Bureau International des Poids et Mesures

Consultative Committee for Time and Frequency (CCTF)

Report of the 19th meeting
(13–14 September 2012)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Note:

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

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

M. Kühne
Director BIPM

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR TIME AND FREQUENCY
as of 13 September 2012

President

L. Erard, Member of the International Committee for Weights and Measures [CIPM], Laboratoire national de métrologie et d'essais, Paris [LNE].

Executive Secretary

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

Members

Centro Nacional de Metrología [CENAM], Mexico

Federal Office of Metrology [METAS], Wabern

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

International Astronomical Union [IAU]

International GNSS Service [IGS]

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International Union of Geodesy and Geophysics [IUGG]

International Union of Radio Science [URSI]

Istituto Nazionale di Ricerca Metrologica [I.N.RI.M], Turin

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

Laboratoire national de métrologie et d'essais, Observatoire de Paris, Systèmes de Référence Temps-Espace [LNE-SYRTE], Paris

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

National Institute of Metrology [NIM], Beijing

National Institute of Standards and Technology [NIST], Boulder

National Measurement Institute of Australia [NMIA], Lindfield

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

National 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 – Measurement Science and Standards Portfolio [NRC], Ottawa

Observatoire Royal de Belgique [ORB], Brussels

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig

Real Instituto y Observatorio de la Armada [ROA], Cadiz
SP Sveriges Tekniska Forskningsinstitut [SP], Borås
Space Research Centre of Polish Academy of Sciences [SRC], Warsaw
Technical University of Graz [TUG], Graz
U.S. Naval Observatory [USNO], Washington
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 19th meeting at the International Bureau of Weights and Measures (BIPM) headquarters, at Sèvres on 13 and 14 September 2012.

The following were present:

J. Achkar (LNE-SYRTE), M. Amemiya (NMIJ/AIST), A. Bauch (PTB), R. Beard (ITU-R), L.-G. Bernier (METAS), S. Bize (LNE-SYRTE), C. Boucher (IUGG), J. Davis (NPL), P. Defraigne (ORB), E. Dierikx (VSL), N. Dimarcq (LNE-SYRTE), Y. Domnin (VNIIFTRI), L. Erard (CIPM), Z. Fang (NIM), P. Fisk (NMIA), F.J. Galindo Mendoza (ROA), X. Gao (NIM), M. Gertsvolf (NRC), P. Gill (NPL), Y. Hanado (NICT), F.-L. Hong (NMIJ/AIST), M. Hosokawa (NICT), T. Ido (NMIJ/AIST), T. Ikegami (NMIJ/AIST), K. Jaldehag (SP), K. Johnston (USNO), M. Kühne (Director of the BIPM), N. Koshelyaevsky (VNIIFTRI),T.Y. Kwon (KRISS), J. Levine (NIST), T. Li (NIM), J.M. Lopez Romero (CENAM), A. Madej (NRC), D.N. Matsakis (USNO), C. Matthee (NMISA), D. McCarthy (IAU), T. O'Brian (NIST), T.E. Parker (NIST), D. Piester (PTB), F. Riehle (PTB), S. Romisch (NIST), A. Sengupta (NPLI), K. Senior (IGS), P. Tavella (INRIM), W. Walls (USNO), B. Warrington (NMIA), D.H. Yu (KRISS).

Observers:

R. Hamid (UME), Liu Yan Ying (A*STAR), M. Yoğun (UME).

Guests: T. Bartholomew, G. Chaparro-Orozco (INM-Colombia), A. Cifuentes (ONBA), F. Cordara (INRIM), R. De Carvalho (ONRJ), H.-T. Lin (TL), C.-S. Liao (TL), L.S. Ma (East China Normal University), R. Nelson (Satellite Engineering Research Corporation), P. Tuckey (LNE-SYRTE).

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

Sent regrets: A. Naumov (VNIIFTRI).

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

The President gave a short recollection of the life and achievements of Dr Sigfrido Leschiutta and the delegates observed a minute’s silence.

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 NMIJ/AIST Japan, presented by Dr Feng-Lei Hong (CCTF/12-13)

The Cs fountain NMIJ-F1 reported seven evaluations of the TAI scale unit to BIPM since the 18th CCTF in 2009, with an uncertainty of 4×10^{-15}. However, operation stopped in March 2011 due to the major earthquake and has not yet been restored. A second fountain NMIJ-F2 is under construction with a target uncertainty of less than 1×10^{-15}, and Ramsey fringes have been observed.

Work has continued on the development of neutral atom optical lattice clocks with both Sr and Yb. Following the first absolute frequency measurement for the $^1S_0$ – $^3P_0$ transition in a 1D ^{171}Yb lattice; reported at the 18th CCTF, the frequency uncertainty has been significantly improved, to 3.9×10^{-15} in a recent second measurement. Development of a Sr lattice clock is almost complete, with an absolute frequency measurement for the clock transition and associated uncertainty evaluation currently in progress.

Report from PTB, Germany, presented by Dr Bauch (CCTF/12-15)

The Cs fountain CSF1 reported 18 evaluations of the TAI scale unit to BIPM since 2010, with systematic frequency uncertainty of 7.4×10^{-16} under optimal conditions. The Cs fountain CSF2 has been improved considerably to reduce uncertainties associated with distributed cavity phase and collisional shift, and is in reliable operation with a total systematic uncertainty as low as 3.4×10^{-16}.

The thermal beam primary clocks CS1 and CS2 continue to be operated as backup frequency references for the realization of the time scales UTC(PTB) and TA(PTB). Both continue to contribute to the determination of the TAI scale unit with maximum weight.

Substantial progress has been made in the development of optical frequency standards based on both single trapped ions and neutral atoms in optical lattices. Two transitions are studied for the $^{171}Yb^+$ ion: the electric quadrupole (E2) transition at 688 THz and the electric octupole (E3) transition at 642 THz. For the E2 transition, a new absolute frequency measurement made in 2011 agrees with earlier results from 2008 within a slightly improved statistical fractional uncertainty of 1×10^{-15}, dominated by the uncertainty of CSF1. For the E3 transition, an absolute frequency measurement was made for the first time at PTB in 2012. Systematic shifts are significantly smaller for the E3 transition than for the E2 transition, giving a combined systematic uncertainty of only 7×10^{-17} and a total uncertainty of 8×10^{-16}, again dominated by the Cs reference. The final result agrees to within 6×10^{-16} with recent measurements for the same transition made at NPL. The agreement seems to become even better after frequency offsets for the two reference Cs fountains against TAI are applied as corrections.

An absolute frequency measurement was also made in 2011 for ^{87}Sr confined in a 1D optical lattice. The systematic uncertainty of the Sr standard is 1.5×10^{-16}, dominated by the shift due to blackbody radiation. The evaluation of this shift has subsequently been improved through a recent measurement of the DC Stark shift, though the total frequency uncertainty is still limited by the local realization of the Cs second.

Report from CENAM, Mexico, presented by Dr López Romero (CCTF/12-17)

The optically-pumped thermal beam standard CENAM CsOP-2 is still in operation, but greater effort is now concentrated on the development of the Cs fountain CENAM CsF-1. The first Ramsey fringes were recently observed, and work is currently in progress to improve the signal-to-noise ratio in preparation for the first uncertainty evaluation.

A new Ti:Sa optical frequency comb has been developed. It is planned to stabilise this comb to a ULE cavity in preparation for future frequency metrology.

The President enquired about the timetable to complete the Cs fountain. Dr López Romero reported that a preliminary evaluation should be completed within approximately six months.

Report from LNE-SYRTE, France, presented by Dr Dimarcq (CCTF/12-18)

LNE-SYRTE currently operates 3 primary standards contributing regularly to TAI: the Cs fountain FO1, the transportable caesium fountain FOM and the dual Cs and Rb fountain FO2, together contributing over 80 evaluations of the TAI scale unit to BIPM from January 2009 to July 2012. Operation of the thermal beam standard JPO was discontinued in 2010 after 20 years of operation.

A new measurement of the Rb hyperfine interval with improved uncertainty has been made by comparisons between Rb and Cs conducted in the dual fountain FO2 from February to August 2012. The first evaluation of the Rb interval as a secondary frequency standard was reported to BIPM and published in *Circular T* in 2012.

Development of the cold atom primary standard PHARAO continues in preparation for the Atomic Clock Ensemble in Space (ACES) mission, with the flight model scheduled to be delivered in early 2013. Other compact microwave clocks are also under development, including designs incorporating magnetically trapped atoms on a micro-circuit, isotropic laser cooling (HORACE), or pulsed Coherent Population Trapping (CPT).

Development of optical lattice clocks based on both strontium and mercury is continuing. For ^{199}Hg, the magic wavelength has been experimentally determined for the first time, a preliminary investigation of systematic shifts has been completed to a combined uncertainty of 5.7×10^{-15}, and a series of absolute frequency measurements has been made using FO2 as a reference with a statistical uncertainty of 3×10^{-16}. The short-term frequency instability is approximately 5.7×10^{-15} at one second.

For ^{87}Sr, a second Sr lattice clock has been operational since 2010. The systematic uncertainty of both Sr lattice clocks is 1.3×10^{-16}. Comparisons between the two show statistical uncertainties down to 2×10^{-17} and good agreement within a combined uncertainty of 1.4×10^{-16}.

Report from KRISS, Korea, presented by Dr Kwon (CCTF/12-23)

A new dual Cs/Rb fountain is currently under development. Ramsey fringes have already been observed for Cs with a linewidth of 1 Hz, and the Rb laser system is currently in preparation.

A new absolute frequency measurement for the clock transition in a 1D ^{171}Yb lattice clock has been conducted over 45 days. The results are in good agreement with previous measurements made at KRISS, NICT and NMIJ, within the uncertainty of 1.5×10^{-14} obtained.

Report from NICT, Japan, presented by Dr Hanado (CCTF/12-07)

The Cs fountain NICT-CsF1 is in regular operation; evaluations of the TAI scale unit are carried out a few times per year with a typical uncertainty of 1.4×10^{-15}. The second Cs fountain NICT-CsF2 is currently under evaluation, with frequency shifts and their uncertainties so far at a level below 5×10^{-16}.

Development continues of optical frequency standards based on single trapped ions and on neutral atoms in an optical lattice. For $^{40}Ca^{+}$, a number of experimental improvements have reduced the absolute frequency uncertainty to 2.9×10^{-15}. For ^{87}Sr, a recent measurement of the clock transition in a 1D vertical lattice agrees with results from JILA, LNE-SYRTE, U. Tokyo-NMIJ and PTB within the measurement uncertainty of 3.3×10^{-15}. A direct measurement of the ratio of the $^{40}Ca^{+}$ and ^{87}Sr clock frequencies in 2012 achieved a fractional uncertainty of 2.4×10^{-15}.

Report from NPL, United Kingdom, presented by Prof Gill and Dr Davis (CCTF/12-28)

NPL currently operates 3 fountain standards: the Cs fountain NPL-CsF2, in regular operation with a combined systematic uncertainty of 2.3×10^{-16} and 31 evaluations of the TAI scale unit since 2010; the older Cs fountain NPL-CsF1, currently undergoing a major refurbishment with evaluation expected in 2013; and a Rb fountain. The Rb fountain completed an uncertainty evaluation in 2011, and is currently performing an absolute frequency measurement of the ground-state Rb hyperfine interval. A preliminary result obtained in 2011 is in good agreement with the recent result obtained at LNE-SYRTE.

Optical frequency standards based on single trapped ions have made good progress. A recent measurement of the electric quadrupole (E3) transition in $^{171}Yb^{+}$ using NPL-CsF2 as a reference achieved a combined uncertainty of 1×10^{-15}, an improvement by a factor of 20 over the previous measurement and in very good agreement with the similar result obtained at PTB. A measurement of the electric quadrupole (E2) transition in $^{171}Yb^{+}$ in 2010 is also in good agreement with the PTB result, though the uncertainty is larger as a hydrogen maser was used as an intermediate reference. Work is currently in progress to measure the ratio of the E2 and E3 transition frequencies.

Work is also under way to prepare for a new measurement of the electric quadrupole transition at 445 THz in $^{88}Sr^{+}$, previously measured at both NPL and NRC. A number of experimental improvements have been made, including to improve the reliability of operation, and the expected level of uncertainty is now 1×10^{-15}. Two separate $^{88}Sr^{+}$ endcap traps show instability of 2.5×10^{-16} at 4000 s and agreement at the 3×10^{-16} level in overnight runs.

A neutral Sr optical lattice clock is also in preparation, with second-stage cooling currently under development incorporating a novel Zeeman slower. The experimental chamber has been designed for an experimental evaluation of the frequency shift due to blackbody radiation, by transporting atoms in a moving lattice into a thermally-stabilised region, holding there in a magic lattice for clock spectroscopy, and finally returning for readout.

Dr Davis provided an update on the NPL timescale, based on an ensemble of 4 active hydrogen masers and 3 commercial Cs standards. Alternate ensemble timescale algorithms have been investigated, with UTC(NPL) currently realized using the most stable maser steered to NPL-CsF2. A number of time transfer systems are also in regular operation including TWSTFT.

Report from METAS, Switzerland, presented by Mr Bernier (CCTF/12-29)

The continuous beam Cs fountain FOCS-2 is in operation and an extensive uncertainty analysis has been completed. The dominant source of uncertainty is presently a large phase gradient in the microwave cavity. A new resonator has been designed to reach a target phase gradient of 3 µrad/mm, and is currently under construction. Operation of the modified FOCS-2 is scheduled for October 2012, and it is hoped that the standard can contribute to the evaluation of TAI in 2013.

