month to month, so that any observed change over time should generally prompt further investigation at the relevant participating laboratory.

4.3 Multi-technique combination for UTC/TAI time/frequency transfers

The President invited Dr Jiang to present this report.

Dr Jiang began by explaining the current ‘single-technique single-link’ transfer strategy used for TAI and UTC: one transfer technique is designated as primary (official) and used alone, in preference to others operating in parallel as backup. TWSTFT and GNSS techniques each have their own advantages and disadvantages, comparing for example performance, complexity, cost and dependence on external service providers. Combining the two techniques may draw on combined advantages, for example to improve robustness, repair data faults such as discontinuities, or reduce diurnal variation.

Three methods have been proposed to combine two-way (TWSTFT) and GPS data: forming a weighted average of TWSTFT and GPS (Petit and Jiang, *EFTF*, 2006); using TWSTFT as a constraint in a least-squares optimization of a GPS carrier-phase network in common view (Defraigne and Martinez, *EFTF/PTTI*, 2008); and using TWSTFT as the absolute scale of a time link and GNSS carrier-phase data as its derivatives (Jiang and Petit, *Metrologia*, **46**(3), 2009).

Dr Jiang presented data showing the advantages of a combination of TWSTFT+PPP over TWSTFT or PPP alone, including a reduction in TDEV at averaging times shorter than one day and an improvement in loop closure for the TL-NICT-KRISS triangle.

A total of 19 laboratories currently operate both TWSTFT and PPP equipment, contributing 88 % of total clock weight in UTC/TAI and covering 100 % of links to operational primary frequency standards. Any improvement in time and frequency transfer for these links can therefore translate to a corresponding improvement in the performance of TAI and UTC.

Dr Bauch asked how many TWSTFT data points are required to enable a combined solution, and Dr Jiang estimated a minimum of four points per day. Dr Matsakis commented that more measurements may be needed to quantify any residual diurnal variation, or fewer if this is shown to be absent.

Dr Tavella asked how exactly measurements are combined, for example PPP observations every 5 min with TWSTFT observations every hour. Dr Jiang replied that the method is not easy to explain clearly, and suggested referring to published details. Dr Arias clarified that the method is based on a filtering approach by application of a tailored smoothing algorithm.

Dr Arias went on to suggest that a detailed proposal for implementation could be prepared following evaluation of advantages and disadvantages. Dr Tavella asked whether further time was needed for this evaluation, and Dr Arias recommended that link comparison results be calculated and published for review. Dr Bauch encouraged the BIPM to continue calculating and publishing these results for all techniques, to gain additional information on link performance.

Dr Tavella noted that once further evaluation is completed, the WG on TAI could be consulted to review a proposal and consider future implementation.

4.4 GLONASS time transfer

The President invited Dr Lewandowski to present this report.

Dr Lewandowski began by noting that [*UTC – GPS time*] as reported in *Circular T* is typically small (currently approximately 20 ns) as GPS time is well controlled. [*UTC – GLONASS time*] shows much larger deviations (several hundred nanoseconds) and lower stability. Also, satellite clocks cannot be computed accurately, for this reason, GLONASS time cannot be used for all-in-view time transfer, but only for common view.

The planned expansion of the GLONASS constellation is progressing, with 17 satellites currently operational. About 12 laboratories are currently equipped with the newest GPS/GLONASS receivers, notably AOS, OP, PTB and VNIIFTRI.

Dr Lewandowski reported that tests of common-view time transfer using GLONASS are showing similar performance to GPS. The BIPM intends to start a GLONASS Time Transfer Pilot Project, with GLONASS code data reported in CGGTTS format and carrier-phase data in RINEX format.

Typical code-only links (for example AOS-PTB or SU-PTB) show RMS scatter of a few nanoseconds without applying IGS precise ephemerides. GPS and GLONASS P1 data for the link between AOS and BIPM show similar performance, with GLONASS RMS a little larger (~1.8 ns).

One particular issue is the selection of a reference frame for antenna coordinates, where the current recommendation is to adopt ITRF as standard. GPS uses WGS84, which is very close, but GLONASS uses PZ90 which differs by some metres. Adopting ITRF as the reference frame avoids inconsistency and facilitates use of IGS data products.

Dr Lewandowski concluded with the observation that use of combined GPS and GLONASS data is helpful in preparation for expanding GNSS constellations, particularly GALILEO.

Dr Bauch noted that PTB is equipped with a GLONASS receiver and is ready to contribute to ongoing evaluation, and Dr Tuckey noted that OP is similarly ready to participate. Dr Lewandowski reported that a link between PTB and VNIIFTRI is planned for the near future.

Dr Bauch enquired about the origin of the offset between GPS time and UTC(USNO), which was apparent in data presented in the report. Dr Matsakis explained that although both [UTC – UTC(USNO)] and [GPS time – UTC(USNO)] are close to zero; [UTC – GPS time] is not zero. This issue is related to the calibration history of the GPS receivers involved, and is associated with the use of different equipment and protocols.

5 TIME AND FREQUENCY TRANSFER METHODS

5.1 Report of the CCTF Working Group on TWSTFT

The President invited Dr Klepczynski to present this report (CCTF/09-16).

Dr Klepczynski began by summarizing participating stations (a total of 22, with 2 in North America, 13 in Europe and 7 around the Pacific Rim). The Working Group has met 16 times, beginning in 1993.

The most critical current issue for the Europe/US network is the impending move of operations from IS-3R, operated by Intelsat, to TS-11N, operated by Telsat. Transfer via IS-3R began in February 2008 as a solution to equipment malfunction on IS-707, but IS-3R will in turn reach end-of-life in September 2009. A key problem is that the cost for operation on TS-11N will be twice the current cost on IS-3R for the same bandwidth. To address this problem, the contract for time on the new satellite will be arranged through an open bidding process, and alternative modulations are under investigation to reduce the bandwidth requirement.

TWSTFT operations in the Asia-Pacific moved from JCSAT-1B to IS-8 on 1 April 2009. This network links KRISS, NICT, NTSC and (in future) TL, with A*STAR no longer covered by the new satellite. A NICT-USNO link is planned, via IS-8 to a relay station in Hawaii.

A TWSTFT network linking Asia and Europe is currently operational using IS-4. Link fees are shared between OP and PTB in Europe and KRISS, NICT, NMIJ, NTSC and TL in Asia. NIM and VSL will join this network in the near future. IS-4 will reach end-of-life in summer 2010, and a search for replacement satellite capacity is in progress.

To reduce required bandwidth, and significantly reduce operational costs, the use of 1 MChip/s codes has been studied as an alternative to the 2.5 MChip/s codes currently used. The results of testing in progress since February 2009 show that for most links, although the lower chip rate degrades stability for averaging times from 2 h to one day, 1 MChip/s and 2.5 MChip/s TWSTFT show the same TDEV for averaging times of one day and longer. However, results at 1 MChip/s show a strong diurnal for most links; the level varies from link to link, but can be up to 2 ns for some stations.

Calibrations of TWSTFT station delays have been carried out by both direct and indirect methods. Three direct calibration campaigns using the TUG portable Ku-band station show typical uncertainties of 1 ns, or a little lower in the best cases, and demonstrate repeatability at a level of approximately 0.5 ns. The NICT portable Ku-band station has been used to calibrate the NICT-TL and NICT-KRISS links, achieving uncertainties of 0.6 ns and 1.3 ns respectively.

The technical memorandum BIPM TM151 presents a strategy for calibration of a TWSTFT network, by propagating direct calibrations of selected links to uncalibrated links by requiring triangle closure. Uncertainties of these indirect calibrations are estimated to be either 2 ns or 6 ns, depending on whether the direct calibration was performed using a portable TWSTFT station or by reference to a GPS link.

Future areas of interest for the development of TWSTFT include the development and evaluation of carrier-phase techniques, and ongoing improvement of links between Europe, North America and the Asia-Pacific.

Dr Warrington noted that the proposed NICT-USNO link would enable a long closed loop around the world, and enquired whether this would offer any particular advantages for evaluation of TWSTFT performance. Dr Klepczynski replied that such a long circuit would provide greater information on the consistency and stability of delay information, but also allows for continued expansion of the operational network. Dr Warrington agreed that this would enable operations to be resumed from Australia, as one example.

Dr Koyama explained that this link is still in preparation by NICT. The arrangements are complicated by the requirement to transfer operations from IS-4 for Asia-Europe links at a similar time.

5.2 Report of the IGS Working Group on Clock Products

The President invited Dr Senior to present this report.

Dr Senior began by summarizing the availability of high-performance clocks within the IGS network. Approximately 25 IGS stations are colocated at timing laboratories, with data from both caesium standards and hydrogen masers available in principle for use in IGS clock products.

Dr Senior also presented a summary of the current suite of IGS core products. Final products are available at a latency of up to 20 days, with accuracy of orbits approximately 2.5 cm and of clocks approximately 0.1 ns. Rapid and Ultra-Rapid products are available at lower latency and a correspondingly reduced accuracy.

The IGS Real Time (IGS RT) Pilot Project began in 2008, with the goal to produce near-real time products with very frequent updates. About 60 global tracking stations currently contribute 1 Hz data, with five real-time analysis centres participating in product generation. The update interval for clock products has not yet been determined but is expected to be a few seconds, and uncertainties of order 0.25 ns are projected. These products are not yet available but are expected soon.

Dr Senior presented a summary of the stability of GPS SV clocks, evaluated from IGS data over averaging times up to one day. These results, together with an analysis of periodic clock perturbations at harmonics of two cycles per day, are used to tailor filter characteristics. They also indicate that clock prediction errors exceed 100 ps after approximately 50 s for Block IIA Cs and Block IIR Rb clocks, which implies that the data latency for real-time clock services should be less than 50 s to maintain prediction accuracy at or below 100 ps. Testing of Block IIF Rb clocks at NRL shows further improved stability, which should allow an increased reporting interval in the future.

Dr Senior also presented a series of examples comparing IGS estimated clocks to IGST. The magnitude of day-boundary discontinuities varies strongly between sites, and provides a quantitative measure of site performance. A hypothesis proposed by Jim Ray is that near-field multipath is a likely cause of these discontinuities, with station performance consequently dependent on appropriate antenna installations but also on cables and receivers. This hypothesis appears to be supported by well-performing IGS sites with good monumentation, for example BRFT with a tripod mount and ONSA where the choke-ring rests in a matrix of microwave absorbing material.

The IGS time scale currently relies on GPS time as the sole reference to UTC. Multiple IGS stations colocated at timing laboratories can provide a higher quality and more robust link to UTC, through data published in *Circular T*. The stability of a selected set of these station clocks suggests a time constant of approximately 70 days for steering a new time scale to UTC. This new IGS time scale has completed testing, with a major reprocessing effort currently under way and the first product results expected in late FY09 or early FY10.