A new system to generate the timescale UTC(CH) was commissioned in 2011. The timescale is based on a small ensemble of commercial Cs standards and a hydrogen maser, and incorporates dual-redundant comparison systems to ensure continuous operation.

The President noted the requirement that new primary frequency standards submit evaluation data to the Working Group on Primary Frequency Standards for review, and Mr Bernier confirmed that data for FOCS-2 will be submitted to this Working Group.

Report from INRIM, Italy, presented by Dr Tavella (CCTF/12-31)

The Cs fountain IT-CsF1 reported seven evaluations of the TAI scale unit to BIPM since the 18th CCTF in 2009, with a typical uncertainty of 1×10^{-15}. Operation has been temporarily suspended since late 2011 for several upgrades to the apparatus, but is expected to resume in the near future.

The Cs fountain IT-CsF2 is currently under development in a collaboration with NIST. The fountain will operate with the Ramsey interaction region at cryogenic temperatures to reduce and better characterize the frequency shift due to blackbody radiation. A preliminary evaluation has yielded an uncertainty of 5×10^{-17} for this component or 6×10^{-16} overall, close to the expected accuracy. Two remote comparisons with NIST fountains also show good agreement within uncertainty.

Development of an optical frequency standard based on neutral Yb atoms in an optical lattice has continued. The clock laser at 578 nm is complete, with instability of 2×10^{-15} between 0.3 s and 100 s and a final linewidth approaching 1 Hz. Completion of the optical lattice is scheduled for late 2012 and preliminary operation is expected in 2013.

Report from NPLI, India, presented by Dr Sen Gupta (CCTF/12-32)

The Cs fountain denoted India CsF1 has been under development for several years with first operation in May 2011. A complete evaluation is currently in progress including mapping of the magnetic field in the flight region and further improvement of the short-term stability. It is hoped that the fountain could contribute to TAI within approximately one year.

Development of a second fountain commenced in March 2011, with a target uncertainty in the low 10^{-16} range. Assembly is planned to be in the new metrology building at NPLI.

Report from NIST, United States, presented by Dr O'Brian (CCTF-09/33)

The Cs fountain NIST-F1 has been in operation since 1998, and reported eighteen evaluations of the TAI scale unit since the 18th CCTF in 2009 with a typical systematic uncertainty of 4×10^{-16}.

Construction and initial testing of the Cs fountain NIST-F2 is now complete. In a joint collaboration with INRIM, the fountain will operate with the Ramsey interaction region at cryogenic temperatures, to reduce and better characterise the frequency shift due to blackbody radiation. The first formal evaluation is planned for early 2013 and a systematic uncertainty in the low 10^{-16} range is expected.

A major upgrade to the timescale is currently in progress, extending the existing ensemble of seven hydrogen masers and four commercial Cs standards. When the upgrade is completed in approximately 2015, at least 10 active masers and 10 high-performance Cs standards are expected to contribute to TAI.

Two 'logic clocks' have been developed based on the $^1S_0 - {}^3P_0$ transition in a single $^{27}Al^+$ 'clock' ion together with $^9Be^+$ or $^{25}Mg^+$ as a companion 'logic' ion. An evaluation of the first such standard in 2010 demonstrated a fractional frequency uncertainty of 8.6×10^{-18}; the performance of the second standard is expected to be similar although no formal evaluation has been completed.

Development of optical frequency standards based on the electric quadrupole (E2) transition in a single $^{199}Hg^+$ ion has also continued. Improved control and cancellation of electric field gradients have constrained the electric quadrupole shift and yielded a fractional frequency uncertainty of 1.7×10^{-17}. A second mercury ion standard is under development.

Progress has also been made in the development of neutral atom optical frequency standards. A precision measurement of the polarizability of ^{171}Yb atoms confined in an optical lattice has been recently completed, reducing the uncertainty of the frequency shift due to blackbody radiation to only 3×10^{-17} near 300 K. Significant progress has also been made in the ^{40}Ca standard, with improvements to laser cooling reducing the temperature of trapped ^{40}Ca to about 10 µK and potentially also reducing systematic frequency uncertainties to the low 10^{-15} range.

Significant work continues on the development of optical frequency combs for frequency metrology and a range of applications. The use of microresonators for comb generation has the potential to be combined with chip-scale atomic clocks, magnetometers or other sensors to form combined 'laboratory on a chip' instruments.

A new Precision Measurement Laboratory was completed at NIST Boulder in 2012 at a cost of USD $120M. Programs of the NIST Time and Frequency Division will occupy approximately 40% of the new facility, which offers tight control of vibration, temperature, humidity and air quality and supports research and development requiring stringent environmental control.

Report from NRC, Canada, presented by Dr Madej (CCTF/12-34)

The Cs fountain NRC-FCs1 is currently under evaluation with results expected next year. The expected fractional frequency uncertainty is in the low 10^{-15} range.

An optical frequency standard based on $^{88}Sr^{+}$ now incorporates a new endcap trap system, which has significantly improved control of ion micromotion and reduced associated systematic shifts to the low 10^{-18} range. The combined fractional frequency uncertainty is presently estimated at 3×10^{-17}, dominated by the blackbody radiation shift. An absolute frequency measurement conducted over two months with an NRC hydrogen maser as intermediate reference gives results in good agreement with a previous measurement made at NPL in 2006.

The 674 nm laser for the $^{88}Sr^{+}$ clock transition has demonstrated a typical linewidth of 4 Hz, and a thermal noise instability limit of 2.6×10^{-16}.

Two frequency combs are in operation: a Ti:sapphire comb used for calibration of standard frequency lasers and a fibre-based comb used for measurements of the $^{88}Sr^{+}$ clock transition frequency at 445 THz.

Report from NIM, China, presented by Dr Fang (CCTF/12-37)

The Cs fountain NIM5 was completed at the end of 2010. After being moved to the new NIM campus at Changping in April 2011, it has been in regular operation since November 2011 with a typical frequency uncertainty of 2×10^{-15}.

An optical frequency standard based on neutral Sr atoms confined in an optical lattice is currently under development. The 698 nm laser for the clock transition has demonstrated a linewidth of approximately 5 Hz, and lattice loading and spectroscopy of the clock transition have been demonstrated for ^{88}Sr atoms in a static magnetic field. Work is currently under way to switch to ^{87}Sr to develop the lattice clock.

Report from USNO, United States, presented by Dr Matsakis (CCTF/12-06)

Dr Matsakis referred to the report (CCTF/12-06) but provided a short presentation in addition.

Four Rb fountain standards are currently in operation, with a fractional frequency instability in the low 10^{-16} range at averaging times of several weeks (noting that interpolation is needed in some cases to bridge across operational outages).

Dr Matsakis also presented data for comparisons via PPP between the Rb fountain NRF5 and EAL; between NRF5 and a modified EAL based only on hydrogen masers, showing improved stability; and finally between NRF5 and LNE-SRYTE FO2, with further improved stability.

Dr Bize asked how many fountains are planned for the USNO ensemble. Dr Matsakis advised that seven fountains are planned in total, with two currently under construction.

Report from VNIIFTRI, Russian Federation, presented by Dr Domnin (CCTF/12-02)

Cs fountain standards have been under development for a number of years within the GLONASS programme, with a target fractional frequency uncertainty of 5×10^{-16}. This uncertainty is currently evaluated as 5.3×10^{-16}, with the largest components due to microwave power dependence and the spin exchange shift. Dr Domnin noted that the Cs fountains МЦР Ф02 and LNE-SYRTE FO2 gave consistent frequency offsets against TAI over a common period, at the level of 1×10^{-15}.

The President gave a short summary of these presentations, as follows: contributions to TAI from new fountain standards are expected; one secondary frequency standard is already submitting data for publication in *BIPM Circular T*, with others potentially contributing soon; and there is significant ongoing activity in the development of optical frequency standards, with frequency stability and absolute frequency uncertainty both continuing to improve.

2.2 Report of the CCTF Working Group on Primary Frequency Standards

The President invited Dr Parker to present this report (CCTF/12-42).

Dr Parker began by explaining that the Working Group was established in 2005, and serves as a group of experts on primary frequency standards (PFS) for consultation by BIPM or by national laboratories. 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, are circulated to the Working Group for comments before the report is accepted by the BIPM.

In total, the group has reviewed the first reports from six new or modified primary frequency standards and one secondary frequency standard, including four standards reviewed since the 18th CCTF in 2009. Reports for one new standard were withdrawn, owing to problems identified with time and frequency transfer. Dr Parker thanked all of the Working Group members who assisted with reviews.

Eleven fountains from seven laboratories have formally reported to BIPM, with ten fountains and two thermal beam standards reporting regularly. Over the last few years each *Circular T* has typically included reports from three or four operating fountains. Several fountains have stated total uncertainties of approximately 4×10^{-16} for a 30 day run, and the uncertainty of the TAI scale interval with several fountains can be as small as 2×10^{-16}.

Comparisons of nine fountains to SYRTE FO2 since February 2008 show frequency offsets of order 5×10^{-16}, consistent with zero within combined uncertainties, and good statistical consistency overall. Similarly, this group of ten fountains are all consistent with their weighted mean at the level of 1×10^{-15} over the period from February 2008 to August 2012. Treating the evaluations as independent, the experimental standard deviation of the mean is 2×10^{-16}.

First reports for a secondary frequency standard, the Rb fountain SYRTE FO2, were submitted to BIPM in February 2012. The Working Group reviewed these reports in the same way as for a primary frequency standard, and on the basis of the data submitted recommended that the Rb hyperfine interval be updated in the list of recommended values of standard frequencies. The group also discussed how reports from secondary frequency standards could contribute to evaluations of the TAI scale interval. The decision was taken to report evaluations of SYRTE

FO2 in *Circular T*, but not to use these to contribute to TAI until the Rb frequency has been updated.

It is proposed that the Working Group will become the Working Group on Primary and Secondary Frequency Standards, with an expanded membership including experts on secondary frequency standards. As Dr Parker's term ends in September 2012, Dr Steve Jefferts is proposed as the new Chair of the Working Group (see CCTF/12-09).

The President thanked Dr Parker for his service as Chair, and noted that the issue of the Rb frequency will be discussed following the report from the CCL-CCTF Joint Working Group on Frequency Standards.

2.3 Report of the CCL-CCTF Joint Working Group on Frequency Standards

The President invited Dr Riehle to present this report (CCTF/12-59).

Dr Riehle summarised the Terms of Reference for the Joint Frequency Standards Working Group (FSWG). The FSWG has the responsibility to maintain a single List of Recommended Frequencies, 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.

The List of Recommended Frequencies is now available online, with the assistance of the BIPM. Due to the large number of modifications a complete list will be submitted for publication in *Metrologia*, following the general outline of the previous publication (*Metrologia* **40** 103–133, 2003). Submission is expected by the end of 2012.

The FSWG also has responsibility for key comparisons of standard frequencies such as CCL-K11, which incorporates comb-based calibrations of laser frequencies. Since the 18th CCTF in 2009, comparison campaigns have been completed at node laboratories, and additional revisions to the protocol have been suggested both by a subgroup within FSWG and in discussion at the FSWG meeting immediately prior to the current CCTF. In particular, for high-accuracy comb measurements with uncertainty below 10^{-11}, self-confirmation by peer-reviewed publication is only sufficient to demonstrate capability where measurements are in agreement with results from other NMIs.

In 2009, the FSWG, CCL and CCTF also discussed the question of frequency ratios, which can be measured to significantly higher precision than absolute frequencies referred to Cs standards. A sub-group was established within the FSWG to further consider this issue, and reported two principal potential uses of measured frequency ratios: first, to generate 'synthesized' frequencies, *i.e.* $f_A = f_A/f_B \times f_B$; and second, for consistency checks at high precision, *e.g.* does $f_A/f_B \times f_B/f_C = f_A/f_C$? In the longer term, measurements of both absolute frequencies and frequency ratios could be collated in a matrix form, and standard algorithms used to reduce this potentially overdetermined dataset to an optimum set of reference frequencies. A discussion of frequency ratios will be included in the forthcoming *Metrologia* paper.

Dr Riehle summarised recommendations to be brought to the CCTF from the meeting of the FSWG held on 10 and 11 September 2012 at the BIPM:

- After extensive discussion, the FSWG recommended a series of amendments to the List of Recommended Frequencies:
    - the unperturbed optical transition $3s^2\ ^1S_0 - 3s3p\ ^3P_0$ of the $^{27}Al^+$ ion be added, combining measurements made at NIST;
    - the unperturbed optical transition $6s^2\ ^1S_0 - 6s6p\ ^3P_0$ of the ^{199}Hg atom be added, to reflect the recent measurement made at SYRTE;
    - the unperturbed optical transition $6s\ ^2S_{1/2}$ (F=0) – $5d\ ^2D_{3/2}$ (F=2, m_F=0) of the $^{171}Yb^+$ ion, a secondary realization of the second, be updated to reflect the recent measurements made at PTB and NPL;
    - the unperturbed optical transition $4f^{14}6s\ ^2S_{1/2}$ (F=0) – $4f^{13}6s^2\ ^2F_{7/2}$ (F=3, m_F=0) of the $^{171}Yb^+$ ion be updated, to reflect the recent measurements made at NPL and PTB;
    - the unperturbed $6s^2\ ^1S_0 - 6s6p\ ^3P_0$ transition of the ^{171}Yb atom be updated, to reflect the recent measurements made at NIST and NMIJ;
    - the unperturbed optical transition $5s\ ^2S_{1/2} - 4d\ ^2D_{5/2}$ of the $^{88}Sr^+$ ion, a secondary realization of the second, be updated to reflect the recent measurement made at NRC;
    - the unperturbed optical transition $4s\ ^2S_{1/2} - 3d\ ^2D_{5/2}$ of the $^{40}Ca^+$ ion be updated, to reflect the recent measurements made at NICT and WIPM;
    - the unperturbed optical transition 1S – 2S of the ^1H atom be updated, to reflect the recent measurement made at MPQ;
    - the unperturbed optical transition $5s^2\ ^1S_0 - 5s5p\ ^3P_0$ of the ^{87}Sr atom, a secondary realization of the second, be updated to reflect recent measurements made at PTB and NICT;
    - the unperturbed optical transition $5d^{10}6s\ ^2S_{1/2}$ (F=0) – $5d^96s^2\ ^2D_{5/2}$ (F=2, m_F=0) of the $^{199}Hg^+$ ion, a secondary realization of the second, be updated to reflect the recent measurement made at NIST; and
    - the unperturbed ground-state hyperfine transition of the ^{87}Rb atom, a secondary realization of the second, be updated to reflect the recent measurement made at SYRTE.
- The FSWG recommended three additions to the list of secondary representations of the second, with details as above:
    - the unperturbed optical transition $^2S_{1/2}$ (F=0) – $^2F_{7/2}$ (F=3, m_F=0) of the $^{171}Yb^+$ ion;
    - the unperturbed $6s^2\ ^1S_0 - 6s6p\ ^3P_0$ transition of the ^{171}Yb atom; and
    - the unperturbed optical transition $3s^2\ ^1S_0 - 3s3p\ ^3P_0$ of the $^{27}Al^+$ ion.
- The FSWG did not recommend any additions to the list of realizations of the metre.

Dr Riehle presented some additional details to illustrate the discussion and decision process undertaken by the FSWG. In particular, in the case of the $^1S_0 - {}^3P_0$ transition in $^{27}Al^+$, a previous absolute frequency measurement was completed in 2007 with an uncertainty of 6 Hz. A new value for the transition frequency was obtained from the measured frequency ratio $f(^{27}Al^+\ {}^1S_0 - {}^3P_0)/f(^{199}Hg^+\ {}^2S_{1/2} - {}^2D_{5/2})$ together with an absolute frequency measurement for the $^{199}Hg^+$ electric quadrupole transition, yielding a combined uncertainty of 0.7 Hz. The recommended frequency was obtained from the weighted mean of the two values, with the combined uncertainty expanded by a factor of three as measurements were contributed from a single laboratory.

In the case of the ground-state hyperfine transition in ^{87}Rb, the Working Group on Primary Frequency Standards recommended that the FSWG consider revising the frequency value after reviewing data submitted for the fountain SYRTE FO2 as a secondary frequency standard. The FSWG considered the SYRTE data, together with an independent but consistent evaluation made by BIPM against the ensemble of primary frequency standards using data submitted for *Circular T*, before recommending an updated value for this transition in the List of Recommended Frequencies.

The President thanked Dr Riehle for the detailed report, and confirmed that delegates were in agreement with the proposed Recommendation to update the List of Recommended Frequencies. Dr Madej and Dr Hong noted some typographical errors in the reference frequency information, and Dr Riehle confirmed that these will be corrected in the final Recommendation.

The President also noted the agreement between the Working Group on Primary Frequency Standards and the FSWG on the need to update the Rb hyperfine interval in the List of Recommended Frequencies, and Dr Bize agreed that the revised value proposed in the Recommendation was appropriate.

2.4 Frequency standards in TAI and realization of TT(BIPM)

The President invited Dr Petit to present this report (CCTF/12-48).

Dr Petit explained that the time scale TT(BIPMxx) is calculated using post-processing of all available data from primary frequency standards. There has been no significant change in computation since the last meeting of the CCTF in 2009. A prediction of TT(BIPM) has been published each month since 2010, and the latest realization, TT(BIPM11), was released in January 2012. The frequency uncertainty of TT(BIPM) has steadily improved since the introduction of Cs fountain standards, from 2.5×10^{-15} in 1999 to a typical value of $2–3\times10^{-16}$ in 2012.

The contribution of fountain standards to TAI similarly continues to increase. There have been more than four fountain evaluations contributing to TAI each month since 2009, with the median uncertainty now below 4×10^{-16} and the corresponding uncertainty in the frequency of TAI approximately 2×10^{-16}. The fractional frequency deviation of TAI d is now reported in *Circular T* with a resolution of 10^{-17}.

Dr Petit and Dr Panfilo have undertaken a study comparing the ensemble of primary frequency standards to TT(BIPM). The distribution of frequency biases against TT(BIPM) is statistically consistent with stated uncertainties, and shows no evidence either of underestimation of uncertainty or of systematic frequency shifts. This also confirms the estimation of the corresponding uncertainty in the frequency of TT(BIPM).

The first evaluation of a secondary frequency standard, the Rb fountain SYRTE FO2, was submitted in January 2012 (see discussion under the report from the Working Group on Primary Frequency Standards). A total of thirteen evaluations were published in *Circular T* 193 in June 2012. Comparisons to primary frequency standards indicate that the value given for the rubidium hyperfine interval in the List of Recommended Frequencies should be increased by approximately 1.7×10^{-15}. Consistent values are obtained for this correction by three separate comparisons for SYRTE FO2: against primary frequency standards locally at SYRTE over 1998–2012; against TT(BIPM) over 2010–2012; and against the best estimate of the ensemble of primary standards over the evaluation intervals for SYRTE FO2.

Dr Petit summarised the report by noting that primary frequency standards continue to gain in accuracy, but that this improvement is not completely passed to TAI and TT(BIPM) owing to noise in time and frequency transfer. The ensemble of primary standards are statistically consistent within reported uncertainties, and the accuracy of TT(BIPM) and the frequency uncertainty of TAI are both approximately 3×10^{-16}. Dr Petit concluded by recommending that the use of secondary frequency standards continue to be discussed by the Working Group on Primary and Secondary Frequency Standards and the Working Group on TAI, and requesting submissions from additional secondary standards to assist the community to gain experience in their use.

Dr Riehle asked whether the Working Group on Primary and Secondary Frequency Standards would recommend that data from rubidium frequency standards contribute to the evaluation of TAI, once the rubidium hyperfine interval is updated in the List of Recommended Frequencies. Dr Parker’s view was that there was no reason in principle not to use this data, but that there needed to be a general discussion of the use of secondary frequency standards, including for example how to handle future updates to reference frequencies and how to take advantage of optical frequency standards.

The President commented that a transition period is presently anticipated where secondary optical frequency standards contribute to the evaluation of TAI in advance of a future redefinition of the second.

The President also enquired as to the minimum number of standards required to steer the TAI scale unit in a given month. Dr Petit advised that as the steer is based on a full year of history, weighted towards the most recent month, a correction can still be determined even if no fountain evaluations are available (though with uncertainty increased to approximately 1×10^{-15}).

Dr Bize asked whether, as more secondary frequency standards become available in future, evaluations of these standards should be made against TT(BIPM) or the ensemble of primary frequency standards in addition to using a local primary standard as a reference. It was felt that this question should be included in the general discussion regarding the use of secondary standards.

3 PRESENT STATUS OF TAI

3.1 Report of the CCTF Working Group on TAI

The President invited Dr Tavella to present this report (CCTF/12-41).

Dr Tavella began by explaining that the aims of the Working Group are to promote knowledge of TAI and UTC, and to facilitate communication between the BIPM Time Department and timing laboratories.

The 9th meeting of representatives of laboratories contributing to TAI was held at the BIPM on 12 September 2012. Dr Tavella presented the agenda for the meeting, and highlighted some of the issues discussed. The first part of the meeting, attended by representatives from contributing laboratories, included a report from the BIPM Time Department on the status of UTC, the performance of time links, the BIPM database, and primary and secondary frequency standards. The status of the pilot project to establish a rapid realization of UTC was also presented. Selected laboratories presented reports on 'real time' monitoring of time scales, and on major changes to time scales or timing equipment. Two new laboratories are contributing to TAI, a further seven are preparing to contribute, and two laboratories have withdrawn.

The second part of the meeting, with CCTF delegates also in attendance, discussed proposed revisions to the UTC time scale following discussions at the World Radiocommunication Conference 2012 in Geneva. Dr Tavella summarised a free-ranging discussion in the following two points:

- the majority of laboratories attending were in favour of a continuous, unique, reference time scale;
- only around half of these laboratories have been actively involved in discussion with the official body representing their nation to the ITU (typically not the NMI itself).

It was recommended that timing laboratories make contact with ITU delegates to provide their input on this issue.

For the first time, a training day was also organised to support new timing laboratories. The training day, entitled 'Fundamentals for a time and frequency metrology laboratory', was held on 11 September 2012 with the assistance of the BIPM. Dr Tavella presented the programme for the day, which included presentations on laboratory equipment, time transfer, contributing to UTC, methods of dissemination, and on the international framework of metrology including the CIPM Mutual Recognition Arrangement and the Regional Metrology Organisations (RMOs). A total of 59 people from 26 countries and 5 continents were registered, but only 46 people were able to be present. The organisers will seek feedback to assess how the day addressed the needs and expectations of those attending. Similar events may be held in future, potentially in consultation with the RMOs or at an alternate location to facilitate regional access.

Dr Tavella thanked the BIPM, the experts providing tutorial presentations, and all laboratories attending.

Dr O'Brian asked whether there were specific opportunities to engage with ITU delegates on the UTC time scale, for example through a seminar program. Dr Beard noted that this topic will be included in the ITU regional seminar to be held in Ecuador at the end of September 2012, and in other international forums. Dr Arias similarly noted the ITU regional seminar for the Russian region and the Baltic states held in Kazakhstan in early September 2012.

Dr Sen Gupta asked whether the tutorials from the training day could be made available for those unable to attend. Dr Tavella confirmed that these would be made publically available through the BIPM website.

3.2 Report of the BIPM Time Department

The President invited Dr Arias to present this report (CCTF/12-45).

Dr Arias began by outlining the present organisation of the Time Department (formerly the Time, Frequency and Gravimetry Section), currently comprising 9 permanent staff. A key goal of the Time Department is to improve the UTC time scale, with the cooperation of participating laboratories and of the BIPM.

Achievements of the Time Department since the 18th CCTF in 2009 include continued improvement of the uncertainty of clock comparison through the development of new methods; improved frequency prediction for both hydrogen masers and caesium clocks in the ALGOS algorithm, eliminating the long-term drift observed in EAL; completion of the pilot project to establish a rapid realization of UTC; ongoing contributions to the international discussion on the future of UTC; and the conclusion of the 8th international comparison of absolute gravimeters, ICAG-2009, and subsequent transfer of this work to other laboratories. Dr Arias observed that the activities and priorities of the Department evolve quickly. For example, the pilot for a rapid UTC was not formally part of the programme of work for 2009–12 approved by the CCTF and CIPM, but this project was clearly a priority for laboratories and it was therefore included as part of ongoing improvements to the UTC time scale.

Seven different methods for time and frequency transfer are currently in operation, including combined time links such as TWSTFT+PPP and GPS+GLONASS. A total of 69 laboratories currently contribute to UTC. The program to characterize the delays of GNSS equipment is ongoing, including differential calibration campaigns using travelling receivers, the consolidation and presentation of results online, and the completion of a PhD project on absolute calibration methods undertaken in a collaboration between BIPM, CNES and OP.

The long-standing drift observed in the time scale EAL with respect to TAI has been addressed by adopting a quadratic prediction model for clock frequencies for both Cs clocks and hydrogen masers, and a pilot project to establish a rapid realization of UTC with lower latency has also been completed (see separate reports on these topics). Dr Arias also reported on a project to develop an online database to centralize and disseminate information necessary for the maintenance of UTC, including information relating to laboratories and their equipment. Testing and evaluation is current in progress, with access expected to be provided to pilot users by the end of 2012.

Dr Arias summarised ongoing discussions regarding the future of UTC, and specifically the question of leap seconds, including representation by BIPM staff at the ITU Radiocommunication Assembly and at regional ITU seminars; the publication of a special issue of *Metrologia* on ‘Modern Time Scales’ in August 2011; and the organisation of the Royal Society Discussion Meeting on ‘UTC for the 21st Century’ in London in January 2012 (see discussion of these issues later in the agenda).

Dr Arias finished by noting that the 8th international comparison of absolute gravimeters, ICAG-2009, concludes a series of comparisons held at the BIPM over approximately three decades. A series of publications are available presenting results and analysis. The next comparison ICAG-2013 will take place in Luxembourg, and will be piloted by METAS.

Dr Madej noted that the proposed programme of work for 2013–2015 included time and frequency transfer for the comparison of optical frequency standards, and enquired as to the specific plans of the Time Department in this area. Dr Arias advised that the BIPM has no specific activity in this area, but is actively contributing to the work of related CCTF Working Groups. In Dr Arias' view, the role of the BIPM in this area is to work with the relevant laboratories to determine the optimal means to include optical frequency standards in the determination of TAI, and to maintain awareness of ongoing technical developments to prepare for this inclusion.

Dr Madej expressed the opinion that the BIPM has an important role to support innovation in this area, and that the lack of specific activity was disconcerting. Dr Arias noted that the BIPM is not equipped with the necessary laboratory facilities, and that the program of work for the next triennium (to be discussed later in the agenda) should include activities that can be developed within available resources, with input from CCTF members regarding strategic priorities.

The President noted that both the CIPM and the CGPM have to date excluded optical clocks from the BIPM work programme, either implicitly or explicitly. Prof. Kühne reminded delegates that the BIPM executes the work programme as agreed by the CIPM based on recommendations from the CCTF; the CCTF could therefore choose to make a recommendation in this area, which the CIPM could prioritize against other requirements. Prof. Kühne welcomed all suggestions.