Dr Bauch requested a clarification regarding the interpretation of the accuracy of predicted SV clocks for ultrarapid products. Dr Senior confirmed that this means that the uncertainty of the difference between station and predicted GPS SV clocks is approximately 5 ns.

Dr Tavella commented that not all realizations UTC(k) are maintained within 100 ns of UTC, despite the recommendation of the CCTF, and that larger offsets may limit the achievable performance when using these data to link IGS time scales to UTC.

Dr Jiang enquired about the future availability of GLONASS clock products. Dr Senior replied that these are under development, but are not yet of sufficient quality for release.

5.3 Report of the CCTF Working Group on GNSS Time Transfer Standards (CGGTTS)

The President invited Dr Levine to present this report (CCTF/09-23).

Dr Levine began by setting out his view of two ‘boundary conditions’ for the Working Group. First, time transfer is needed to support optical clocks with an intrinsic accuracy at the level of 1×10^{-16}, and new techniques are consequently needed to deliver performance significantly below this level. Second, established laboratories have a responsibility to support emerging laboratories in developing Economies, particularly in the area of time transfer.

Dr Levine noted that older C/A code-based receivers are currently being replaced by P-code and carrier-phase techniques. Software available to convert observations from RINEX format to CGGTTS format cannot fully realize CGGTTS technical directives, for example because data is often decimated at 30 s intervals. It is conventionally argued that this difference is not significant, and that both protocols yield effectively identical results. In this case, are the technical directives still necessary? These directives may be seen as an artefact of the original single-channel receivers, and may be revised over the longer term to better reflect current practices. For example, 13 min tracks are not needed for newer receivers, and current storage capacity, processing speed and transmission bandwidth could all support full-arc measurements.

Dr Levine went on to identify two current issues in GNSS time and frequency transfer. First, carrier-phase transfer is very important for the development of primary frequency standards and next-generation optical clocks, but although many processing packages are available these disagree at the 0.1 ns level, which should consequently be interpreted as an estimate of the intrinsic uncertainty of any one analysis. Some analyses also differ in estimating frequency at the 10–15 level.

Second, timing laboratories generally submit GPS data to the BIPM monthly, but could send them every day. Daily transmission would support new timing products, for example a real-time estimate of laboratory comparisons $[UTC(k_1) - UTC(k_2)]$ at latencies of one day. This would provide additional information to assist smaller laboratories to track local realizations UTC(k) over shorter time scales than currently supported by *Circular T*.

Dr Levine concluded with a set of specific recommendations:

- The CGGTTS technical directives are obsolete and should be phased out; new protocols should support shorter and more frequent tracks, with complex averaging not necessary.
- Discrepancies among geodetic analyses should be addressed and understood.
- The advantages of rapid data submission should be exploited to improve the stability of realizations of UTC at smaller laboratories.
- The functions of CCTF Working Groups should be reviewed, and the work of the CGGTTS potentially reallocated or subsumed within related groups.

The President invited comment from the BIPM regarding the proposed review of technical directives. Dr Arias agreed to a revision of the technical directives, and that analysis discrepancies should be investigated. Dr Arias also drew a clear distinction between possible new products supported by more rapid submission and previous proposals for more ‘real time’ dissemination of UTC.

Dr Arias also reported that smaller laboratories are asking questions (sometimes simple) of the BIPM, and noted from discussion at the meeting of the Working Group on TAI that the need for support is increasing. This need can be met in part by workshops or formal training, but also through provision of tools which all laboratories can use. Dr Levine clarified that his proposal did not necessarily require the BIPM to undertake this work, but that the key requirement is to make data available.

Dr Arias commented that laboratories seeking to compare two realizations UTC(*k*) typically have all the information required, at least in principle. A ‘black box’ solution provided externally is not necessarily the best, as laboratories need to be enabled to undertake this work themselves.

Dr López-Romero suggested that experience within SIM may be helpful in this area, for example through provision of tutorials to emerging laboratories. Dr O’Brian stressed that SIM is a cooperative network where all agencies collaborate, rather than a framework for NIST alone to provide support.

Dr Petit commented that agreement in time-transfer analyses to the 0.1 ns level can also be regarded as an achievement. Dr Defraigne reported that a project is currently under way at ORB to undertake a strict comparison of techniques.

Dr Warrington expressed a view that support and education programmes can be particularly successful when undertaken cooperatively within the metrological regions. Each of these regions contains a mix of established and emerging Economies, where RMO structures provide an effective framework for cooperation. Dr Warrington also commented that support in the area of time transfer enables laboratories to support wider dissemination within their own Economies in turn.

The President concluded discussions by noting that ongoing examination of these key issues is required, and recommended that the CCTF continue to refine the mix of Working Groups and revise terms of reference as necessary.

5.4 Report of the CCTF Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques

The President invited Dr Tuckey to present this report.

Dr Tuckey began by reporting that the Working Group was established following a CCTF recommendation in 2006 but had not yet been convened. The report therefore summarizes the current situation regarding the performance of both clocks and comparison techniques, and discusses future prospects.

Regarding microwave standards, several Cs fountains and at least one Rb fountain show accuracy better than 10^{-15}, with instability reaching 2×10^{-14} at 1 s and local comparisons achieving statistical uncertainties of 1×10^{-16} at one day. For optical standards, the best single-ion clocks have estimated systematic uncertainties of 2×10^{-17}, and an instability of 3×10^{-15} at 1 s reaching 4×10^{-17} at a few hours. Optical lattice clocks already rival primary microwave standards and continue to evolve rapidly. Systematic uncertainties in the 10^{-18} range are expected; stability depends on ultra-stable laser oscillators, projected into the 10^{-16} range at 1 s in coming years.

Turning to transfer techniques, the instability of TWSTFT is approximately 2×10^{-15} at one day with GPS carrier-phase methods comparable, and stabilities continue to improve at longer times. Dr Tuckey noted that the emphasis in the report is on frequency comparison rather than time transfer, where calibration issues also enter.

Optical fibre links carrying stable optical references are in routine use for local and ‘semi-local’ links up to tens of kilometres. Links up to 100 km have been demonstrated, achieving stabilities of 2×10^{-16} at 1 s to below 10^{-18} at one day.

Transportable references require excellent stability and repeatability rather than accuracy. The SYRTE transportable Cs fountain, conceived as a primary frequency standard rather than an explicitly transportable reference, currently has an instability of 1×10^{-13} at 1 s and an accuracy of 7×10^{-16}.

The Time Transfer by Laser Link (T2L2) experiment was launched on the Jason-2 satellite in 2008. The expected instability in common view is 1×10^{-16} at one day, one order of magnitude better than current TWSTFT. Stability is degraded by the on-board oscillator in non-common view, but this is a limitation of the existing satellite only.

Dr Tuckey summarized current prospects for further improvement in transfer techniques:

- TWSTFT: increase chip rate or adopt carrier-phase techniques; an instability of 1×10^{-16} at one day appears plausible.
- PHARAO/ACES: launch scheduled for 2013, with the onboard microwave link and clock ensemble a tool for long-distance clock comparisons. Non-common-view design instability is 5×10^{-17} at one day.
- Long-distance optical fibre links: these need repeater systems. Assuming stability scales with the square root of distance, a 1,000 km link has a projected instability of 1×10^{-15} at 1 s, reaching the 10^{-18} level at one day.
- Transportable standards: European space agencies are currently supporting the development of a transportable optical frequency standard, initially an Sr lattice clock.

In discussing this situation, Dr Tuckey pointed out that the limited reliability of currently operating standards introduces dead time which limits the performance of comparisons. Long distance comparison methods need to reach clock stability rapidly, with the current situation unsatisfactory.

A consensus on optical frequency comparisons is an essential requirement to move towards a future redefinition of the second. Optical fibre links show significant promise, but much work remains and there are practical and cost implications in securing access to available fibre. Intercontinental comparisons currently require satellite-based methods, where drift in equipment delays may set a limit on achievable frequency accuracy.

Dr Tuckey concluded with two proposed recommendations:

- first, vigorous development of optical fibre link methods for comparisons between optical clocks in support of a future change in the definition of the second;
- second, vigorous development of improved methods for intercontinental comparisons between optical clocks in support of a future change in the definition of the second (for example, TWSTFT using increased chip rates and carrier-phase data, ACES MWL and T2L2).

The President thanked Dr Tuckey for the report, and suggested that the report to the next meeting of the CCTF include a quantitative comparison showing the improvement since the current meeting.

Dr Koyama pointed out that NICT is currently investigating a number of precise transfer methods, and would be interested to participate in the activities of the Working Group. NICT also suggest the possibility of exploring VLBI time transfer, where current geodetic techniques estimate clock offset between global stations at the level of 20 ps.

Dr Boucher raised two further suggestions: redefining time scales to avoid uncertainties associated with the geoid, and extending the T2L2 technique to satellites with improved on-board clocks and higher orbits. Responding to the first, Dr Petit noted that any redefinition of time scales does not address the primary problem of a comparison between two clocks at different points on the geoid. Responding to the second, Dr Tuckey confirmed that proposals are already under consideration, including for dedicated missions.

Dr Gill noted that there was significant discussion within the European community regarding future ESA missions involving optical clocks. The technological readiness of optical clocks would need to be improved over the next decade to enable such a mission, which might have fundamental science as its primary focus but would also enable a potential ‘master clock in space’ for the future.

Dr Arias reminded the meeting of the CCTF recommendation in 2006 to establish the Working Group, and asked for confirmation of the need for it, as well as its composition. Dr Bauch also asked whether there was any overlap with the work of the proposed Working Group on Strategic Planning. The President expressed a view that the Working Group on Advanced Transfer Techniques should still exist, and that little overlap was expected. Dr Riehle noted that this Working Group was also recommended by the CCL-CCTF Working Group on Frequency Standards, which did not have detailed expertise in time and frequency transfer.

The President suggested that Dr Tuckey prepare a proposal on the composition of the Working Group and draft terms of reference for review by the CCTF, in accordance with the recommendation at CCTF 2006 and drawing on established research activity in this area.

6 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 Cordara to present this report (CCTF-09/20).

Dr Cordara began by reporting actions since the 17th CCTF, including a new formation of the Working Group with a new chair and new representatives from the RMOs; a change of the identification of the key comparison for time in the KCDB, to CCTF-K001.UTC (March 2007); collaboration with the BIPM to develop a proposal for a new key comparison for frequency, CCTF-K002.FREQ; and collaboration with the JCRB on CMC review matters.

Dr Cordara explained that he had worked closely with the BIPM Time, Frequency and Gravimetry section following the resignation of the previous chair. The process to form the Working Group of nominated RMO representatives (chairs of RMO technical committees) had been somewhat lengthy, with still no representative from COOMET. Dr Arias is secretary and Dr Cordara chair of the Working Group.

A series of informal meetings was held to discuss the proposed key comparison for frequency, with the BIPM and also EURAMET and SIM representatives. The first formal meeting of the Working Group was held in Besançon (France) in April 2009, to evaluate a study of the key comparison performed at the BIPM and the proposed implementation (CCTF/09-18).