The President thanked Dr Arias for the report.

4 LATEST AND FUTURE DEVELOPMENTS FOR UTC AND TAI

4.1 Improvements in ALGOS

The President invited Dr Panfilo to present this report (CCTF/12-47).

Dr Panfilo began by explaining that until July 2011 a linear prediction model was used to describe clock behaviour in the ALGOS algorithm, excluding frequency drift during the calculation period. Owing to the observed aging of the clocks contributing to TAI, this gives rise to a drift in the time scale EAL with respect to TAI of approximately -1.3×10^{-17} per day.

To eliminate this drift, a new quadratic prediction algorithm has been validated and implemented from August 2011, incorporating frequency drift for both Cs clocks and hydrogen masers. TT(BIPM) is used as an internal frequency reference to estimate the frequency drift. In consequence the drift in EAL has been almost completely eliminated, as shown in both simulations reprocessing data since 2006 or a comparison against the ensemble of primary frequency standards. The fractional deviation d of the scale interval of TAI from that of TT(BIPM) was previously approximately 6×10^{-15} but is now decreasing towards zero. The fractional frequency difference between TAI and the ensemble of primary standards was previously approximately -5×10^{-15} but is similarly now approaching zero.

Dr Panfilo pointed out that the new prediction algorithm has no effect on clock weights. Under existing weighting, clocks with deterministic drift (including hydrogen masers) have low weight. A new algorithm is proposed which attempts to weight predictable clocks rather than strictly stable clocks, following a publication by Dr Levine. A test using six years of data from 2006 to 2011 shows that the typical total maser weight increases from 15% to 30%, while the typical total caesium weight reduces from 85% to 70%. The number of masers at maximum weight also increases, while the number of Cs clocks at maximum weight decreases. The modified EAL time scale has improved short-term and long-term stability, evaluated against a USNO Rb fountain and against TT respectively. These initial results are promising, but additional studies are necessary to validate the new weighting algorithm.

Dr Panfilo concluded by noting the possibility to test the new weighting algorithm making use of available daily clock data which are currently submitted for the rapid realization of UTC. This should permit an evaluation of the short-term contribution of the hydrogen masers to the ensemble.

Dr Levine commented that studies of the new weighting algorithm were interesting and useful, and suggested that revisions to the maximum weight may also need to be considered.

Dr Matsakis asked about the strength of weighting filter, for example as seen in the relative weights of one-month and three-month old data. Dr Panfilo advised that the filter was not strongly weighted in favour of recent data.

4.2 Multi-technique link combination

The President invited Dr Jiang to present this report (CCTF/12-46).

Dr Jiang began by observing that for several years a number of laboratories have operated more than one transfer technique, and both the number of laboratories and the number of techniques is increasing. Currently, 69 laboratories contribute data to the evaluation of TAI and UTC, and 28% of these links use a combined technique.

Two examples of combined links were presented. In the case of TWSTT+GNSS, the short-term stability of GNSS carrier-phase transfer is used to interpolate between TWSTT sessions and to reduce diurnal variation in the two-way data. In the case of GPS+GLONASS, data for several baselines demonstrate good consistency at or below the level of 1 ns between GPS C/A and GLONASS L1C over almost three years to February 2012.

Dr Jiang also presented data from a trial computation of GLONASS PPP without correction for inter-frequency biases, where a comparison to GPS PPP on the same link shows residual instability with standard deviation $\sigma = 1.6$ ns, relatively large for a PPP link. GLONASS PPP cannot be used for links contributing to UTC without correcting for inter-frequency biases.

Dr Defraigne asked how the calibration was achieved for the GLONASS links. Dr Jiang explained that this was done in an initial transfer from calibrated GPS equipment but not subsequently updated through the period of comparison, indicating good stability of the calibrated delays.

Dr Defraigne also noted that the NRCan software can also calculate GLONASS PPP solutions, but these are processed separately from GPS data and a comparison between solutions from the two systems similarly shows a standard deviation of 1.6 ns. Dr Defraigne suggested an alternate approach where individual observations are combined before processing for a single integrated solution. Dr Jiang advised that work was in progress along these lines.

Dr Matsakis noted that the combination technique currently in use for UTC assumes that TWSTT is more accurate in the long term but GPSCP more stable in the short term. He presented for comparison additional data from USNO evaluating TWSTT and GPS techniques on the same links, and made the following observations:

- the history of repeated calibrations between USNO and PTB/NIST, and the double-difference between Ku-band and X-band data for the USNO-PTB link, both appear to show variations of up to 3 ns in TWSTT system delays; and
- TWSTT triangle closure sums of the form (A–B)+(B–C)+(C–A), which are expected to be zero and are insensitive to clock variations, show typical peak-to-peak variations of 2 ns over several years for sample triangles including OP-PTB-USNO and IT-NPL-SP.

These variations are of the same order as those expected from modern GPS equipment. Dr Matsakis suggested that laboratories consider establishing an ensemble of GNSS receivers, and potentially also TWSTT equipment, with a common clock, so that regular comparisons could assist in monitoring any variation in equipment delays.

Dr Senior expressed agreement that TWSTT results could not always be regarded as truth, but that there is nevertheless value in a combination, particularly as the TWSTT data is independent.

Dr Jiang was not in full agreement with Dr Matsakis, noting that he had not seen similar levels of variation in TWSTT results but by contrast had observed a drift of 1 ns per month in the calibration of the ROA GPS receiver over an extended period. Dr Matsakis commented that such a drift would be detected through the use of a receiver ensemble as suggested, and Dr Jiang noted that this would apply equally to an ensemble of GLONASS or multi-constellation receivers.

Dr Piester observed that use of a receiver ensemble does not give a unique transfer solution for the local reference clock, agreed with Dr Senior that TWSTT data is valuable because it is independent, and noted that both techniques are used for example in fountain comparison campaigns.

The President suggested that further work is required in this area, noted that a corresponding recommendation was in preparation (CCTF/12-40), and encouraged laboratories to continue to share information.

4.3 Report on Rapid UTC

The President asked Dr Petit to present this report (CCTF/12-49).

Dr Petit began by summarising some of the benefits of a rapid realization of UTC, including improved accuracy and stability of local realizations UTC(*k*) by assisting contributing laboratories with monitoring and steering. Following an initial invitation to participate issued in September 2011, the pilot project began in January 2012, with the first publication on 29 February 2012.

The new rapid time scale, denoted UTCr, is reported weekly from data submitted daily, and is generated independently of the monthly computation of UTC. Automated processes are used for data reporting and checking. Time links are similarly calculated automatically, but are based on CGGTTS (code) data only in contrast to the full computation of UTC; TWSTT and potentially PPP links may be added in future. The processing algorithm is similar to ALGOS, and adopts a similar weighting model, but is currently restricted to linear clock frequency prediction. Steering to UTC is applied, based on a weighted average of the differences between UTC and UTCr.

Dr Petit reported results from a detailed comparison between UTCr and UTC. Approximately 60% of TAI clocks contribute to UTCr, with similar overall behaviour, suggesting UTCr should be roughly 20% less stable than UTC. More than 25 of the 50 laboratories contributing to UTCr have some weight, compared with 50 of approximately 69 contributing to TAI. The weight in UTCr is more variable due to the real-time nature of the calculation.

The first seven months of operation show large excursions of up to 6 ns between UTCr and UTC. Some of the largest features are understood to be linked to bad clock data or to specific clocks missing from the solution, but this is not a complete explanation. Several trial computations have been carried out in post-processing to test the influence of various configurations on UTCr. The best trial (a free scale with ‘optimal’ data, quadratic clock prediction and steering as for TAI) gives agreement with UTC within approximately 2 ns. This is consistent with the expected effect of key features different between UTC and UTCr, for example the use of different time-transfer links and a reduced data set. This suggests a possible future revision of the algorithm to a more ‘UTC-like’ solution, but a method to maintain consistency between UTCr and UTC is still to be chosen. Further experience with UTCr is needed to inform these decisions, and results are published with the ‘disclaimer’ that development is continuing.

Dr Petit concluded by noting that UTC is unchanged, but will benefit from UTCr due to improved anticipation and easier detection of problems with both clocks and links.

Dr Levine suggested that the means of steering UTCr to UTC should be chosen according to whether frequency stability or time accuracy has higher priority. Dr Petit explained that the simple steering mechanism initially adopted was based on the expectation that the difference between UTCr and UTC accumulated over one month would be small, which has not proven to be the case.

Dr Levine further suggested that the characteristics of UTCr should be tailored for the expected users of the product and their requirements. Dr Petit noted that all users can choose how they will use the product, for example by refining their own algorithm to steer a local UTC(k) with input from UTCr.

Dr Matsakis expressed the opinion that rapid computation was the ‘way of the future’, and asked whether the performance of UTCr was primarily limited by computing resources or available staff time. Dr Petit confirmed that the principal limit is staff time, noting that the requirement to begin in January 2012 and report to the 19th CCTF in September 2012 afforded only limited time for development. For example, the inclusion of PPP links would have required additional development to automate this calculation. The current calculation of UTCr therefore entailed a series of pragmatic decisions within available resources.

Dr Tavella asked for more details about the change to the steering procedure applied in April 2012. Dr Petit explained that the series of differences between UTCr and UTC was initially used to determine both a step change and a rate correction, but that in practice the rate correction was always negligible and had no practical effect. The steering procedure was therefore simplified to apply only a step change.

Dr Tavella noted that UTCr is expected to be an intermediate reference over the interim period until UTC is available, and asked Dr Senior whether alignment is required between similar ‘rapid’ and ‘final’ timescale products generated by the IGS. Dr Senior explained that both IGRT and IGST are separately steered to UTC, which provides agreement at some level, but no explicit alignment is imposed.

Dr Arias commented that as resources were limited, the UTCr project had begun in a relatively simple way to make initial progress, but further improvements are anticipated based on experience. Dr Arias noted that the BIPM Time Department is adjusting to the challenges of a more ‘real time’ operation, in contrast to the regular monthly calculation of UTC, and further that as the expectation increases that rapid products are available there is also increased vulnerability to problems with data communication.

The President concluded by noting that a recommendation was in preparation regarding the future of the UTCr project (see further discussion under Recommendations).

5 TIME AND FREQUENCY TRANSFER METHODS

5.1 Report of the CCTF Working Group on TWSTFT

The President asked Dr Piester to present this report (CCTF/12-19).

Dr Piester began by summarizing participating stations (a total of 23, with two in North America, 15 in Europe and six in Asia). The Working Group has met annually from 2009 to 2012, and there have been five additional meetings of participating stations associated with conferences over this period. Revised terms of reference (CCTF/12-25) were approved at the most recent meeting, held on 6 and 7 September 2012 at the BIPM.

Three broad networks are currently in operation:

- within Europe (14 stations), and between Europe and USA (two stations), using the T-11N satellite, with bandwidth reduced from 3.6 MHz to 1.6 MHz to reduce costs;
- between Asia (six stations) and Europe (two stations) using the AM-2 satellite, with a bandwidth of 2.5 MHz; and
- within the Asia-Pacific rim (two stations) using the GE-23 satellite, also used for domestic links within Japan.

A link has also been established between Asia and North America, to the USNO via Hawaii, establishing a global network.

Currently, 19% of time links used for TAI are combined TWSTFT/GPS PPP links, with a typical statistical uncertainty of 0.3 ns. This includes five links between Asia and Europe.

Dr Piester summarised several studies indicating that calibration uncertainties are broadly consistent at the 1 ns level, including the paper by L. Breakiron *et al.* (PTTI 2004); the history of operational links, which is generally consistent with this figure (D. Piester *et al.*, EFTF 2006); and the level of agreement with GPS calibration procedures (T. Feldmann, PhD thesis 2011). There is an ongoing need for regular calibration, and for operation of multiple techniques, to maintain accuracy within 1 ns.

Dr Piester also summarised recent developments in TWSTFT techniques from several laboratories:

- Absolute calibration using a satellite simulator is currently under investigation at VSL and OP, with the potential for sub-ns accuracy.
- A collaboration between OP, PTB and NIST has studied the optimal conditions for TWSTFT and identified the presence of multiple simultaneous transmissions as a limiting factor. A TDEV of 40 ps at 1 day is possible with a chip rate of 1 MChip/s in quiet periods with no other transmitting stations.
- New transfer methods under development include dual pseudo-random noise modulation (NICT, in collaboration with TL) and carrier-phase techniques (NICT and also OP). NICT have achieved instabilities of 2×10^{-13} at 1 s and 1×10^{-15} at 4000 s with a common clock, comparable to hydrogen maser performance.

Other current activities include a new database for real time TWSTFT computation (SP), the development of a mobile calibration station (TIM), and investigation of network solutions and potential limiting factors such as satellite movement (TL).

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

The President invited Dr Levine to present this report.

Dr Levine summarised discussion at the Working Group meeting on 10 September 2012 by noting that GNSS time transfer accuracy of 0.1 ns, as a long-term goal, would support the current resolution of reporting in *Circular T* and prepare for next-generation standards and applications. Time transfer stability of 0.1 ns RMS, as a short-term goal, is needed to support comparisons of current and next-generation frequency standards within practical averaging times.

Meeting these goals for time-transfer performance will require further studies of multipath effects, the stability of receiver delays, and methods for carrier phase analysis. The use of multiple receivers and multiple transfer methods can assist with monitoring and evaluation (see CCTF/12-40). Processing and data formats should also evolve to meet modern requirements; however, although the standard CGGTTS protocol and reporting format is increasingly outdated for modern receivers, there is still a requirement to support 13-minute tracks on a 16-minute schedule and the legacy CGGTTS format, as these are adequate for many applications.

Dr Levine concluded by recommending ongoing development of standardised time-transfer hardware, open sharing of receiver firmware and processing software, and greater automation of laboratory comparisons.

It is proposed that the Working Group will become the Working Group on Global Navigation Satellite Systems. Dr Defraigne is proposed as the new Chair of the Working Group (see CCTF/12-09).

The President thanked Dr Levine for the report.

5.3 Calibration of GNSS equipment

The President invited Dr Arias to present a verbal report.

Dr Arias noted that the characterization of GNSS equipment delays continues to be coordinated by the BIPM Time Department, in accordance with Recommendation CCTF 2 (2009) of the 18th CCTF in 2009. This activity has been part of the approved programme of work for 2009-2012, as presented in the report of the BIPM Time Department, and will continue to be part of the work programme for 2013-2015 (see CCTF/12-21). This work is closely related to the activities of the Working Group on the CIPM MRA and the proposed Working Group on Global Navigation Satellite Systems.

Dr Arias confirmed that the BIPM intends to develop guidelines to coordinate activity in this area, following Recommendation CCTF 2 (2009), but that limited resources have meant that progress has been slower than anticipated. BIPM will continue to work with the Regional Metrology Organisations (RMOs) to develop guidelines, and to enable RMOs to coordinate regional calibration campaigns.

Dr Achkar confirmed that LNE-SYRTE will continue to support BIPM and the RMOs in this area by providing access to a calibrated receiver.

5.4 Report of the IGS Working Group on Clock Products

The President invited Dr Senior to present this report (CCTF/12-44).

IGS real-time clock products are still in a pilot phase, but will provide real-time GPS orbits and satellite clocks as well as raw data. Accuracy is improving, and real-time IGS clocks are now mostly consistent with observed Ultra-rapid data, though some biases still exist. The service start date is still to be confirmed but may be as early as November 2012.

A new version of the IGS time scale has been developed to provide a stable and robust reference with improved long-term stability. A new clock model includes an additional phase state to model a pure white phase noise and to couple to any harmonic states (such as diurnals). The use of multiple weights per clock uses mixed clock types optimally and can improve stability over a wider range of averaging intervals. A fully automated Kalman filter is used with adaptive estimation of clock parameters. A linear-quadratic-Gaussian (LQG) steering algorithm is used for alignment to UTC, with a weighted ensemble of realizations UTC(k) also contributing as steering references.

Dr Senior presented a series of results comparing version 1.0 and version 2.0 of IGST. The new time scale shows significantly improved stability at averaging intervals beyond one day, and good consistency of both stability and weights over time. The alignment IGST – UTC is routinely below 5–10 ns, and is somewhat larger for the rapid time scale IGRT.

Dr Warrington asked how many realizations UTC(*k*) are used for steering to UTC. Dr Senior advised that this number is currently four, with GPS time also used as a reference and always available as a backup as for version 1.0 of the time scale.

Dr Tavella asked about the choice of pivot clock. Dr Senior explained that a well-behaved reference clock is chosen for each epoch, using a robust technique based on the median of data predictions. The pivot clock selected cannot be downweighted at that epoch.

Dr Arias noted the value of timing laboratories participating in the IGS network. Dr Senior agreed, noting that the use of UTC(*k*) for steering is a significant component of the improved alignment of IGST to UTC. Dr Arias encouraged additional laboratories to participate.

5.5 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 (CCTF/12-43).

Dr Tuckey began by thanking the members of the Working Group and Dr Robertsson for his work as Executive Secretary, and welcomed Dr Hong as the proposed new chair (see CCTF/12-09). Dr Tuckey also encouraged laboratories to propose a Working Group representative to the chair.

Two meetings of the Working Group have been held since the 18th CCTF in 2009, on 28 June 2011 at the BIPM and on 25 April 2012 in Göteborg in conjunction with the European Time and Frequency Forum. A workshop on the development of advanced time and frequency transfer techniques was held at the BIPM on 28 and 29 June 2011, and presentations are available through the BIPM website.

Optical fibre links have now demonstrated long-distance frequency comparisons at an instability in the low 10^{-19} range at 1 day, over distances of order 1000 km. This is approximately three orders of magnitude lower than routine GNSS and TWSTT comparisons, and sufficient to compare the best current and future optical clocks within averaging times of a few hours. This is the basis for a proposed recommendation to the CCTF in favour of continued development of optical fibre links and networks (CCTF/12-35).

However, there is as yet no clear candidate for achieving a similar significant improvement in the stability of intercontinental comparisons, although a number of methods are currently under development. The costs of accessing relevant infrastructure, including satellite time or dark fibre, may also become significant. There is therefore a need to explore partnerships with infrastructure providers, and the Working Group plans to collaborate with the European fibre network project NEAT-FT on this subject.

Dr Tuckey concluded by presenting the draft Recommendation for discussion (CCTF/12-35).

Dr O’Brian thanked the Working Group for their efforts, and stressed the importance of intercontinental links as an ongoing challenge for the time and frequency community. Dr Madej also thanked the Working Group for noting the important role the BIPM has in this area.

The draft recommendation was discussed, with a number of suggestions from delegates. Dr O’Brian suggested clarification of the role of national metrology institutes; Dr Warrington suggested adding the role of regional metrology organisations; and Dr Riehle and Prof. Kühne suggested modifications to the point regarding coordination and consultation. Dr Levine noted that the proposed developments require collaboration with telecommunication companies and other infrastructure bodies, and suggested the Recommendation promote this collaboration. Dr Tuckey stressed the importance of ensuring that the BIPM can take full advantage of new transfer methods for time scale generation.

The President proposed that further revisions to the draft Recommendation be discussed by a small subgroup comprising Dr Tuckey, Dr Warrington, Dr O'Brian, and Dr Levine.

5.6 Report on the status of fibre links

The President noted information already provided in laboratory reports relating to primary frequency standards, and asked laboratory representatives to present an additional brief report on the status of optical fibre links.

Report from NICT, Japan, presented by Dr Hosokawa (CCTF/12-07)

A 60 km fibre link has been established between NICT and the University of Tokyo, with transfer instability of 2×10^{-15} at 1 s and 4×10^{-18} at 1000 s. The link enables a direct comparison between Sr lattice clocks at the two laboratories, which has demonstrated agreement within the combined systematic uncertainty 7×10^{-16} for the two clocks.

Report from NMIJ/AIST Japan, presented by Dr Feng-Lei Hong (CCTF/12-13)

A 120 km fibre link has been established between NMIJ and the University of Tokyo. Optical amplification is not needed as the total loss is 55 dB. The link enables an absolute frequency measurement for the Sr lattice clock at the University of Tokyo using the Cs fountain NMIJ-F1 as a reference, where the measurement is not limited by the performance of the link. An urban network connecting NMIJ, NICT and the University of Tokyo is planned, in part to prepare for the Atomic Clock Ensemble in Space (ACES) mission.

Report from LNE-SYRTE, France, presented by Dr Dimarcq (CCTF/12-18)

The approach adopted at SYRTE is to use a 'dark channel' (a vacant channel in parallel to other active DWDM channels) rather than a 'dark fibre' for transfer of a stable optical frequency, as this facilitates large-scale deployment at reduced operational cost. An optical link of 2×150 km on the RENATER network including bidirectional optical amplifiers and a signal regeneration station has demonstrated instability of 4×10^{-15} at 1 s and below 10^{-19} at one day, in a measurement bandwidth of 10 Hz, with no perturbation to Internet traffic carried on the same fibre. This link has recently been extended to 500 km. SYRTE have initiated national and regional projects to develop fibre networks, and are collaborating with other European institutes to work towards long-range comparison of optical frequency standards.

Dr Dimarcq noted that SYRTE are also developing free-space optical links for ground-to-space or space-to-space transfer and as a potential method for intercontinental comparison of ground-based standards. A laser system stabilized to a fibre spool delay line has been developed, and will be used to test coherent transmission to a corner-cube reflector on a Low Earth Orbit satellite. The laser system requires a tuning range of approximately ±10 GHz to compensate for the Doppler shift due to satellite motion. SYRTE are similarly participating in the Time Transfer with Laser Link (T2L2) pulsed optical link project, with common-view comparisons among six laser-ranging laboratories in agreement with TWSTFT and GPS CP comparisons within 2 ns over several months.

Report from NIM, China, presented by Dr Li (CCTF/12-37)

The two Beijing campuses of NIM are connected by a 45 km fibre link, which has demonstrated instability of 10^{-17} at one day for the transfer of a 9.6 GHz reference frequency. A 40 km link has also been established to Tsinghua University, with instability of order 10^{-17} at one day.

Report from SP, Sweden, presented by Mr Jaldehag (CCTF/12-27)

A long-range fibre link has been established between SP in Borås via STUPI in Stockholm to MIKES in Helsinki. The link spans three separate networks over a total distance greater than 1120 km. The time transfer method is based on passive detection of SDH frame headers of Ethernet data traffic, and is applicable in principle to any packet-based data transmission network.

Custom hardware detects the unique binary sequence of the frame alignment bytes which begin the SDH header, and generate an electrical pulse for timing against the local clock. Time intervals measured on both the incoming and outgoing signals at both ends of the link can be combined following the standard two-way technique. An intermediate station is needed at STUPI with a local slave clock. Data show peak-to-peak time-transfer performance of 1 ns under optimal conditions, and an instability below 10^{-15} at 1 day.

Dr Bauch asked how many intermediate amplifiers were required for the fibre runs within Sweden. Mr Jaldehag answered that this number is approximately eight.

Report from PTB, Germany, presented by Dr Riehle (CCTF/12-15)

A 146 km fibre loop has been established from PTB in Braunschweig to the University of Hannover and back to PTB. This link has been used to measure the Mg optical frequency standard in Hannover against primary standards at PTB, with a frequency resolution of 3×10^{-15}, and for time transfer tests using standard two-way equipment, with an uncertainty below 100 ps.

A 920 km fibre link has been established between PTB and the Max-Planck-Institut für Quantenoptik (MPQ) in Garching near Munich. The link uses a pair of dark fibres and eight intermediate bidirectional amplifiers, together with two fibre Brillouin amplification (FBA) stages with up to 60 dB of optical gain. The instability of the 2×920 km loop is $5\times10^{-14}/\tau$, and the combined uncertainty at long integration times is below 4×10^{-19}. The link enables an absolute frequency measurement for the 1S 2S transition in atomic hydrogen clock at MPQ, with an uncertainty limited by the hydrogen spectroscopy to the low 10^{-15} range.

Report from NPL, United Kingdom, presented by Prof Gill (CCTF/12-28)

Several experiments have investigated transfer of a microwave frequency by propagation of approximately 30 nm of an optical frequency comb over optical fibre, including a demonstration over 86 km on the JANET-Aurora network with transfer instability of 5×10^{-15} at 1 s and 4×10^{-17} at 1600 s. A stable optical carrier has also been transferred over 118 km on the same network, with instability of 3×10^{-16} at 1 s and 5×10^{-18} at 20 000 s and a measured accuracy of 3×10^{-18}. NPL is also a partner in the NEAT-FT collaboration; a link in preparation from NPL to Harwell, near Oxford, will pass through nodes in London which could form the starting point for transfer to other European laboratories.

Report from INRIM, Italy, presented by Dr Tavella (CCTF/12-31)

Funding has been awarded from the Italian government to establish a network linking several national institutions, including a 650 km link between INRIM in Torino and the European Laboratory for Nonlinear Spectroscopy in Florence. Tests have been conducted on fibre spools in the laboratory and on a 47 km fibre loop in Torino with good results. INRIM is also a partner in the NEAT-FT collaboration working to establish links between European laboratories.

Report from NMIA, Australia, presented by Dr Warrington

NMIA is participating in a collaboration including the University of Western Australia, the Australian National University, Macquarie University and the Australian Academic and Research Network. The collaboration is working towards establishing continental-scale links across Australia. Microwave transfer has been demonstrated on the ICON network in Canberra over distances up to 150 km, including a digital transfer technique implemented on an FPGA system, and a test between two radio-observatory sites is planned for early 2013. Transfer of optical frequencies is also in preparation on test links in metropolitan Perth.

5.7 GNSS processing techniques

Report on new techniques in GNSS processing

The President invited Dr Petit to present a report on this topic (CCTF/12-50).

Dr Petit summarised the present performance of GNSS transfer as frequency uncertainty of 1×10^{-15} at 1 day and time uncertainty well below 1 ns (see also the report from the CCTF Working Group on Time Transfer Standards), and presented recent progress in new areas towards further improving this performance.

Phase ambiguities in precise point positioning (PPP) are integer-valued but solutions conventionally adopt real values. However, random errors in ambiguity resolution may accumulate and contribute random-walk noise. Solving for integer ambiguities to improve long-term stability requires special data products, and BIPM are collaborating with the CNES-CLS IGS Analysis Centre ‘GRG’ in Toulouse and NRCan to develop these products. Initial results for ‘integer PPP’ (IPPP) show long-term agreement with standard PPP, but with differences of up to 1 ns which may present a performance improvement.

New codes and new combinations are also under study. Dr Petit presented data from a recent PhD thesis exploring the E5AltBOC code on the Galileo L5 frequency, where a code-plus-carrier approach (‘E5CPC’) shows improved performance over other GPS and Galileo ionosphere-free combinations.

The IGS Bias and Calibration Working Group is addressing the issue of code and phase biases, including operational determination of GPS biases. The Working Group is developing a treatment for GLONASS interfrequency biases. Galileo biases are more numerous but expected to be smaller.

Dr Petit concluded by noting that these topics may provide input to the new Working Group on Global Navigation Satellite Systems, with further progress expected in these areas before the next meeting of the CCTF.