The Working Group also prepared responses to questionnaires received from the JCRB secretary in April 2007 and December 2008, regarding maintenance activities of CMCs in the field of time and frequency and related issues.

Dr Cordara presented a list of tasks assigned to the CCTF within the framework of the MRA. Some of these are delegated in turn to the BIPM TFG section, in particular review and publication of key comparison results. Additional tasks cover review of bilateral key comparisons, and key and supplementary comparisons undertaken by RMOs. In these cases no new results are known to the WGMRA, and consequently no action has been required.

A key motivation for the development of the proposed key comparison in frequency CCTF-K002.FREQ is that most CMCs of calibration laboratories accredited within ILAC and regional accreditation bodies are in the field of frequency. Monitoring key comparison results to support the frequency CMCs claimed by the NMIs therefore has a high priority, in accordance with the request of the JCRB.

A similar motivation for the development of the proposed key comparison of primary frequency standards CCTF-K003.PFS is that a few laboratories declare CMCs where the frequency reference is a primary frequency standard, and these CMCs may not be adequately supported by CCTF-K001.UTC. The Working Group agreed in April 2009 to prepare a proposal for CCTF-K003.PFS, comparing the frequency of primary standards to that of TAI and UTC using results published regularly in Section 4 of *Circular T*. The BIPM agreed to draft the written proposal to be submitted to the CCTF.

The Working Group had also prepared a response to a questionnaire received from the JCRB in December 2008. The questionnaire covered several matters related to CMCs:

- Revision of lists of CMCs: According to JCRB directives, this revision should take place after five years. The WGMRA has agreed to take on this responsibility. No revision of CMCs has yet been made, because the first time and frequency CMC declarations were published in 2003 and the first key comparison results in January 2005. The key comparison for frequency is also not yet implemented.
- Inclusion of the uncertainty of the device under test (DUT) in CMCs: Dr Cordara pointed out that the approach adopted by WGMRA Guideline 2 is a special case, not adopted in other technical areas.
- Traceability: Document CIPM2008-46 on traceability makes a statement concerning laboratories with a primary realization of a unit of measurement that should be interpreted by the WGMRA.
- Low-level services: these are already covered in WGMRA Guideline 1 for the field of time and frequency, and no revision is foreseen by the WGMRA.

Regarding review of CMCs for time scale difference, Dr Cordara noted that the uncertainty in the prediction of [$UTC - UTC(k)$] is a key contribution to these CMCs, and that values for this uncertainty declared by laboratories show a large variation from 20 ns to 200 ns for a 20-day prediction interval. Dr Cordara suggested that the Working Group study this issue and prepare a formal guideline for evaluating this uncertainty.

In conclusion, Dr Cordara proposed revised terms of reference for the Working Group, as follows:

a) Authorization on a provisional basis for any action needed between meetings of the CCTF as indicated by the MRA, in consultation with the CCTF President;

b) Perform coordination activities relating to the MRA between RMOs;

c) Act as point of contact for the BIPM and JCRB on MRA matters;

d) Report actions to the next CCTF meeting, the CCTF revising the decisions as required;

e) Identify areas where additional key comparisons and supplementary comparisons are needed, and develop the necessary guidelines and procedures;

f) Provide guidance on the range of CMCs supported by particular key and supplementary comparisons;

g) Establish and maintain a list of service categories, and where necessary rules for the preparation of CMC entries;

h) Agree on detailed technical review criteria;

i) Coordinate the review of existing CMCs in the context of new results of key and supplementary comparisons.

Report on the Key Comparison CCTF-K001.UTC

Dr Arias explained that this report is no longer necessary. Beginning in 2005 and following a decision of the CCTF, the BIPM is mandated to update the formal results of the key comparison each month after publication of *Circular T* following a format and procedure agreed with the KCDB.

Dr Thomas noted that this key comparison is unique in that it is updated every month. The key comparison reference value (UTC) is computed from all participating clocks, including some in Economies not signatories to the CIPM MRA. Published degrees of equivalence are restricted to those Economies that are signatories.

Dr Achkar commented that this situation is unusual. Dr Thomas explained that while there is no scientific reason for this decision, it does encourage laboratories to reduce the uncertainty in $[UTC - UTC(k)]$, which is a scientific output. Dr Arias noted that this issue had been considered at length in the preparation of the key comparison.

Prof. Kühne noted that WGMRA Guideline 2 refers to an ‘ideal’ DUT, and observed that this is at odds with the common definition of CMCs agreed with ILAC. The President suggested returning to this point after all presentations under this agenda item, but time did not ultimately permit further discussion.

Proposal for a Key Comparison in Frequency, CCTF-K002.FREQ

Dr Panfilo presented an evaluation of uncertainties for the proposed key comparison in frequency (CCTF/09-18), with reference to further results available in the literature.

The frequency deviation between UTC(k) and UTC can be determined from values of $[UTC - UTC(k)]$ available at five-day intervals. The degree of equivalence for frequency can therefore be derived from the existing key comparison for time, with an uncertainty linked to the uncertainties for $[UTC - UTC(k)]$ reported in Section 1 of *Circular T* and to link uncertainties reported in Section 6. Assuming white phase noise, the uncertainty in the mean frequency is

$2\,u_A^2/\tau^2$, where only the statistical uncertainty u_A in $[UTC - UTC(k)]$ appears (as the calibration uncertainty u_B does not affect frequency) and it is assumed that u_A is constant over the period τ.

Dr Panfilo noted that this information is only available in retrospect, after publication of *Circular T*. Prior to publication, laboratories must predict the frequency uncertainty, based on the stability of their realization UTC(*k*). Laboratories can also extrapolate evaluation of the frequency offset and its uncertainty to shorter time intervals by following WGMRA guidelines, refined as necessary if further information about link uncertainties is also available.

The President noted that this protocol was requested by the 17th CCTF, prepared by the BIPM TFG section, submitted to the WGMRA, and approved by the Working Group.

Dr Tuckey asked why the frequency of UTC was adopted as the reference for the comparison, rather than the SI hertz. Dr Arias explained that the reference value was chosen to be consistent with CCTF-K001.UTC, to adopt the same reference for both time and frequency. She also noted that the proposed CCTF-K003.PFS is not merely a comparison of primary frequency standards, but is more strictly a key comparison for participating frequency standards with a reference value derived from the definition of the SI second. Dr Tuckey commented that although there is a practical argument for adopting the frequency of UTC as the reference, this is not the SI unit, and it appears anomalous to adopt a key comparison with a frequency reference that is not the SI base unit.

Prof. Kühne also asked whether this key comparison was new, or whether it was simply a re-analysis of the existing key comparison for UTC. Dr Quinn echoed these comments, and observed that *Circular T* had been in a sense a model for the development of the CIPM MRA, with regular comparisons and a reference value. Noting that a key concern since the establishment of the MRA has been the need to minimize bureaucracy, Dr Quinn suggested that it may be more practical for the CCTF to retain a single key comparison and extract from it whatever data are required, rather than trying to adapt its activities to the MRA comparison framework.

Dr Arias reiterated that this key comparison had been requested by the 17th CCTF in 2006, with the motivation to support CMCs in frequency. Dr Quinn asked whether this support could be provided from the existing key comparison. The President observed that the requirement for the proposed key comparison did not appear to be agreed. Prof. Kühne also requested that this requirement be clarified, in order to support the additional implementation workload for the BIPM.

Dr Warrington expressed the opinion that the existing comparison CCTF-K001.UTC appears sufficient to support CMCs in the field of frequency, based on successful peer assessments conducted to date within RMOs. NMIs already analyse the results of CCTF-K001.UTC to support their frequency CMCs, and these CMCs have been successfully reviewed prior to publication in the KCDB. Dr Warrington suggested that it may be sufficient to standardize this analysis through a formal protocol, similar to the existing guidelines prepared by the WGMRA.

The President suggested further discussion on this proposal by the WGMRA, BIPM, the KCDB Coordinator, Prof. Kühne and Dr Warrington.

Dr Arias noted the effort required to prepare the proposed protocol, and asked for a clear direction from the CCTF regarding the preferred developments in this area. Dr Cordara similarly observed that revisiting the proposal would be a change in direction from the 17th CCTF in 2006.

Dr Parker agreed that CCTF-K002.FREQ does not appear to be required, noting that the comparisons of primary frequency standards reported in Section 4 of *Circular T* are of an essentially different character. Dr López-Romero also agreed that a guideline from WGMRA should provide sufficient support for frequency CMCs. Prof. Kühne expressed the opinion that CCTF-K002.FREQ is not in principle a new key comparison but rather a re-analysis of the results CCTF-K001.UTC. If reviewers can rely on this re-analysis through a specified procedure, there appears no real need for a new comparison.

The President proposed to revisit the decision of the 17th CCTF in 2006 to develop this new comparison, and to consult further to revise the proposal as discussed. Dr Bauch commented that one motivation for the earlier decision may have been to improve the presentation of results, which might also be achieved through presentation of derived frequency data. Dr Arias observed that many of these issues were discussed during the early formation of the MRA since 1999. They arise owing to the special character of time and frequency comparisons, which do not relate to an artefact but to a continuous time scale. The presentation of results in the KCDB is therefore a challenge, but is required under the principles of the MRA to support transparency and to allow clients to compare services. Some of the difficulty in repeated discussions expresses an essential conflict between the existing MRA structure and the special character of time and frequency standards, which cannot 'keep a second in a bottle'.

Dr Thomas commented that effective presentation of results may be sufficient to ensure that the calculation of UTC meets the formal requirements of the MRA. For example, it may be more efficient to replace the graph of results for [$UTC - UTC(k)$] currently prepared monthly for the KCDB by a reference to *Circular T* for this information.

Dr Quinn expressed the opinion that if he were asked now how the time and frequency community might participate in the CIPM MRA, he would recommend that *Circular T* be adopted as the key comparison in this area. Publication in the KCDB may not be needed if equivalent procedures could be formalized by the CCTF.

The President reiterated that WGMRA should revisit this issue, including analysis protocols and presentation of data, in order to deliver information useful to support CMCs without unduly increasing the workload required to deliver this information. Dr Cordara asked whether it was therefore appropriate to withdraw the proposal for CCTF-K002.FREQ. The President formally proposed that this recommendation be withdrawn, and there was no disagreement.

Proposal for a Key Comparison of Primary Frequency Standards, CCTF-K003.PFS

Dr Arias tabled a report on the proposed comparison (CCTF/09-31), and noted that the proposal is essentially the same as previously presented to earlier CCTF meetings.

The President queried the motivation for this comparison, and in particular which laboratories would need it to support CMCs. Dr Bauch and Dr Parker confirmed that PTB and NIST would make use of it, but asked if the key comparison was required for such a small number of laboratories. Dr O'Brian expressed the opinion that it was not, and suggested revisiting how the capabilities of these laboratories are supported within the framework of the MRA, in a similar way to the discussion of CCTF-K002.FREQ.