Report on GLONASS P3 data and combinations

The President invited Ms Harmegnies to present a report on this topic (CCTF/12-51).

Ms Harmegnies advised that a new version of the software for conversion between RINEX and CGGTTS data was released in March 2012, incorporating processing of GLONASS pseudorange data and related minor extensions to the CGGTTS format.

These studies are conducted in a collaboration between the BIPM Time Department and the ORB. Using the new software, GLONASS data (REFGLN) show increased noise over GPS (REFGPS) due to interfrequency biases. Daily values for these biases may be determined by comparison to GPS all-in-view data, weighted by elevation. Correcting for interfrequency biases gives a typical noise reduction of 60% for a range of GLONASS P3 links.

An all-in-view combination of both GPS and GLONASS P3 data does not show significant improvement in residual noise over GPS only, but does provide greater redundancy and consistency. This combination can be applied to a range of links including very long baselines such as BRUX-AUS.

Dr Bauch asked which receivers can produce both GPS and GLONASS data. Dr Defraigne explained that there are several receivers with this capability.

Dr Tavella commented that the lack of improvement on combining GLONASS data with GPS data was surprising, and asked about the level of correlation between the bias data and GPS. Ms Harmegnies noted that the ability to correct for interfrequency biases does depend on the quality of the GPS data as these are used as the reference when evaluating the bias correction.

Dr Matsakis asked whether values for the interfrequency biases obtained for different receivers are consistent. Ms Harmegnies explained that this comparison has not been made, but noted that biases of up to 25 ns have been observed.

The President invited any further contributions relating to new GNSS processing techniques. Dr Defraigne advised that ORB has developed a real-time PPP processing service using real-time and ultra-rapid IGS orbit and clock data, to assist with monitoring of local realizations UTC(*k*), as presented to the meeting of laboratories contributing to TAI on 12 September 2012.

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

6.1 Report of the CCTF Working Group on the CIPM MRA

The President invited Dr Cordara to present this report (CCTF/12-11).

Dr Cordara began by summarising the membership and terms of reference of the Working Group and the work undertaken since the 18th CCTF in 2009.

At the beginning of 2012, NMIs and Designated Institutes (DIs) of 45 countries are listed in the Key Comparison Database (KCDB) as providers of time and frequency calibration services, with dates of approval ranging from 2005 to 2011. Several new guidance documents relating to MRA activities have been released since the 18th CCTF and are available through the BIPM website.

Following a decision of the 18th CCTF, the KCDB does not report the degree of equivalence between the results of CCTF-K001.UTC and local realizations UTC(*k*). The KCDB instead includes a link to BIPM *Circular T*, with a note referring to the CCTF decision and to the document "Guidelines for participation in the ongoing key comparison in time CCTF-K001.UTC". This mechanism is somewhat different to reporting in other metrological areas.

Dr Panfilo presented a summary of two new guidelines prepared in response to issues raised at the 18th CCTF. In the first (CCTF/12-04), the uncertainty in the mean frequency of UTC(*k*) over a five-day interval is obtained by the standard method of propagating the uncertainties UTC–UTC(*k*), noting that the calibration uncertainty u_B is negligible in this case. In the second (CCTF/12-05), uncertainty in predicted values of UTC–UTC(*k*) is evaluated with reference to the expected clock performance (dominant noise type) combined with time transfer uncertainties. Representative uncertainties in typical cases are included in the guideline.

These guidelines, and minor editorial revisions to the existing Guidelines 2 and 3 (CCTF/12-03), were discussed and agreed at a meeting of the Working Group on 12 September 2012. Dr Cordara therefore recommended that the CCTF approve the new and amended guidelines, following any necessary discussion.

Dr Cordara concluded by suggesting future topics to be discussed by the Working Group, including development of common protocols for calibration of time transfer equipment, and coordination of information on regional calibration campaigns; development of technical criteria for review of Calibration and Measurement Capabilities (CMCs); and establishing principles for periodic evaluation of the degree of equivalence between the CMCs claimed by NMIs and the results of CCTF-K001.UTC.

Dr Achkar thanked Dr Cordara for the report and presentation, and expressed the opinion that there is still some confusion over the link between *Circular T* and CCTF-K001.UTC. In particular, if *Circular T* is regarded as the result of the key comparison, this may imply that all laboratories appearing meet the requirements of the CIPM MRA (for example that they have a quality management system and approved CMCs) which is not the case.

Dr Arias noted that not all laboratories contributing to TAI are in NMIs which are signatories to the CIPM MRA or in DIs. The discussion at the 18th CCTF confirmed CCTF-K001.UTC as the only key comparison in time and frequency, but also agreed that the KCDB was not the best way to communicate degrees of equivalence. This leaves *Circular T* as the best means of reporting results from CCTF-K001.UTC. Dr Arias also suggested that it may however be possible to add additional information to *Circular T* to identify which participating laboratories meet the requirements of the MRA.

The President noted that a laboratory realizing a local UTC(*k*) cannot provide services recognised under the CIPM MRA unless it also has approved CMCs.

Dr Thomas expressed the opinion that the principal value of establishing CCTF-K001.UTC as the unique key comparison is that it requires careful evaluation and dissemination of the uncertainties UTC–UTC(*k*). These establish the degree of equivalence between UTC and

UTC(k), but cannot easily be represented in the KCDB. The most complete presentation of this data is BIPM *Circular T*.

The President suggested that the decision taken by the 18th CCTF not be revisited, and sought comment on the proposed new and amended guidelines. Delegates agreed to adopt the new guidelines in accordance with the recommendation from the Working Group. The President thanked Dr Cordara and Dr Panfilo for their work.

7 REDEFINITION OF UTC

7.1. Report of events at the ITU-R, and future actions

Report from the BIPM

The President invited Dr Arias to present a report entitled ‘Possible redefinition of UTC’ (CCTF/12-57).

Dr Arias summarized the specific responsibilities of various agencies involved in the definition, generation and dissemination of time scales. Dr Arias also presented a brief history of previous discussions regarding a possible redefinition of UTC discontinuing the use of leap seconds, including the activities of ITU-R Study Group 7 (SG7) and Working Party 7A (WP7A). The proposed modification was discussed at the ITU Radiocommunication Assembly (RA) in January 2012 and forwarded to the World Radiocommunication Conference (WRC). Resolution 653 of WRC-12 forms the basis of studies for WRC-15 Agenda item 1.14, ‘to consider the feasibility of achieving a continuous reference time-scale, whether by the modification of coordinated universal time (UTC) or some other method’. Resolution 653 also instructs the Secretary General to bring the resolution to the attention of relevant bodies including the CGPM, CCTF, BIPM and a wide range of other international organisations. A letter from the ITU General Secretary to the Director of the BIPM to this effect was received in June 2012 (CCTF/12-10).

The President confirmed that the CIPM will provide a single response on behalf of the CIPM, CCTF and BIPM. Prof. Kühne clarified that the CCTF may prepare a recommendation for the CIPM, to be endorsed by the CGPM in 2014.

Report from ITU-R

The President invited Dr Beard to present a report entitled ‘The future of the UTC time scale’ (CCTF/12-56).

Dr Beard explained that ITU Study Groups continue the programme of work between meetings of the WRC and to prepare for future decisions at the next Conference. SG7 is responsible for science services, and WP7A for broadcast time and frequency services.

Dr Beard also summarised the history of discussions regarding the leap second, noting that it was the 14th CCTF in 1999 who asked Dr Quinn (as the Director of the BIPM) to write to the ITU raising this issue. WP7A exhausted technical studies, and noted that consensus was not reached on other than technical grounds. The issue was submitted to SG7 who forwarded to the RA for resolution. As noted by Dr Arias, the RA forwarded to WRC-12, who passed Resolution 653 deferring to WRC-15 and established agenda item 1.14.

Following WRC-12, the Director of the Radiocommunication Bureau will include presentation on the topic in future World Radiocommunication Seminars, including the next Regional Seminar for the Americas Region to be held in Ecuador on 20 and 21 September 2012, and in other international forums.

The Conference Preparatory Meeting (CPM) CPM 15-1, held on 20 and 21 February 2012, designated WP7A as the group responsible for preparing the final text for the WRC agenda item. In accordance with Resolution 653, WP7A will undertake further studies, and administrations are invited to participate by submitting contributions to ITU-R.

The President asked for clarification regarding the timeline for preparing the text for the WRC. Dr Beard advised that the CPM must complete the text by 1 August 2014, and a more detailed schedule is available.

Technical considerations

The President invited Dr Nelson to present a report entitled ‘Summary elements for consideration — Coordinated Universal Time (UTC)’ (CCTF/12-58). Dr Nelson thanked the CCTF for the opportunity to make a presentation.

Dr Nelson summarised observations relating to the increase in the length of the day, and the current operation of the leap second system including the role of the International Earth Rotation and Reference Systems Service (IERS). There are costs associated with implementation of the current system: NASA JPL spent over 400 k$ and several months of staff time to prepare for the most recent leap second, and Google chose to develop a ‘leap smear’ method following some issues observed on their network in 2005. Discontinuities reduce the reliability of systems depending on time and introduce the possibility of catastrophic failure; one key example is the operation of financial markets in Asia if a leap second is applied during a trading day. It is consequently advantageous to modern timekeeping systems to eliminate leap seconds and produce a uniform, continuous timescale.

Dr Nelson expressed the opinion that UTC is the only timescale that can provide the necessary precision for many timekeeping applications. Although in principle TAI may be used as an alternative, this time scale is not widely disseminated in practice.

It has been argued that a change to UTC may require changes to national legislation where civil time is defined with respect to UTC. Dr Nelson noted that this is not true for the USA, and that no change to legislation would be needed in this case.

It has also been argued that the current definition allows UTC to be used as an approximation to UT1, for example for navigation at sea. However, the advent of global navigation satellite systems means that this application is largely obsolete. Dr Nelson further argued that UTC is a time but UT1 is conceptually an angle, as it relates to the rotation of the Earth. UTC is used for timing purposes and there is therefore a need to disseminate UTC in real time. However, UT1 is used primarily for satellite tracking and astronomy, and the needs of these communities can be met by the data published in IERS *Bulletin A* with no need for signal transmission.

Dr Nelson concluded by expressing the opinion that ‘coordinated’ refers to coordination of participating laboratories, not to coordination of the time with the Sun; that ‘universal’ refers to global synchronization, and not necessarily to solar time; and that in consequence the name ‘Coordinated Universal Time’ should be retained if a continuous time scale is established by discontinuing the use of leap seconds.

Discussion at the meeting of laboratories contributing to TAI

The President invited Dr Tavella to summarise discussion on this issue at the 9th meeting of representatives of laboratories contributing to TAI on 12 September 2012.

Dr Tavella advised that the meeting did not come to a specific conclusion (see the report from the CCTF Working Group on TAI). It was however considered important that timing laboratories discuss the issue with their national administrations responsible for delegation to the ITU. The meeting also noted that some laboratories contributing to TAI were not involved in internal consultations within their countries (up to one half of approximately forty laboratories present). A small number of laboratories were in favour of retaining the leap second, a large majority were in favour of discontinuing the current practice, and a small number of laboratories declined to take a position.

7.2. Other contributions

The President asked the representatives of the IAU (Dr McCarthy) and IUGG (Dr Boucher) for additional information regarding the preparation of a submission to the ITU on this issue.

Report from the IAU

Dr McCarthy advised that an IAU Working Group established in 2000 to consider this issue found no reason to continue the practice of leap seconds, and was discontinued in 2006. Based on a poll of members of Commission 31 (Time), and other input from members, the IAU submitted a document to the WP7A meeting in October 2010 supporting the proposed change to the definition of UTC.

At the recent General Assembly held in Beijing in August 2012, the IAU decided to form a new Working Group within Commission 31 to prepare a further response for the ITU CPM, noting the 2014 deadline. The draft terms of reference for this Working Group have stressed that the issues should be considered solely from a technical viewpoint.

Dr McCarthy also noted that it appears likely that the IERS will become a Commission within the new structure of the IAU. Elevation to the level of a Commission indicates IAU support for the work of the IERS and for ongoing development of IERS products.

Report from IUGG

Dr Boucher advised that the position of the IUGG is still to be finalised following consultation among eight member organisations, and will also be informed by consultation with other international bodies such as the IERS. However, a preliminary draft position contains the following points:

- IUGG confirms that UTC should be the preferred timescale for geodesy;

- IUGG is in favour of modifying the current definition to obtain a continuous time scale;
- GNSS providers should be asked to make all efforts to disseminate the revised UTC;
- IUGG will write to the ITU to propose a joint forum between CIPM and ITU for future coordination on this issue; and
- IUGG will ask the IERS to continue and improve the estimation and dissemination of UT1.

Discussion by CCTF delegates

The President summarized the presentations by noting that CCTF members prefer a continuous time scale, which entails discontinuing the current practice of leap seconds, and opened the issue for further discussion.

Dr O'Brian asked Dr Beard whether the WRC require consensus to reach a definitive decision. Dr Beard advised that this is true in principle and a vote is not the usual practice, as any issues are more normally addressed in preparation by the relevant Study Group.

Dr O'Brian agreed that it was appropriate for the CCTF to make a recommendation on technical issues, but expressed concern over the ability of the WRC to resolve the long-standing lack of agreement and asked whether any alternative or additional approach could be followed. The President noted that one such approach is for representatives of laboratories to discuss the issue with their national administrations responsible for delegation to the ITU.

Dr Bauch suggested that any recommendation from the CCTF should focus on potential modification to ITU-R TF.460-6 and associated technical issues, such as the requirement to disseminate UT with an uncertainty of 0.1 s.

Dr Matsakis noted that consensus does not necessarily mean anonymity, and may not in fact mean universal acceptance.

Dr Defraigne asked what was meant by the term 'metrology' in Resolution 653 ('recognizing that some organizations involved with space activities, global navigation satellite systems, metrology, telecommunications, network synchronization and electric power distribution have requested a continuous time-scale'). Dr Achkar suggested that this was intended to cover a variety of metrology institutions with a range of responsibilities.

Dr Arias presented a draft recommendation for consideration by the CCTF. Noting that it was not possible to finalize this recommendation within the available time, the President suggested a short period of further discussion, and proposed in addition the formation of a working party to refine the recommendation so that it may be provided to the next meeting of the CIPM in June 2013. The proposed working party would include Dr Achkar, Dr Bauch, Dr Tavella, Dr O'Brian and Dr Arias, and be coordinated by the President.

Dr O'Brian asked for the view of the IAU regarding whether UT1 should properly be regarded as an angle rather than a time. Dr McCarthy felt that the IAU would be in general agreement on this point. Dr Bauch noted that the difference UT1–UTC has units of seconds, but Dr McCarthy expressed the opinion that this is primarily a question of terminology. Dr Koshaelyevsky reminded delegates of the BIPM monograph on time scales (Monograph 94/1, 1994), and queried the emphasis in the draft recommendation that UT1 is not a time scale. Dr Arias noted that UT1 is not mentioned in the monograph.

The President raised the question of transferring responsibility for the definition of UTC from ITU to the CGPM. Dr Quinn strongly supported the IUGG proposal to form a joint working group between ITU and CGPM on these issues, as this would allow both organisations to separate definition from dissemination with long-term positive benefits. Dr Quinn proposed that the CCTF should recommend this to the CIPM for their decision, and Dr Tavella suggested that this be added to the draft recommendation. CCTF delegates supported these proposals.

Dr Achkar suggested that the reference to national metrology institutes in the draft recommendation should include designated institutes. The President agreed, and closed the session for this discussion.

8 SPACE-TIME REFERENCES AND GENERAL RELATIVITY

8.1 Report on the IERS Conventions Product Centre

The President invited Dr Petit to present this report (CCTF/12-54).

The BIPM and USNO have been providing the Conventions Centre of the IERS since 2001. The IERS Conventions (2010) were published electronically in December 2010, defining the standard reference systems realized by the IERS along with the models and procedures used for this purpose. Technical updates to the Conventions (2010) have commenced, with planned updates to or expansions of a number of sections as well as the addition of new topics.

Dr Petit also asked delegates to note the recent ITU-R Recommendation TF.2018 on relativistic time transfer in the vicinity of the Earth and in the solar system (August 2012). An algorithm to account for relativistic effects is detailed in a 12-page technical annex.

9 GLOBAL NAVIGATION SATELLITE SYSTEMS

9.1 Reports on the present state of GNSS

No reports were received on the current status of GPS, GALILEO or BeiDou/COMPASS.

Report on GLONASS, presented by Dr Koshaelyevsky

Dr Koshaelyevsky presented a brief verbal report. Under a new Federal program adopted for 2012 and continuing until 2020, the existing GLONASS satellite constellation will be upgraded, with the addition of a geostationary segment and new frequency bands. The program will improve the accuracy of satellite navigation and the Russian geodetic system, and the coordination of GLONASS system time to UTC(SU) and of UTC(SU) to UTC.

Report on GAGAN/IRNSS, presented by Dr Sen Gupta

Dr Sen Gupta provided a brief update on the present status, noting that he was not able to give a formal report on behalf of IRNSS. The IRNSS NetWork Timing Centre (IRNWT) has been established, and currently consists of three hydrogen masers and four Cs clocks. Traceability to UTC will be through UTC(NPLI), and common-view GNSS data links have been established between IRNWT and NPLI using dual frequency P-code receivers. The IRNSS constellation will consist of 3 geostationary and 4 geosynchronous satellites, with launch of the first satellite IRNSS-1A scheduled for March 2013.

Dr Matsakis asked whether the IRNSS clock ensemble will contribute to UTC. Dr Sen Gupta advised that existing clocks do not yet contribute, but that no formal decision has been made.

Dr Bauch asked for confirmation that the IRNSS will be a regional augmentation system. Dr Sen Gupta confirmed that based on the planned constellation, coverage will have a radius of approximately 1500 km and encompass the Indian subcontinent.

9.2 Report on activities at the International Committee for GNSS (ICG)

The President invited Dr Arias to present a short verbal report.

The International Committee on GNSS (ICG) was established as an initiative of the United Nations, to promote the global use of GNSS infrastructure and to provide a forum for discussion and coordination between GNSS providers and users. As the number of GNSS constellations increases, a key objective is to promote interoperability to minimise cost for end users. Meetings are held annually and hosted by a GNSS provider, with the 7th meeting of the ICG to be held in Beijing in November 2012.

The membership of the ICG includes service providers and observers from international agencies such as the ITU and BIPM. The structure includes Working Group D on Reference Frames, Timing and Applications, incorporating one task force on time references and another on geodetic references for GNSS systems. Several important recommendations have been approved by GNSS providers since the 18th CCTF in 2009, including the adoption of UTC as the unique reference for GNSS system times, and agreement that geodetic reference systems should align to the International Terrestrial Reference System (ITRS).

Dr Matsakis asked whether the ICG has determined a position on continuation of leap seconds, and in particular whether this was implicit in the adoption of UTC as the reference time scale. Dr Arias advised that the ICG has not yet adopted a formal position on this issue.

10 REPORTS ON TIME AND FREQUENCY ACTIVITIES BY THE REGIONAL METROLOGY ORGANISATIONS

10.1 Report on SIM time and frequency activities

The President invited Dr López Romero to present this report (CCTF/12-16).

The SIM Time Network links together a number of NMIs using GPS monitoring systems casting data to several SIMTN servers. A total of 171 bilateral comparisons among 19 NMIs are processed in real time. Web publishing extends traceability to secondary laboratories which are not currently participating in UTC (currently only 6 laboratories).

A regional time scale SIMT has also been generated since 2010 by combining clocks from across the SIM Time Network. The aim is to facilitate real-time monitoring of local realizations SIMT(k), and SIMT is not intended to be an alternative to UTC. SIMT is currently computed and published hourly, and a recent update to the weighting algorithm has improved stability. Remote realization of SIMT to within 50 ns can also be made at laboratories in small economies operating a rubidium standard.

Future plans include adding a new time network server at OBRJ in Brazil; further development of SIMT; new SIM GPS systems which generate data in CGGTTS format, potentially enabling more SIM NMIs to contribute to TAI; and potentially recognizing SIMT as a regional key comparison for time in the framework of the CIPM MRA.

The President asked how many SIM economies contribute to TAI, and Dr López Romero advised that this number is currently six.

The President also expressed the opinion that SIMT may appear to be in competition with UTC. Dr López Romero said that the aim is to assist smaller nations in the region to establish traceability, and to disseminate the SI second to the Americas. The President advised that it is important to be explicit with the interpretation of traceability in this context.

Dr Ziang asked what method is used for the time links. Dr López Romero explained that a simple time difference is determined based on GPS code measurements. The data format and processing do not use the CGGTTS format but this is planned for the future.

Dr Lewandowski recommended that the best way for a small country to establish traceability is to participate directly in a key comparison. Dr O'Brian agreed with Dr López Romero that SIMT is not intended to be seen as an alternative to UTC as the key comparison in time and frequency, but as a means to assist smaller economies to develop towards participating in UTC in the longer term. The cost of participating in the SIM Time Network is only around $10K, which is within the resources of a larger number of laboratories than those able to contribute to UTC. Joining the regional network provides an opportunity for developing economies to gain experience and demonstrate to governments the value of participating, and thus to work towards full participation. The regional time scale SIMT is also a demonstration of the effectiveness of real-time time scales, again not as a replacement for UTC or UTCr.

Dr Arias agreed that the SIM regional network allows laboratories not yet participating in the CIPM key comparison to compare local realizations to another time scale traceable to UTC, and that this assists laboratories to work towards greater participation. However, Dr Arias queried the additional value of the regional time scale SIMT, noting that bilateral comparisons within the network already provide a means to establish traceability to UTC through another laboratory. Dr O'Brian agreed that the ultimate goal is a single global network coordinated by CIPM and hence BIPM. However, many nations are not yet ready to participate, for a variety of technical, financial or political reasons. Modest participation in a smaller-scale network is a first step, and importantly a stimulus to assist further development. Dr López Romero also commented that one additional value of SIMT is its reduced vulnerability to failure, which can be transferred to participating laboratories.

Prof. Kühne asked whether the regional time scale SIMT should strictly be regarded as a key comparison. Dr Thomas expressed the opinion that it should be more properly regarded as a pilot study, since it enables laboratories to gain experience as for pilot studies in other technical areas.

10.2 Report on APMP time and frequency activities

The President invited Dr Huang-Tien Lin to present this report (CCTF/12-38).

Dr Lin outlined the structure of the APMP Technical Committee on Time and Frequency (TCTF), including four current Working Groups: on the MRA, with responsibility for review of CMC submissions; on GNSS, coordinating GPS receiver calibrations; on TWSTFT, with a number of APMP laboratories participating in links to Europe; and on optical frequency metrology, exchanging information relating to the development of new frequency standards.

A regional workshop on the development of technical guidelines for CMCs was hosted by NICT in Tokyo from 30 November to 2 December 2011. Draft guidelines were reviewed within APMP and have been made available online. Comments and suggestions are invited from CCTF delegates.

The next APMP Time and Frequency Workshop will be held in conjunction with the Asia-Pacific Radio Science Conference (AP-RASC) in Taipei in September 2013.

Dr Cordara asked whether there was any restriction on access to the published CMC guidelines, and Dr Lin confirmed that these documents are open-access.

11 THE NEW SI

11.1 Advice of the CCTF on Resolution 1 of the 24th CGPM, "On the possible future revision of the International System of Units, the SI"

The President presented a short report on the current status of the proposed revision to the International System of Units (CCTF/12-14).

The proposed revision will be considered by the CGPM in 2014. As first noted in 2009, the definition of the second may require clarification regarding the phrase 'at rest at a temperature of 0 K'. The CCU has requested the CCTF to consider modifying the proposed definition of the second to remove reference to the Kelvin, for example by adopting the alternative phrases 'at zero thermodynamic temperature' or 'at rest in the absence of blackbody radiation'. The President noted that input has been requested for the meeting of the CCU in June 2013, and invited discussion.

Dr Madej noted that adopting the phrase 'at zero thermodynamic temperature' may not exclude a systematic frequency shift due to blackbody radiation from the surrounding environment. Dr Fisk noted earlier discussion by the CCTF on this point in the mid-1990s. A footnote was added to the 7th edition of the SI brochure (1998), which was intended to clarify that the SI second is based on a Cs atom unperturbed by black-body radiation, that is, in an environment whose temperature is 0 K (see for example the report on the 14th CCTF in 1999).

Dr Riehle expressed the opinion that the phrase 'at rest in the absence of blackbody radiation' placed too much weight on this particular systematic shift, where the intent is that the definition refers to a Cs atom which is unperturbed. The current definition does not include the word 'unperturbed' but a sentence or footnote could be added to exclude perturbations.

Dr Quinn agreed with Dr Riehle, but suggested that the word 'unperturbed' should be included in the definition rather than a footnote. Dr Madej agreed with Dr Quinn.

Dr Levine noted that earlier versions of the definition took exactly this form, but the meaning of 'unperturbed' was considered unclear and there was discussion over whether blackbody radiation should be regarded as a perturbation. The current discussion is therefore revisiting old ground.

Dr Thomas explained that the note added (86th CIPM, 1998) to the original definition (13th CGPM, 1967–68) became incorporated into Parts I and II of the proposed redefinition (24th CGPM, 2011).

Dr Quinn suggested further consideration of the proposed definition by an expert group, to avoid a potentially hasty decision. The President agreed and nominated Dr Riehle, Dr Madej, Dr Warrington and Dr López Romero for this group, with the text to be finalised before the next meeting of the CCU. Dr Thomas requested a short paper including conclusions be prepared by April 2013.

Dr Riehle raised a further question regarding the proposed definition. Noting general feedback that this definition is complex and more difficult to understand, Dr Riehle observed that the standard phrasing adopted for other units may not be the most appropriate form in the case of the second, for example owing to the interrelationships between the Cs hyperfine interval and other fundamental constants.

Prof. Kühne was not in favour of further amendments to the text of Resolution 1 from the 24th CGPM unless these are necessary for technical reasons. Dr Riehle observed that amendments may not be feasible but may nevertheless be desirable, noting that Resolution 1 includes an invitation to the CIPM to 'continue its work towards improved formulations for the definitions of the SI base units in terms of fundamental constants...'. Dr Quinn expressed the opinion that the current text in Resolution 1 gives an elegant system of definitions. Amendments of the type proposed by Dr Riehle may gain simplicity in one definition but lose the value of consistent expression, so that some compromise may be necessary.

12 STRATEGIC PLANNING

12.1 Outcomes of the 24th CGPM

The President presented a short report summarizing the outcomes of the 24th CGPM held from 17 to 21 October 2011.