Dr Thomas presented specific suggestions for adapting publication of results in the KCDB to provide additional links to *Circular T*. Dr Arias asked whether it was useful to formally republish *Circular T* in the KCDB, and whether equivalent results might be achieved by adopting appropriate guidelines as for CCTF-K002.FREQ. This would help to minimize the effort required monthly by the BIPM, which may be used more effectively elsewhere. Dr Thomas agreed that this should meet the requirements of the KCDB office and Coordinator, but pointed out that it is important to retain the formal decision by the CCTF in 2001 that UTC is the key comparison reference value for the key comparison in time and frequency.

The President observed that accreditation bodies may also need the information currently published in the KCDB. Dr Arias noted that this information would still be available in *Circular T*, although it may be in a slightly different form.

Dr Arias showed the meeting results from the KCDB online, including equivalence values and the graphical presentation of [UTC – UTC(k)]. The general feeling of the meeting was that publication of this information in the KCDB is not required.

Concluding this discussion, the President established formally that CCTF-K003.PFS is not required by requesting opinions from PTB and NIST. Dr Arias summarized the decisions taken, to interrupt the existing monthly publication of *Circular T* results as CCTF-K001.UTC in the KCDB; to replace this publication with a statement to be prepared by the WGMRA, identifying *Circular T* as the key comparison for time and frequency in the framework of the MRA and as the source of all information; and to withdraw the proposed key comparisons CCTF-K002.FREQ and CCTF-K003.PFS.

Dr Tavella commented that this discussion is really the work of the WGMRA, rather than of the entire CCTF, but the current membership of the Working Group does not make this easy. Dr Tavella suggested that adding additional technical experts to the WGMRA would enable the group to better address these issues.

Dr Riehle observed that it is necessary to retain all existing data already published in the KCDB, and to make it clear that this now continues in *Circular T* with only the publication procedure changed.

Dr Quinn noted in conclusion that the CIPM MRA text identifies that the CIPM is primarily responsible for the MRA. The CCTF is responsible for the key comparisons to support CMCs, and has the authority to review these as required.

The President proposed revision of the terms of reference of the WGMRA, including extension of membership to add additional technical experts. Dr Warrington (NMIA) and Mr Dierikx (VSL) volunteered to assist the WGMRA.

7 REPORTS OF TIME AND FREQUENCY ACTIVITIES BY THE REGIONAL METROLOGY ORGANIZATIONS

Report of SIM Time and Frequency Activities

The President invited Dr López-Romero to present this report.

Dr López-Romero began with an overview of the Interamerican Metrology System (SIM), which consists of NMIs in 34 members of the Organization of American States, with about two-thirds of its total population in the United States, Mexico and Brazil. Not all SIM Economies are well established in international timekeeping, but participation from the Americas is increasing and has significant potential for future expansion.

The SIM Time Network is operated by the Time and Frequency Metrology Working Group. The overall goals of this network are to support cooperation and communication between SIM time and frequency laboratories, and to provide smaller Economies not appearing in *Circular T* with a convenient way to compare their standards with the rest of the world.

A simple measurement system has been developed to support the SIM Time Network, based on a single-frequency GPS receiver, time-interval counter and rack-mounted PC. Units are built and calibrated at NIST. Time-transfer does not adopt the CGGTTS data format, but instead calculates average REF – GPS over 1 min and 10 min periods. Typical uncertainties at an averaging time of one day are a TDEV of typically 1.5 ns (Type A), with a combined standard uncertainty less than 15 ns for time and 1×10^{-13} for frequency.

Eleven such systems have been deployed around the SIM region, most recently in Paraguay in 2008, with further expansion of the network planned. Intercomparison results are retrieved and displayed in real time online (tf.nist.gov/sim), including one-way GPS data, common-view difference between two sites, and other analysis. A SIM time scale is also calculated from these data and made available in real time through the network.

The benefits of the Time Network to the region include improved coordination, with closer agreement between local realizations UTC(*k*); improvement of time standards and expansion of services maintained at many SIM laboratories; and an increased awareness of the importance of time and frequency to the region, and of the role of national institutes within their local economy. The intention is to support national institutes to enable contribution of data to the BIPM for TAI, and to continue to expand the network.

Dr Arias pointed out a recommendation from the CCTF that the notation UTC and UTC(*k*) can only be used by laboratories operating clocks that contribute to TAI, and that online results from the SIM Time Network are in disagreement with this recommendation. Dr López-Romero agreed, and undertook to change the presentation of results to take the recommendation into account.

Dr O'Brian apologized to the BIPM and the CCTF for this inadvertent oversight. He reiterated that one aim of the network is to encourage greater participation and involvement by emerging laboratories, and that the presentation of results can be revisited for individual laboratories as they do begin to contribute to TAI and UTC. Dr Arias said that the BIPM recognizes this aim and supports this motivation.

The President thanked Dr López-Romero for the presentation.

8 REDEFINITION OF UTC

Two recommendations in this area were discussed under this agenda item (CCTF/09-37 and CCTF/09-38, below). A working document on UTC prepared by the BIPM for ITU-R (CCTF/09-27) and a comprehensive summary prepared by Dr McCarthy (CCTF/09-32) were also tabled.

Report of Working Party 7A of ITU-R

The President invited Dr Beard to present this report.

Dr Beard began by explaining that Working Party 7A on Time Signals and Frequency Standard Emissions is part of Study Group 7 on Science Services within ITU-R, and is responsible for both terrestrial and satellite standard frequency and time signal services including dissemination and coordination of these services worldwide. The goals of the Working Party are to develop and maintain ITU-R Recommendations in the TF series and relevant Handbooks, with important applications to telecommunication administrations and industry but also to many other fields.

ITU-R current questions are assigned to Study Groups, and include many specific questions in the time and frequency area. Fourteen questions are currently under consideration, one of which (236/7) is the future of the UTC time scale. This question includes the requirements for time scales for navigation, telecommunication systems and civil timekeeping, and possible alternatives to the current leap second procedure.

Responses to current questions become recommendations for formal approval and adoption. Recommendation TF.460, adopted in 1972, gives the formal definition of the current UTC system, and TF.535 governs use of the term UTC. Dr Beard noted that TF.460 allows for the introduction of leap seconds at the end of any UTC month, with December or June preferred and March or September as second choices. This is relevant as the frequency of leap seconds is expected to increase.

A proposal to WP7A proposed specific modifications to UTC, including increasing the tolerance of $|UT1 - UTC|$ to leap hours; discontinuing the application of leap seconds; and discontinuing broadcast of DUT1, with this quantity made available at greater accuracy by other dissemination methods.

A preliminary Draft Recommendation TF.460-7 was prepared by the Working Party in October 2007, revised in April 2008, further discussed in October 2008 and will be taken up again at the September 2009 meeting. The most significant outstanding issue is the date on which the revised system might take effect. If the draft is acceptable, it will be forwarded to the Study Group for formal approval.

Dr Beard concluded by noting that any modification to UTC raises complex issues, as for example UTC is the basis of civil and legal time in many nations. Resolving these complex issues is a work still in progress.

Dr Gill asked for clarification regarding the possible timeline for adopting the draft recommendation. Dr Beard explained that a recommendation submitted during the study period would become an agenda item for the next World Radio Conference, in 2011. If approved, it would be published and disseminated for some time, but not necessarily enforced immediately as the effective transition date and time may be written into the recommendation. Dr Gill conveyed the formal opposition of the UK Government to the draft recommendation.

Draft Recommendation CCTF/09-37, 'On the weakness of the present definition of UTC'

Dr Arias presented the draft recommendation for discussion.

Dr Beard asked about the urgency of a decision regarding the future definition of UTC. Dr McCarthy pointed out that software is currently being written for GNSS systems and will be expected to operate over the next few decades, so that any delay in the decision complicates the work of software and hardware developers in this area. Dr Arias reminded that in 2003, ESA had requested the community to make a decision, because development for GALILEO needed to know the outcome and anticipate the planned date of any change, with software development in particular being a key issue. Dr Beard commented that software development is also used to argue the opposite view, in favour of maintaining the status quo to allow use of existing software, and that this has not yet been a sufficiently compelling issue to encourage Member States to reach a decision.

Dr Levine asked whether the recommendation would assist the Study Group to reach a decision. Dr McCarthy expressed a view that the recommendation might be more useful to national agencies, to allow interested parties to highlight the recommendation and encourage resolution of national decision-making processes.

Dr O'Brian asked whether the Study Group has not yet made a decision, or whether the decision is currently split with some parties in favour and some not. Dr Beard clarified that the ITU has not yet made a formal decision. The existing definition therefore remains in force, notwithstanding individual decisions made within Member States. Dr O'Brian asked whether the recommendation is still needed, given that some Member States have already developed a position. Dr Beard replied that not all Member States have done so, and repeated that there is still a requirement for formal decisions to be reached by the Study Group and subsequent ITU processes. Dr Bauch asked whether a majority vote may be taken on this issue in the event that not all parties are in agreement, and Dr Beard replied that a formal decision requires consensus.

In further discussion, Dr Beard reiterated the view that the recommendation was primarily to national bodies rather than to the ITU. Dr Arias explained that the CCTF had previously communicated directly to the ITU, through the working document on UTC (CCTF/09-27) prepared following discussion at the 17th CCTF in 2006 and forwarded to the ITU in 2007. This document urged the ITU to make a decision on the future of UTC as soon as possible, and the draft recommendation was therefore complementary to this earlier correspondence. Dr Levine suggested that the use of examples might help to accentuate the urgency of a decision, and pointed out that the British Lighthouse Authority has committed to the use of LORAN, as an alternative time scale not subject to leap seconds. Dr Gill raised the concern that the recommendation may not in practice have significant effect as it may not help to resolve a variance in existing positions.

The President noted that there was no strong opposition to the draft recommendation, but suggested that it be further revised to reflect issues raised during the discussion.

Draft Recommendation CCTF/09-38, 'Concerning definition of time scales'

Dr Arias presented the draft recommendation for discussion, and explained that it was essentially separate to the preceding recommendation as it related to the formal responsibility for the definition of time scales rather than to current or proposed details of these definitions. In response to a question from Dr McCarthy, Dr Arias also clarified that the 24th CGPM will take place in October 2011.

Dr Gill conveyed the position of the UK Government that responsibility for definition and governance of time scales should remain with the ITU.

A key concern raised in general discussion was that in practice, definition of time scales includes not only technical but also regulatory and other aspects. Dr Arias expressed the opinion that the ITU may not be the ideal forum to discuss technical issues, and Dr Cordara similarly recommended that UTC be under the technical jurisdiction of the CCTF. In response, Dr Beard pointed out that regulatory and related activities are also key issues for definition of time scales, and that the ITU is an international treaty organization with regulatory functions. Both Dr Beard and Dr Bauch expressed doubt that full responsibility for UTC could make the transition from the regulatory structure of the ITU to the CGPM. Dr Levine and Dr McCarthy argued moreover for a formal separation between technical and other aspects, and for the CCTF to retain its primary focus as a technical body.

The President summarized the discussion by noting that the CCTF was not yet ready to endorse the draft recommendation. Although the BIPM retains technical responsibility for the implementation of UTC, further consultation is needed between the BIPM and ITU to clarify and develop responsibilities in this area.

9 SPACE-TIME REFERENCES AND GENERAL RELATIVITY

9.1 Report of the IERS Conventions Centre

The President invited Dr Petit to present this report.

Dr Petit began by explaining that since 2001, the BIPM and USNO have been providing the Conventions Centre of the International Earth Rotation and Reference Systems Service (IERS). The Conventions define the standard reference systems realized by the IERS, together with associated models and procedures. The latest version, IERS Conventions (2003), was published in 2004 as a 128-page book. Ongoing developments and updates are made available online (tai.bipm.org/iers) including a full modification history.

A workshop on the IERS Conventions was held on 20–21 September 2007, with around 65 participants attending from 15 countries. The workshop provided guidance and information on a wide range of topics including new models, technique-dependent effects, and terminology concerning reference systems.

Updating the Conventions is a continuing process with much work already completed over many years. Topics currently under revision include a new conventional model of the geopotential, a new formulation of ocean loading, and diurnal and semidiurnal atmospheric pressure loading effects. The assistance of the Advisory Board for the IERS Conventions Update, chaired by Jim Ray, was acknowledged. The IERS Directing Board endorses major updates, with the next major edition planned for the end of 2009.

The President thanked Dr Petit and the authors of the IERS Conventions.

9.2 Use of the international standards ITRS and UTC for geodetic and time referencing

The President invited Dr Arias to address this agenda item. Dr Arias began by pointing out that although the structure for coordinating UTC as an international reference is well established, there is no comparable international structure for geodetic reference systems. The International Terrestrial Reference System (ITRS) has been recommended by international organizations such as IAG and IUGG, but these recommendations do not carry the same authority as intergovernmental treaties. A related issue is that the International Committee on GNSS, ICG (on which the BIPM is an observer) is the only common forum to date for connecting GNSS service providers and civil users; this structure exists for individual GNSS systems such as GPS and GALILEO, but ICG supports interoperability for the benefit of all civil users. It is therefore proposed that the CCTF also consider these issues, and make recommendations as appropriate to motivate GNSS service providers in this area.

Dr Arias also tabled a report on the ICG (CCTF/09-28) and a report from the IUGG (CCTF/09-17) as related working documents.

Draft Recommendation CCTF/09-30

Dr Arias presented the proposed recommendation CCTF/09-30, concerning the alignment of geodetic references and synchronization of time references to international standards.

Dr Boucher expressed full support for the underlying principles of this recommendation on behalf of the IUGG, but suggested two modifications to wording: ‘astronomical sciences’ for ‘space and Earth sciences’, and the use of a more qualitative ‘cm to m level’ in place of specific figures on the alignment of other frames to ITRF. Dr Arias commented that the latter question had been discussed in the preparation of the recommendation.

Dr McCarthy pointed out that the ITRS is a system rather than just a frame, and suggested recommending compliance with ITRS rather than alignment to ITRF. Dr Tavella suggested reference to a ‘real-time approximation’ instead of a ‘real time realization’ of UTC, as a clarification. Dr Tuckey queried the year for the 15th General Conference of Weights and Measures, and this was clarified by Dr Beard.

Dr Beard asked whether it was within the purview of the CCTF to make a recommendation regarding geodetic reference systems. Prof. Wallard expressed his view that it was appropriate for the CCTF to express an opinion in this area. Dr Koshelyaevsky expressed a view that a key theme in metrology is the trend towards standardization of references, and also expressed support for the general principles of the recommendation.

Dr Beard commented that the ICG is an informal or voluntary group, and consequently may not have the force to guarantee implementation of the recommendation. He suggested that a similar recommendation could also be raised within the ITU.

Dr Arias noted that the recommendation was practical, not merely philosophical. The adoption of reference systems has practical consequences for the work of time and frequency transfer, and ensuring compatibility makes this work easier.

The President summarized the agreement of the meeting that the recommendation be modified as discussed.

Draft Recommendation CCTF/09-33

Dr Arias went on to present the proposed recommendation CCTF/09-33, concerning adoption of a common terrestrial reference frame by the CGPM.

Dr Boucher noted the essential similarity between the two proposed recommendations, and expressed full support for both. He suggested replacing ‘geodetic unions’ by ‘international scientific unions’ and ‘terrestrial reference frames’ by ‘terrestrial reference systems’ in the second.

Prof. Wallard asked whether it is possible for the CGPM to adopt the ITRS, as this is in a different sphere to the SI units, and suggested that the CCTF instead recommend to the CIPM to take action to implement the overall objectives. Dr Beard observed that the ITU may again play a role in this area, as for the previous recommendation.

Dr Defraigne observed that the final phrase ‘in particular by satellite navigation systems’ may repeat considerations already discussed earlier in the recommendation. Dr McCarthy suggested replacing this phrase by ‘for use in precise metrological applications’, broadening applications to any requiring precise reference systems.

The President summarized the agreement of the meeting that the recommendation be modified as discussed.

10 NEW DEFINITION AND REALIZATION OF THE SECOND

10.1 Report on discussions at the 19th meeting of the Consultative Committee for Units (CCU)

This agenda item was included under the report of the CCL-CCTF Frequency Standards Working Group.

10.2 Establishment of the Working Group on Strategic Planning

The President reported the recommendation of the CIPM that each Consultative Committee establish a Working Group on Strategic Planning, to oversee the work of the Consultative Committee Working Groups and the relevant section of the BIPM, and to prepare recommendations. He proposed that membership of such a group consist of the President of the CCTF and of each CCTF Working Group chair.

Dr Arias explained that there is a need to support a long-term strategic overview of the activities of the BIPM, and to adapt the structure of the Consultative Committees to meet evolving needs. The responsibility of these new Working Groups will be to review the structure of the Consultative Committees and their Working Groups, to ensure that the BIPM work programme and the activities of each CC are adapted to the needs of the relevant metrological community.

Prof. Wallard noted that in some Consultative Committees, for example the CCEM, the President has asked such a Working Group to prepare documents outlining major evolving strategic challenges or issues. These documents can assist national institutes in their own strategic planning by providing an international perspective.

Dr Arias commented that the existing structure of CCTF Working Groups covers the spread of CCTF activity well, so that the chairs of these groups provide a good spread of representation across the CCTF to comprise the new Working Group on Strategic Planning.

The President formally proposed the establishment of the new Working Group on Strategic Planning, with terms of reference to be prepared and presented to the next CCTF meeting for formal approval. The proposal was agreed. The President noted that such a group had already met informally in April 2009 to prepare for this CCTF.

Dr Riehle asked who would chair the new Working Group, and it was explained that this would be the President of the CCTF.

Dr Tavella suggested that work towards a new definition of the second should be included in the terms of reference for the new Working Group. Dr Madej commented that this would require high-level technical expertise to be represented in the group. The President noted that the chair of the CCL/CCTF Frequency Standards Working Group (currently two co-chairs) will be included in the membership, and also that the new group would not work in isolation but undertake appropriate consultation.

11 THE BIPM WORK PROGRAMME FOR 2013–2016

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

Dr Arias began by noting that the CIPM needs to approve the BIPM work programme before presentation to the CGPM, for budgetary approval in 2011. The CIPM will review the first draft before the end of 2009, with further modifications possible until the following CIPM meeting at the end of 2010.

Dr Arias summarized some of the achievements of the BIPM in the last ten years, including timely production of UTC/TAI/TT, better use of primary frequency standards in TAI, and provision of extensive information on time scales online. The BIPM continues to promote contributions to UTC/TAI, and to support participating laboratories by responding to technical requests. A programme of international scientific coordination is well established, both between NMIs and RMOs and with international scientific organizations such as IERS, IGS and ITU.

The work programme for 2009–2012 is in progress, as modified after prioritization of BIPM programmes following the 2007 CGPM. This programme includes support for key comparisons, ongoing improvements to the algorithm for UTC/TAI, and characterization of equipment delays. Development of optical frequency standards is supported by coordinating with NMIs, by contributing to transfer techniques and studying the use of secondary representations of the second to improve the accuracy of TAI.

Dr Arias reported that a CIPM workshop was held in November 2008 to discuss the future of the BIPM in preparation for CGPM 2011 and to develop a vision for BIPM activity over the next ten years. The goals identified for the BIPM were to maintain the highest technical competence in metrology; to promote the benefits of an organized structure for metrology, in particular of access to the Metre Convention and the CIPM MRA; and to provide support to NMIs for key activities in metrology (including for example through the provision of training programmes).

Within this overall vision, the core activities of the Time, Frequency and Gravimetry section under the new work plan include:

- calculating UTC/TAI, as mandated by the Member States;
- supporting gravimetry measurements by NMIs, and operating the watt balance;
- increasing competence in time transfer (new GNSS and multi-system transfer for clock comparison, supported by characterization of equipment delays);
- implementing use of secondary frequency standards (microwave and optical) for TAI;
- contributing to discussion on a possible new definition of the second;
- coordinating the network of participating laboratories, including the provision of new products and support for training programmes;
- liaising with international organizations, for example regarding the definition of and responsibility for UTC, or the adoption of time and geodetic standards.

A small increase in staffing level is proposed, to enable delivery of work programme services to NMIs.

The President recommended that the draft work plan be made available for discussion within NMIs, with any comments before the end of August 2009. Dr Arias observed that a provisional programme is needed by the end of June for the bureau of the CIPM, so comments are needed now for the first draft.

Dr Riehle commented that the work programme is important and substantial, and asked what resources are available to undertake additional new activities as these evolve through the period. Dr Arias replied that this will require ongoing evaluation, as some particular challenges such as optical frequency comparisons depend on the rate of technical progress.

Dr Levine suggested that if the BIPM were to develop a standardized reporting framework for participating laboratories, this might solve ongoing problems with late data or inconsistent data formats. Dr Arias observed that software is already provided by the BIPM for data extraction, and suggested that NMIs could also share software developed within individual laboratories for more general application.

Prof. Wallard raised the level of involvement in optical frequency comparisons as a key question, and asked what resources might be required over the work period. In reply, Dr Lemonde stressed that current developments are in both optical frequency standards and in new time-transfer techniques, for example ACES and optical fibre links in particular. These provide significant amounts of new data to be included in performance comparisons. Dr Madej asked whether the BIPM will be ready for these new technologies, and whether it can respond to rapid technical evolution integrated with the current programme within existing resources. In reply, Dr Arias noted some specific possibilities, including support for secondments and post-doctoral appointments focused on completing evaluation projects or developing new products and services.

Prof. Wallard expressed his confidence that the capabilities and resources of the TFG section will be sufficient to deliver these core functions, and noted that any comments or concerns expressed by NMIs in a brief email for review by the Bureau of the CIPM would be greatly appreciated.

12 RECOMMENDATIONS

Three recommendations were further discussed under this agenda item:

- the recommendation from the CCL/CCTF Frequency Standards Working Group (FSWG) concerning updates to the List of Radiations;
- the second recommendation from the FSWG, concerning the terms of reference for the Working Group;
- a recommendation concerning the characterization of delays of GNSS time-transfer equipment in laboratories contributing to TAI (CCTF/09-39).

After some minor amendments all were agreed.

A draft recommendation regarding 'Traceability to UTC of real-time realizations UTC(*k*) disseminated by Global Navigation Satellite Systems' (CCTF/09-29) was also considered. Although there was general agreement with the intent of the proposed recommendation, two areas of concern were raised: first, whether 'realization' of UTC should be replaced by 'approximation' or 'prediction', and second, whether 'traceability' may have a specific metrological interpretation not supported by the recommendation.

The President noted that there was insufficient time available to resolve these concerns. A small discussion group was therefore established (Dr Lewandowski, Dr Tuckey, Dr Defraigne, Dr Tavella and Dr Koshelyaevsky, led by Dr Arias) to prepare an amended draft within two weeks, with further discussion to be otherwise delayed until the next meeting of the CCTF.

The President also raised the date of the next meeting. Although this would normally be after a period of three years, it was noted in discussion that joint activity with the length community is increasing and that the CCL meets every two years. The question was ultimately left open, with the President confirming that no meeting would be held in 2010 and postponing the decision to be made in future having regard to the evolving state of the field.

13 GLOBAL NAVIGATION SATELLITE SYSTEMS

13.1 GPS

Dr Matsakis presented a brief status report on current and planned changes to GPS, and noted that further information was available online (www.pnt.gov).

GPS monitoring has expanded with extensions to the network of monitoring stations. The current GPS constellation is the largest to date, with 30 healthy satellites in orbit and further launches planned. New signals expand use of the available spectrum to include:

- the second civil signal L2C, offering higher accuracy through improved ionospheric correction, with the first launch in September 2006 and 24 satellites projected around 2016;
- the third civil signal L5, designed to meet demanding requirements for safety-of-life applications, with the first launch in March 2009 and 24 satellites projected around 2018;
- the fourth civil signal L1C, designed with international partners to support GNSS interoperability, with the first launch planned for 2014 and 24 satellites projected around 2021.

Dr Matsakis briefly outlined the US national space-based PNT organization structure and PNT policy. He concluded with a concise summary of projected time transfer accuracy given in the GPS III Capability Development Document, which includes for example an objective of 1 ns accuracy (2σ for a static timing user over a 24 h period (using broadcast signals only, without post-processing).

13.2 GLONASS

The President invited Dr Koshelyaevsky to present this report, entitled 'Time and Frequency Activity at the VNIIFTRI'.

Dr Koshelyaevsky began by noting the federal programme adopted for modernization of GLONASS up to 2011, covering the space segment, control segment and user segment. The early situation was that accuracy was insufficient for key applications and no commercial receivers were available, but the current situation is much improved.

A number of changes have taken place since early 2007 in the State Service for Time and Frequency (SSTF) and the VNIIFTRI timekeeping laboratory which are relevant to the GLONASS control segment. Work at VNIIFTRI includes the development of Cs fountain standards, environmental control systems, hydrogen masers and intercomparison systems.

Time transfer connecting SSTF laboratories uses GPS/GLONASS TTS-3 receivers with TWSTFT links in preparation. It is planned to join the European/Asian laboratory network through the IS-4 satellite, and to extend the network eastwards in the Russian Federation.

Dr Matsakis asked how many staff were involved in the upgrade programme. Dr Koshelyaevsky quoted approximately 20 staff, excluding the fountain laboratory.

13.3 GALILEO

The President invited Dr Tavella to present this report.

Dr Tavella presented a summary timeline for Galileo deployment, moving from the In-Orbit Validation (IOV) phase in 2010–2012 towards the Fully Operational Constellation (FOC) phase beginning in 2013.

Prototype GPS/Galileo receivers are in operation at INRIM and USNO using GSTB V2 broadcast signals.

Galileo System Time (GST) will be a continuous coordinate time scale in a geocentric reference frame, steered towards UTC modulo 1s. The start epoch is given in the Galileo Open Service SIS ICD. The two time offsets in seconds [*GPS time – UTC*] and [*GST – UTC*] are equal. Galileo week number 0 corresponds to GPS week number 1024, so that broadcast week numbers for GPS and Galileo will be equal until next rollover.

13.4 GAGAN

A status report on the IRNSS and GAGAN projects was tabled (CCTF/09-35).

13.5 COMPASS/Beidou

The President invited Prof. Gao to make a presentation on the status of the COMPASS/Beidou system. Prof. Gao began by clarifying that the presentation was prepared by the China Satellite Navigation Project Centre, as NIM does not participate directly in this project.

Five geostationary and 30 MEO satellites will comprise the proposed Space Segment. The User Segment will include equipment which is interoperable with GPS, GLONASS and Galileo.

COMPASS/Beidou time (BDT) is based on a clock ensemble using an algorithm similar to ALGOS. BDT is synchronized to UTC within 100 ns through UTC(NTSC). Interoperability will be supported through planned broadcast of offsets to other GNSS time scales. The reference coordinate system will be the China Geodetic System (CGS2000), which is consistent with ITRS and coincident with ITRF at the 5 cm level.

The performance specification for the Open Service is a positioning accuracy of 10 m and a timing accuracy of 20 ns. The Authorized Service is intended to provide high reliability, for example through a wide-area differential positioning service to 1 m accuracy.

In the first phase of deployment, a demonstration system of three GEO satellites was launched in 2000, providing basic services in a regional area. The first MEO satellite was launched in 2007; three satellites will be launched in 2009, with ten expected over the next two years. The geostationary satellite COMPASS-G2 was launched in April 2009, with in-orbit testing currently in progress. First regional coverage of the Asia-Pacific is planned for 2010.

Dr Lewandowski asked what will be the offset between BDT and UTC. Dr Bauch pointed out that the two time scales are synchronized at the beginning of 2006, as noted in the presentation. Dr Lewandowski also asked about the subsequent application of leap seconds, and Prof. Gao suggested this query be referred to the China Satellite Navigation Project Centre.

14 OTHER BUSINESS

The President referred the question of the future of the Working Group on CGGTTS, raised at the end of the presentation by Dr Levine as Working Group chair, to the Working Group on Strategic Planning.

Prof. Wallard explained that the meeting would be his last CCTF as he would be retiring as Director of the BIPM at the end of 2010. He wished all attendees *bonne chance* for the future, and thanked them for their support of the BIPM and of the Time, Frequency and Gravimetry section.

The President thanked Prof. Wallard and all delegates, experts and attendees for their participation in the 18th CCTF. He thanked Dr Arias and her staff for their preparation for the meeting and for the activity of the Time, Frequency and Gravimetry section over the past three years.

Dr Arias thanked the BIPM staff for their support for the meeting, on behalf of all attendees.

The President commented that he had enjoyed the robust discussion and good progress made at his first CCTF meeting, and closed the proceedings at 5:30 pm.

R. B. Warrington, rapporteur

August 2009

APPENDIX 1.
Working documents submitted to the CCTF at its 18th meeting

Documents restricted to Committee members can be accessed on the restricted–access CCTF website.

Document CCTF/	
09-00	Draft Agenda
09-01	NIST (United States). — Report of the CCTF WG on primary Frequency Standards, T. Parker, 4 pp.
09-02	PTB (Germany). — PTB report on activities, 8 pp.
09-03	CENAM (Mexico). — CENAM report on activities, 14 pp.
09-04	USNO (United States). — USNO report on activities, D. Matsakis, 17 pp.
09-05	VSL (Netherlands). — VSL report on activities, E. Dierikx, 1 p.
09-06	NICT (Japan). — NICT report on activities, 7 pp.
09-07	NRC (Canada). — NRC report on activities, 3 pp.
09-08	NMISA (South Africa). — NMISA report on activities, 3 pp.
09-09	KRISS (Rep. of Korea). — KRISS report on activities, 4 pp.
09-10	NMIJ/AIST (Japan). — NMIJ/AIST report on activities, 7 pp.
09-11	ROA (Croatia). — ROA report on activities, F.J. Galindo, 3 pp.
09-12	NIM (Beijing). — NIM report on activities, X. Gao, T. Li, 4 pp.
09-13	INRIM (Italy). — INRIM report on activities, 13 pp.
09-14	NPL (United Kingdom). — NPL report on activities, 7 pp.
09-15	METAS (Switzerland). — METAS report on activities, 3 pp.
09-16	CCTFWG on TWSTFT. — Report of the CCTF WG on TWSTFT, 14 pp.
09-17	IUGG. — Report of the IUGG, 3 pp.
09-18	BIPM. — The uncertainty for the key comparison in frequency CCTF-K002.FREQ, G. Panfilo, E.F. Arias, 7 pp.
09-19	BIPM. — Report on BIPM TAIPPP pilot experiment, presented at IFTF-IFCS2009, G. Petit, 4 pp.
09-20	INRIM (Italy). — Progress report from the CCTF WG on the MRA, F. Cordara, 7 pp.
09-21	ORB (Belgium). — ORB report on activities, P. Defraigne, 3 pp.
09-22	LNE-SYRTE (France). — LNE-SYRTE report on activities, 7 pp.
09-23	NIST (United States). — Report of the CCTF WG on GNSS Time Transfer Standards (CGGTTS), J. Levine, 2 pp.
09-24	BIPM. — Report on studies and improvement of the EAL algorithm, presented at the EFTF-IFCS2009, G. Panfilo, E.F. Arias, 6 pp.
09-25	A*STAR (Singapore). — A*STAR report on activities, 3 pp.

Document CCTF/	
09-26	BIPM. — BIPM report of on activities, E.F. Arias, 10 pp.
09-27	CCTF. — CCTF note on UTC (September 2007) presented to the ITU-R, 4 pp.
09-28	BIPM. — Report on the International Committee on GNSS, E.F. Arias, 4 pp.
09-29	VNIIFTRI (Russian Fed.). — Proposed recommendation - Traceability to UTC of real-time realizations UTC(k) disseminated by GNSS, 1 p.
09-30	BIPM, IGS, IUGG. — Proposed recommendation - Alignment of Geodetic References and synchronization of Time References to international standards, 1 p.
09-31	BIPM, WG on the MRA. — Proposal - Key comparison of Primary Frequency Standards, E.F. Arias, 2 pp.
09-32	USNO. — Note on Coordinated Universal Time, D. McCarthy, 23 pp.
09-33	CGPM. — Concerning the adoption of a common terrestrial reference frame by the CGPM, T.J. Quinn, 1 p.
09-34	NIST (United States). — NIST report on activities, 15 pp.
09-35	SATNAV (India). — Information on IRNSS and GAGAN projects, S. Kibe, 1 p.
09-36	NMIA (Australia). — NMIA report on activities, 3 pp.
09-37	CCTF. — Proposed recommendation - On the weakness of the present definition of UTC, 1 p.
09-38	CCTF. — Proposed recommendation - Concerning definition of time scales, 1 p.
09-39	BIPM. — Proposed recommendation - Characterization of delays of GNSS time transfer equipment in TAI contributing laboratories, 1 p.

RECOMMANDATION CCTF1 (2009)

Mises à jour de la liste des fréquences étalons

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

considérant

- qu'une liste commune des « valeurs recommandées de fréquences étalons destinées à la mise en pratique de la définition du mètre et aux représentations secondaires de la seconde » a été établie ;
- que le Groupe de travail commun au CCL et au CCTF sur les étalons de fréquence a examiné plusieurs fréquences candidates en vue de leur inclusion dans cette liste ;

recommande

que les fréquences de transition suivantes soient incluses ou mises à jour dans la liste des fréquences étalons recommandées :

- la transition optique non perturbée $5s^2\ {}^1S_0 - 5s\ 5p\ {}^3P_0$ de l'atome neutre de ^{87}Sr, à la fréquence de 429 228 004 229 873,7 Hz, avec une incertitude-type relative de 1×10^{-15} (cette radiation a déjà été approuvée par le CIPM comme représentation secondaire de la seconde) ;
- la transition optique non perturbée $5s^2\ {}^1S_0 - 5s\ 5p\ {}^3P_0$ de l'atome neutre de ^{88}Sr, à la fréquence de 429 228 066 418 012 Hz, avec une incertitude-type relative de 1×10^{-14} ;
- la transition optique non perturbée $4s\ {}^2S_{1/2} - 3d\ {}^2D_{5/2}$ de l'ion de $^{40}Ca^+$, à la fréquence de 411 042 129 776 393 Hz, avec une incertitude-type relative de 4×10^{-14} ;
- la transition optique non perturbée ${}^2S_{1/2}\ (F = 0) - {}^2F_{7/2}\ (F = 3, m_F = 0)$ de l'ion de $^{171}Yb^+$, à la fréquence de 642 121 496 772 657 Hz, avec une incertitude-type relative de 6×10^{-14} ;
- la transition optique non perturbée $6s^2\ {}^1S_0\ (F = 1/2) - 6s\ 6p\ {}^3P_0\ (F = 1/2)$ de l'atome neutre de ^{171}Yb à la fréquence de 518 295 836 590 864 Hz, avec une incertitude-type relative de $1,6 \times 10^{-13}$.

RECOMMANDATION CCTF 2 (2009)

Caractérisation des retards des équipements de comparaison de temps par systèmes globaux de navigation par satellite (GNSS) des laboratoires contribuant au Temps atomique international (TAI)

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

considérant

- que la détermination des caractéristiques des retards des équipements de comparaison de temps est essentielle pour garantir l’exactitude des liens horaires du TAI ;
- que les changements non corrigés des retards des équipements impliqués dans un lien horaire donné peuvent générer une instabilité significative du TAI ;
- que le Comité consultatif pour la définition de la seconde (CCDS), puis le Comité consultatif du temps et des fréquences (CCTF) ont souligné l’importance d’étalonner les équipements de comparaison de temps des laboratoires participant au calcul du TAI effectué au BIPM ;

sachant

- que la section du temps, des fréquences et de la gravimétrie du BIPM s’applique à mesurer les retards relatifs des équipements des systèmes globaux de navigation par satellite des laboratoires fournissant des données pour le calcul du TAI ;
- que des ressources considérables, tant en personnel qu’en matériel, sont nécessaires pour étalonner l’ensemble des équipements des systèmes globaux de navigation par satellite utilisés pour le calcul du TAI, ainsi que pour maintenir à jour ces étalonnages ;

recommande

- que le BIPM continue d’organiser et de conduire des campagnes de mesure des retards des équipements des systèmes globaux de navigation par satellite en fonctionnement dans les laboratoires ;
- que l’objectif principal de ces campagnes soit d’étalonner les équipements d’un sous-ensemble de laboratoires sélectionnés ;
- que les organisations régionales de métrologie apportent leur soutien au BIPM en organisant des campagnes de mesure des retards au niveau régional, qui seront liées à celles menées par le BIPM ;
- que le BIPM élabore des directives à ce sujet, en concertation avec les organisations régionales de métrologie.

RECOMMANDATION CCTF 3 (2009)

Au sujet de la faiblesse de la définition actuelle de l'UTC

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

considérant

- que l'insertion non prévisible de secondes intercalaires, dont on ne connaît pas à l'avance le nombre, génère des sauts du Temps universel coordonné (UTC), tel qu'il a été défini en 1972, qui affectent de manière défavorable son utilisation ;
- que cette définition de l'UTC ne peut répondre aux exigences des nombreux systèmes de navigation, actuels et à venir, qui nécessitent une échelle de temps uniforme ;
- que d'autres échelles de temps, non affectées par l'insertion de secondes intercalaires, sont élaborées et prolifèrent ;
- que la nécessité de connaître l'angle de rotation de la Terre dans des systèmes de référence célestes, destinés à être utilisés dans le domaine de la navigation maritime céleste, n'est plus d'actualité ou peut facilement être satisfaite par les valeurs de [*UT1* – *UTC*] telles que évaluées et publiées par le Service international de la rotation terrestre et des systèmes de référence (IERS) ;
- que l'UT1 peut entièrement satisfaire aux besoins liés à la détermination de l'angle de rotation terrestre ;
- qu'il est nécessaire de disposer d'un délai suffisant pour permettre la mise en place de programmes informatisés pour les systèmes de navigation terrestre ou par satellite, adaptés à tout changement de la définition de l'UTC ;
- qu'au cours des dix dernières années, un certain nombre d'organisations techniques nationales et internationales ont exprimé leur inquiétude croissante concernant la définition actuelle de l'UTC et la prolifération simultanée d'autres échelles de temps ;

recommande

que les agences nationales et internationales, ainsi que les unions scientifiques concernées par la définition des échelles de temps internationales, réfléchissent de toute urgence aux décisions à prendre concernant la définition à venir de l'UTC, afin de parvenir dès que possible à un accord international à ce sujet.

RECOMMANDATION CCTF 4 (2009)

Concernant l’adoption d’un système de référence terrestre commun par la Conférence générale des poids et mesures

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

considérant

- qu’il n’existe à l’heure actuelle que quelques systèmes globaux de navigation par satellite (GNSS), mais que de nouveaux systèmes sont mis au point et que beaucoup d’autres le seront probablement à l’avenir ;
- que les différents systèmes de référence temporels et géodésiques, utilisés par ces systèmes globaux de navigation, rendent l’interprétation des solutions de positionnement et de temps plus ambiguë pour les utilisateurs, et l’interopérabilité des systèmes plus compliquée ;
- que, même si les unions scientifiques concernées recommandent l’utilisation du système international de référence terrestre (ITRS), ce système n’est à l’heure actuelle adopté par aucune organisation intergouvernementale ;
- que l’adoption d’un système commun par l’organisation intergouvernementale appropriée serait un avantage pour les utilisateurs en termes d’unification des solutions globales de positionnement et de temps, et de l’interopérabilité des systèmes globaux ;

notant

que l’un des facteurs clés ayant conduit à la création de la Convention du Mètre et du BIPM fut la recommandation adoptée lors de la deuxième Conférence géodésique internationale pour la mesure des degrés en Europe, réunie à Berlin en 1867, pour qu’un Bureau international des poids et mesures, situé en Europe, soit fondé afin d’unifier les étalons géodésiques européens ;

recommande

que le directeur du BIPM, après concertation avec les unions scientifiques concernées, discute de façon formelle avec le CIPM des mesures nécessaires à prendre afin de demander à la Conférence générale des poids et mesures, lors de sa 23^{e} réunion, d’adopter l’ITRS, tel que défini par l’Union géodésique et géophysique internationale (UGGI), et réalisé de manière pratique par le Service international de la rotation terrestre et des systèmes de référence (IERS) et le Service international GNSS (IGS), comme système de référence international terrestre unique pour toutes les applications métrologiques.

RECOMMANDATION CCTF 5 (2009)

Alignement des références géodésiques et synchronisation des références de temps par rapport aux références internationales

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

considérant

- que le Système international de référence terrestre (ITRS) a été recommandé par l'Union astronomique internationale (UAI) et l'Union géodésique et géophysique internationale (UGGI) pour les applications dans le domaine des sciences de la terre et de l'espace ;
- que le Repère international de référence terrestre (ITRF) fournit l'accès primaire à l'ITRS, et que les systèmes géodésiques globaux WGS84, PZ-90, GTRF (Galileo Terrestrial Reference Frame), CGS'2000 (China Geodetic System 2000), assortis de densifications régionales, y donnent également accès avec une incertitude estimée de 3 cm à 40 cm ;
- que l'échelle de temps approuvée par la Conférence générale des poids et mesures, lors de sa 15e réunion en 1975, afin d'assurer la coordination et la dissémination du temps dans le monde est le Temps universel coordonnée (UTC) ;
- que le BIPM assure la collaboration nécessaire afin de maintenir et de disséminer l'UTC ;
- que le temps du GPS est asservi à la réalisation en temps réel de l'UTC maintenue par l'Observatoire naval des États-Unis d'Amérique, UTC(USNO) (modulo 1 s), et le temps du GLONASS asservi à la réalisation en temps réel de l'UTC maintenue par le VNIIFTRI, UTC(SU) ; et que le temps de Galileo sera asservi à un ensemble de réalisations européennes de l'UTC, en conservant le même décalage en nombre de secondes que le temps du GPS ;
- que le BIPM participe au Comité international sur le GNSS (ICG) en tant qu'observateur ;

sachant

- que de nouveaux systèmes globaux de navigation par satellite (GNSS) sont actuellement conçus et mis au point ;
- que l'interopérabilité des différents systèmes globaux de navigation par satellite serait facilitée par l'adoption de références internationales temporelles et géodésiques ;
- que des références temporelles et géodésiques, communes et reconnues au niveau international, sont nécessaires aux activités scientifiques et civiles partout dans le monde ;

reconnaît

- que le Comité international sur le GNSS (ICG) procure une structure unique qui permet aux fournisseurs de services globaux de navigation par satellite d'aligner leurs références de temps et géodésiques sur l'UTC et l'ITRS de manière opérationnelle ;

recommande

- que les références géodésiques utilisées pour les systèmes globaux de navigation par satellite soient alignées le plus exactement possible sur l'ITRS ;

- que les échelles de temps internes des systèmes globaux de navigation par satellite soient synchronisées le plus exactement possible sur l'UTC (modulo 1 s) ;
- que les systèmes globaux de navigation par satellite diffusent, outre leurs propres échelles de temps :

  - l'écart entre leur échelle de temps et une réalisation en temps réel de l'UTC,

  - les écarts entre les échelles de temps des divers systèmes globaux ;

et demande

- que le BIPM coordonne les actions nécessaires pour ce faire au sein du Comité international sur le GNSS (ICG).

RECOMMANDATION CCTF 6 (2009)

Relation entre les prédictions des échelles de temps locales UTC(*k*), disséminées par les systèmes globaux de navigation par satellite (GNSS), et le Temps universel coordonné (UTC) et le Temps atomique international (TAI)

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

considérant

- que la mission du BIPM est d'assurer l'unification mondiale des mesures et leur traçabilité au Système international d'unités (SI) ;
- qu'à l'heure actuelle, deux systèmes globaux de navigation par satellite sont en fonctionnement et que d'autres sont en cours de mise au point ;
- que les systèmes globaux de navigation par satellite actuellement utilisés disséminent des prédictions des échelles de temps locales UTC(*k*) ; par exemple, le GPS dissémine des prédictions de la réalisation en temps réel de l'UTC maintenue par l'Observatoire naval des États-Unis d'Amérique, UTC(USNO), et le GLONASS celles de la réalisation en temps réel de l'UTC maintenue par le VNIIFTRI, UTC(SU) ;
- que la Section 5 de la *Circulaire T* du BIPM publie la relation entre l'UTC et le TAI et les échelles de temps de ces systèmes globaux de navigation par satellite ;

ayant pour objectif

- de faciliter l'accès, pour tout utilisateur, aux prédictions des échelles de temps locales UTC(*k*) disséminées par les systèmes globaux de navigation par satellite actuels et à venir ;

recommande

- que la Section 5 de la *Circulaire T* intègre des données sur la relation entre l'UTC et le TAI et les échelles de temps locales prédites UTC(*k*), disséminées par les systèmes globaux de navigation par satellite ;
- que la Section 5 de la *Circulaire T* soit renommée « Relation entre l'UTC et le TAI et les prédictions des échelles de temps locales UTC(*k*) disséminées par les systèmes globaux de navigation par satellite, ainsi que leurs échelles de temps ».

RECOMMENDATION CCTF1 (2009)

Updates to the list of standard frequencies

The Consultative Committee for Time and Frequency,

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” has been established;
- the CCL-CCTF Frequency Standards Working Group (FSWG) has reviewed several promising candidates for inclusion in the list;

recommends

that the following transition frequencies shall be included or updated in the list of recommended standard frequencies:

- the unperturbed optical transition $5s^2\,{}^1S_0$ – $5s\,5p\,{}^3P_0$ of the ^{87}Sr neutral atom with a frequency of 429 228 004 229 873.7 Hz and a relative standard uncertainty of 1×10^{-15} (this radiation is already endorsed by the CIPM as a secondary representation of the second);
- the unperturbed optical transition $5s^2\,{}^1S_0$ – $5s\,5p\,{}^3P_0$ of the ^{88}Sr neutral atom with a frequency of 429 228 066 418 012 Hz and a relative standard uncertainty of 1×10^{-14};
- the unperturbed optical transition $4s\,{}^2S_{1/2}$ – $3d\,{}^2D_{5/2}$ of the $^{40}Ca^+$ ion with a frequency of 411 042 129 776 393 Hz and a relative standard uncertainty of 4×10^{-14};
- the unperturbed optical transition ${}^2S_{1/2}$ (F = 0) – ${}^2F_{7/2}$ (F = 3, m_F = 0) of the $^{171}Yb^+$ ion with a frequency of 642 121 496 772 657 Hz and a relative standard uncertainty of 6×10^{-14};
- the unperturbed optical transition $6s^2\,{}^1S_0$ (F = 1/2) – $6s\,6p\,{}^3P_0$ (F = 1/2) of the ^{171}Yb neutral atom with a frequency of 518 295 836 590 864 Hz and a relative standard uncertainty of 1.6×10^{-13}.

RECOMMENDATION CCTF 2 (2009)

Characterization of delays of global navigation satellite system (GNSS) equipment in laboratories contributing to International Atomic Time (TAI)

The Consultative Committee for Time and Frequency,

considering that

- the characterization of the delays of time-transfer equipment is essential to ensure the accuracy of the time links for International Atomic Time (TAI);
- uncompensated changes of the hardware delays in a time link may cause significant instability in TAI;
- the Consultative Committee for the Definition of the Second (CCDS) and subsequently the Consultative Committee for Time and Frequency (CCTF) have stressed the importance of calibrating the time-transfer equipment in laboratories contributing data for the calculation of TAI at the BIPM;

aware that

- the Time, Frequency and Gravimetry Section of the BIPM devotes effort to measuring the relative delays of GNSS equipment in laboratories contributing data to the formation of TAI;
- considerable human resources and equipment are necessary to calibrate all the GNSS equipment involved in the formation of the TAI, and to keep these calibrations up to date;

recommends that

- the BIPM continues to organize and run campaigns to measure delays in GNSS equipment in laboratories;
- the principal objective of these campaigns be principally organized to calibrate the equipment in a selected subset of laboratories;
- the Regional Metrology Organizations (RMOs) support the BIPM by organizing campaigns of measurement delays within the frame of regional comparisons to be linked to those conducted by the BIPM;
- the BIPM develop guidelines for this, in consultation with the RMOs.

RECOMMENDATION CCTF 3 (2009)

On the weakness of the present definition of UTC

The Consultative Committee for Time and Frequency,

considering that

- the use of Coordinated Universal Time (UTC) as defined in 1972 is negatively affected by steps caused by the unpredictable insertion of an unpredictable number of leap seconds;
- this definition of UTC can not meet the requirements of many existing and future navigation systems needing uniform time;
- alternative time scales, not affected by leap seconds, are being developed and have started to proliferate;
- the need to represent the Earth's rotation angle in celestial reference systems for use in maritime celestial navigation is either no longer required or can easily be met through values of
[*UT1 – UTC*] as published by the International Earth Rotation and Reference Systems Service (IERS);
- UT1 can fully satisfy needs related to the determination of the Earth rotation angle;
- sufficient lead time must be allowed for developers of satellite- and land-based navigation system software to accommodate any change in the definition of UTC;
- over the last ten years a number of national and international technical organizations have expressed increasing concern about the present definition of UTC and the concomitant proliferation of alternate time scales;

recommends that

national and international agencies and relevant scientific unions concerned with the definition of international time scales urgently consider decisions regarding the future definition of UTC so that international agreement can be reached as soon as possible.

RECOMMENDATION CCTF 4 (2009)

Concerning adoption of a common terrestrial reference system by the CGPM

The Consultative Committee for Time and Frequency,

considering that

- at present there exist only a few global satellite navigation systems, but that new ones are being created and in the future there may be many more;
- the various time and geodesy reference systems in use in these navigation systems give rise to additional ambiguities with regard to the interpretation of navigation and timing solutions and makes interoperability between the systems more difficult;
- although use of international terrestrial reference system (ITRS) is recommended by relevant scientific unions, it has not yet been adopted by an intergovernmental organization;
- such an adoption by the appropriate intergovernmental organization would benefit users in terms of unifying navigation and timing solutions and facilitating systems interoperability;

noting that

one of the key factors that led to the creation of the Metre Convention and the BIPM was the recommendation of the Second International Conference on Geodesy for the Measurement of Degrees in Europe, held in Berlin in 1867, that a European international bureau of weights and measures be set up in order to unify European geodesy standards;

recommends that

after agreement with the relevant scientific unions, the Director of the BIPM formally discuss with the CIPM the steps that must be taken such that the 24th CGPM be asked to adopt the ITRS, as defined by the IUGG and realized by the IERS and IGS, as the international standard for terrestrial reference frames used for all metrological applications.

RECOMMENDATION CCTF 5 (2009)

Alignment of geodetic references and synchronization of time references to international standards

The Consultative Committee for Time and Frequency,

considering that

- the International Terrestrial Reference System (ITRS) has been recommended by the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG) for applications in space and Earth sciences;
- access to the ITRS is primarily achieved through the International Terrestrial Reference Frame (ITRF), and with an uncertainty of between 3 cm and 40 cm by WGS84, PZ-90, the Galileo Terrestrial Reference Frame (GTRF), the China Geodetic System 2000 (CGS’2000), and regional densifications;
- the time scale endorsed by the 15th General Conference of Weights and Measures (1975) for world-wide time coordination and dissemination is Coordinated Universal Time (UTC);
- the BIPM provides coordination for the maintenance and dissemination of UTC;
- GPS time is steered to UTC(USNO) (modulo 1 s), GLONASS time is steered to UTC(SU), and Galileo time will be steered to an ensemble of European realizations of UTC, keeping the same number of seconds as GPS time;
- the BIPM participates as observer in the International Committee on GNSS (ICG);

aware that

- new global navigation satellite systems (GNSS) are being designed and developed;
- interoperability of the various GNSS would be facilitated by the adoption of international geodetic and time references in the various GNSS;
- civil and scientific activities world-wide need to refer to common internationally recognized geodetic and time references;

recognizes that

- the ICG is a unique structure to enable GNSS Service Providers to align their geodetic and time references to the ITRS and UTC for the operation of their systems;

recommends that

- the geodetic references for GNSSs be aligned as closely as possible to the ITRS;
- the internal system times (ST) of the GNSS be synchronized as closely as possible to UTC (modulo 1 s);
- the GNSS broadcast, in addition to their own ST:

    the difference between the ST and a real-time realization of UTC, the differences between the time scales of the various GNSS;

and

requests

- the BIPM to coordinate actions within the ICG for the accomplishment of this recommendation.

RECOMMENDATION CCTF 6 (2009)

Relationship of predictions of local timescales UTC(*k*) as disseminated by Global Navigation Satellite Systems, to the international reference time scales Universal Coordinated Time (UTC) and International Atomic Time (TAI)

The Consultative Committee for Time and Frequency,

considering that

- the task of the BIPM is to ensure world-wide uniformity of measurements and their traceability to the International System of Units (SI);
- two Global Navigation Satellite Systems (GNSS) already exist and others are under development;
- existing operational GNSS disseminate predictions of local timescales UTC(*k*), e.g. GPS disseminates predictions of UTC(USNO) and GLONASS disseminates predictions of UTC(SU);
- Section 5 of *BIPM Circular T* publishes the relationship between UTC, TAI and the GNSS System Times (ST);

aiming to

- facilitate access for all users to predictions of UTC(*k*) as disseminated by existing and future GNSS**;**

recommends that

- Section 5 of *Circular T* include information on the relationship of UTC and TAI with the predicted UTC(*k*) disseminated by the GNSS;
- Section 5 of *Circular T* be renamed “Relations of UTC and TAI with predictions of UTC(*k*) disseminated by the GNSS and their System Times”.