The President summarized the list of attendees and the reports made to the meeting. The main topics discussed were the programme of work for 2012 to 2016, and the role, mission, long-term strategy and governance of the BIPM. The President also summarised the resolutions adopted by the CGPM, as follows:

- Resolution 1 on the possible future revision of the International System of Units, which was adopted unanimously;
- Resolution 2 on the importance of collaboration to place measurements to monitor climate change on an SI traceable basis;
- Resolution 3 regarding the dotation of the BIPM for 2013 to 2015, adopted for a three-year period with a 1% allowance for inflation before the next CGPM reconsiders the budget in 2014; no additional discretionary contribution was made, which will require adjustments to the programme of work;
- Resolutions 4, 5, 6 and 7 regarding Associate of the General Conference and financial arrangements;
- Resolution 8 on the revision of the *mise en pratique* for the metre and the development of new optical standards, arising from work of the CCL-CCTF Joint Working Group on Frequency Standards;
- Resolution 9, on the adoption of a common terrestrial reference system; and
- Resolution 10 on the role, mission, objectives, long-term strategy and governance of the BIPM

Regarding the last, the President reported the establishment of an *ad hoc* working group to review the role, mission, objectives, long-term financial stability, strategic direction and governance of the BIPM, with findings to be reported to the CIPM, Member States and NMI Directors in October 2012. The CIPM will propose actions in response to be implemented over the period 2013 to 2014, and report to the 25th CGPM in 2014.

12.2 BIPM programme of work for 2013–2015 and 2016–2019

The President invited Dr Arias to present this report (CCTF/12-21 and CCTF/12-55).

Dr Arias noted that the programme of work is generally well known to CCTF members, with a primary focus on UTC so that the programme has strong continuity. Projects do not typically begin and conclude, but rather have an ongoing impact either for the improvement or operation of UTC or for the support of NMIs.

The programme of work for 2013 to 2015 has been derived from that originally proposed for 2013 to 2016, and is divided into activity areas including: assuring the frequency stability and accuracy of TAI; dissemination of time scales and enabling traceability to UTC through the publication of CCTF-K001.UTC and UTCr; underpinning the accuracy of time links through characterization of delays in GNSS equipment; improving the accuracy of TAI by incorporating secondary representations of the second; and coordination and international liaison.

One physicist will retire in the period from 2013 to 2015 and will not be replaced. BIPM will seek opportunities for guest workers or secondments for relevant programs such as absolute GNSS receiver delay measurements. Planned capital equipment expenditure over the triennium totals 280K€, covering a replacement Cs standard and several GNSS receivers.

The planned programme for 2016 to 2019 largely continues activities from 2013 to 2015. Planned activities include the development of novel methods of time transfer, including multi-GNSS links; consideration of new algorithms for a major upgrade to the generation of UTC; and increased use of secondary representations of the second and optical frequency standards to contribute to the accuracy of TAI.

Dr Levine noted that it is anticipated that several new laboratories will begin contributing to TAI, and suggested the need for continued training to support laboratories. Dr Arias agreed, noting that training also saves time for the BIPM by assisting laboratories to be well-organized and understand the requirements of contributing to TAI. BIPM resources for this activity are limited, but the BIPM can support training activities arranged for example by an individual NMI, an RMO, or the Working Group on TAI. Dr Levine agreed that this support from the BIPM is valuable even where training is provided by other bodies.

Dr Madej expressed appreciation for the work of the BIPM in coordinating time transfer, but also concern over the limited ability of the BIPM to prepare for the challenges of optical frequency standards, where significant work is needed well in advance of a possible redefinition of the second. Dr Arias agreed that although the BIPM has significant expertise in time transfer, it may be difficult to take full advantage of new techniques without additional resources.

Dr Boucher noted that IAG was not included in the list of agencies under area T-A5, Coordination and International Liaison, and Dr Achkar observed that URSI is similarly not included. Dr Arias explained that the omission of IAG was an oversight and coordination activities are continuing, but that there has historically been limited interaction with URSI.

Dr Fisk also commended the BIPM Time Department for their work, recognizing the challenge of meeting increasing demand for services and capabilities within increasingly limited resources, as for his own NMI. Dr Fisk suggested that harmonization and mutual assistance are potentially beneficial in this environment, for example in training activities or in the development of the BIPM database with assistance from other NMIs.

12.3 Report of the Strategic Planning Working Group

The President presented this report, and began by summarizing the membership of the Working Group, the terms of reference, and meetings since the 18th CCTF in 2009.

Following a directive of the CGPM in November 2011, the Working Group is preparing a strategic planning document, including terms of reference for all Working Groups (9 for CCTF, under the proposed structure to be discussed); a ‘baseline’ description of activities and achievements up to and including 2012; a list of stakeholders and their level of involvement; and a ‘future scan’ for the period 2013 to 2023, identifying measurement challenges, new and ongoing requirements and potential major step changes; planned key comparisons (in this case CCTF-K001.UTC, published monthly); and the resources required for these comparisons.

Working Groups have identified a range of proposed content spanning the activities of the CCTF, and further information will be sought from Working Group chairs. The first draft of the planning document will be circulated to Working Group members in November 2012, and subsequently to CCTF members in January 2013. The final version will be forwarded to the CIPM.

Dr Fisk noted that, as a director of a national institute operating in a financially constrained environment, he strongly supported sharing information on stakeholders, to assist in communicating the impact of metrology to national governments.

Prof. Kühne noted that it was agreed at CIPM that the BIPM should receive this information by mid-January 2013 at the latest, as it is essential to inform the first draft of the proposed programme of work for the next cycle. Timing is now very tight, so the BIPM must anticipate somewhat the likely content of strategic documents from the Consultative Committees. The intent in future is to have greater involvement from NMI directors in the development of the programme of work.

Dr McCarthy noted that the IAU General Assembly in August 2012 has established a working group on pulsar time scales as a potential contribution to the formation of Terrestrial Time (TT), which would benefit from a linkage to BIPM. Dr Matsakis advised that Dr Petit is a member of the new working group.

The President and Prof. Kühne concluded by strongly encouraging CCTF delegates to provide information on their needs. It may not be possible to meet all of these, as the use of resources must be carefully prioritised, but it is important to have all information available.

12.4 Designation of chairs of Working Groups

The President presented the proposed structure of CCTF Working Groups including the proposed Working Group chairs (CCTF/12-09). It is proposed that chairs be appointed for two CCTF cycles with the possibility of renewal.

Dr Riehle confirmed that the terms of reference for the CCL-CCTF Joint Working Group on Frequency Standards were approved by CCTF and amended by CCL in 2009.

Dr Arias noted that the terms of reference for several Working Groups require updates to reflect the new structure, including the Working Group on Primary Frequency Standards, to include consideration of secondary realizations of the second, and the Working Group on GNSS, to update the work of the former Working Group on GNSS time transfer standards. The terms of reference for the Working Group on TAI may also require updating regarding the Working Group on Algorithms.

CCTF delegates agreed with the proposed structure and proposed chairs.

The President thanked the outgoing chairs for their work: Dr Tavella for the Working Group on TAI, Dr Parker for the Working Group on Primary Frequency Standards, Dr Levine for the Working Group on GNSS Time Transfer Standards, Dr Tuckey for the Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques, and Dr Cordara for the Working Group on the CIPM MRA.

Dr Tavella thanked the CCTF and the laboratories contributing to TAI for their support.

13 RECOMMENDATIONS

Discussion on draft Recommendations is summarised here. In practice this discussion and associated revisions took place at several points during the meeting, as the agenda permitted.

Recommendation CCTF1 (2012)

The Recommendation prepared by the CCL-CCTF Joint Working Group on Frequency Standards regarding proposed updates to the List of Recommended Frequencies was summarized in the report of the Joint Working Group. Dr Riehle advised that the reference frequency information had been updated to correct typographical errors, and delegates approved the revised Recommendation.

Recommendation CCTF2 (2012)

Dr Matsakis presented a draft Recommendation regarding the communication of data, results and ancillary information by the BIPM.

Prof. Kühne noted that the draft Recommendation was addressed to the BIPM, where a rephrasing to recommend that the CIPM make resources available to support the corresponding outcomes would be more appropriate. The Recommendation was revised accordingly and approved by delegates.

Recommendation CCTF3 (2012)

Dr Tavella presented a draft Recommendation prepared by the Working Group on TAI regarding the calculation and publication of UTCr.

Dr Senior suggested clarifying the target timeframe for BIPM to provide a report to the Working Group on TAI on the possibility of establishing UTCr as a regular product. Dr Arias affirmed that the pilot project will continue until the formal decision of the Working Group on TAI, which need not necessarily be taken at the next meeting.

Prof. Kühne noted that the draft Recommendation was addressed to the BIPM, where a rephrasing to recommend that the CIPM make resources available to support the corresponding outcomes would be more appropriate. The draft Recommendation was revised accordingly to separate recommendations addressed to the BIPM and to the CIPM, and approved by delegates.

Recommendation CCTF4 (2012)

Dr Defraigne presented a draft Recommendation prepared by the Working Group on GNSS Time Transfer Standards (CGGTTS) regarding the upgrade and calibration of GNSS equipment in timing laboratories contributing to TAI, with minor revisions suggested by several Working Group members. Delegates approved the revised Recommendation.

Recommendation CCTF5 (2012)

Dr Tuckey presented a draft Recommendation prepared by the Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques regarding the continued development of optical fibre links and networks (CCTF/12-35), with minor revisions suggested by several Working Group members.

Prof. Kühne noted that the formulation of the recommendation to the BIPM had been improved in the revised Recommendation, which was approved by delegates.

Recommendation CCTF6 (2012)

The Recommendation regarding ‘A contribution from the Consultative Committee on Time and Frequency (CCTF) on achieving a continuous reference time scale’ was referred to a working party for further consideration, as described in the agenda item on the redefinition of UTC.

Dr Bauch commented that significant effort is represented in the scale of work presented in the Recommendations CCTF2 and CCTF3. Prof. Kühne noted that the budget of the BIPM has already been agreed for the period to 2015, so that any additional call on resources would require a corresponding reduction of effort in another area, and no additional staff would be possible within the agreed budget. Resources are more limited following the outcome of discussions at the CGPM, in particular regarding the level of contribution from Member States, and this makes it particularly important that BIPM strategic plans are informed by input from Consultative Committee members.

Dr Arias suggested that it is still appropriate to identify evolving needs as these become apparent, regardless of the present availability of resources to meet all of these needs. Prof. Kühne agreed that both Recommendations should be supported, but cautioned that there may be some delay in the ability of the BIPM to realize the corresponding outcomes.

14 OTHER BUSINESS

Dr Achkar asked for clarification of actions to be undertaken by the BIPM regarding the key comparison CCTF-K001.UTC. The President noted that these would be described in the report of the meeting, and included a possible clarification to be added by BIPM to *Circular T*.

The President suggested that the 20th meeting of the CCTF could be held in 2015, the year after the next meeting of the CGPM. Dr Arias noted the need to coordinate with the CCL and to accommodate other meetings during the year such as of the CIPM. Prof. Kühne suggested the month of September 2015, assuming that the NMI Directors meeting would be held in October.

The President thanked all delegates, experts and attendees for their participation in the 19th CCTF. He thanked Dr Arias and her staff for their preparation for the meeting and for the activity of the Time Department over the past three years.

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

The President wished all those attending a safe journey home and closed the meeting at 4:30 pm.

R.B. Warrington, *rapporteur*

October 2012

RECOMMANDATION CCTF 1 (2012) :
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 des transitions suivantes soient incluses ou mises à jour dans la liste des fréquences étalons recommandées :

- la transition optique non perturbée $3s^2\ ^1S_0 - 3s3p\ ^3P_0$ de l'ion de $^{27}Al^+$, à la fréquence de f_{27Al+} = 1 121 015 393 207 857,3 Hz avec une incertitude-type relative estimée de $1{,}9 \times 10^{-15}$.

  Il est recommandé que le CIPM approuve cette radiation comme représentation secondaire de la seconde ;
- la transition optique non perturbée $5d^{10}6s\ ^2S_{1/2} - 5d^{\,9}6s^2\ ^2D_{5/2}$ de l'ion de $^{199}Hg^+$, à la fréquence de f_{199Hg+} = 1 064 721 609 899 145,3 Hz avec une incertitude-type relative estimée de $1{,}9 \times 10^{-15}$ (cette radiation a déjà été approuvée par le CIPM comme représentation secondaire de la seconde) ;
- la transition optique non perturbée $6s^2\ ^1S_0 - 6s6p\ ^3P_0$ de l'atome neutre de ^{199}Hg, à la fréquence de f_{199Hg} = 1 128 575 290 808 162 Hz avec une incertitude-type relative estimée de $1{,}7 \times 10^{-14}$;
- la transition optique non perturbée $6s\ ^2S_{1/2} - 4f^{\,13}6s^2\ ^2F_{7/2}$ de l'ion de $^{171}Yb^+$, à la fréquence de f_{171Yb+} (octupôle) = 642 121 496 772 645,6 Hz avec une incertitude-type relative estimée de 1,3 × 10¯15.

  Il est recommandé que le CIPM approuve cette radiation comme représentation secondaire de la seconde ;
- la transition optique non perturbée $6s\ ^2S_{1/2}$ (F = 0, m_F = 0) – $5d\ ^2D_{3/2}$ (F = 2, m_F = 0) de l'ion de $^{171}Yb^+$, à la fréquence de f_{171Yb+} (quadripôle) = 688 358 979 309 307,1 Hz avec une incertitude-type relative estimée de 3×10^{-15} (cette radiation a déjà été approuvée par le CIPM comme représentation secondaire de la seconde) ;
- la transition optique non perturbée $5s\ ^2S_{1/2} - 4d\ ^2D_{5/2}$ de l'ion de $^{88}Sr^+$, à la fréquence de f_{88Sr+} = 444 779 044 095 485,3 Hz avec une incertitude-type relative estimée de $4{,}0 \times 10^{-15}$ (cette radiation a déjà été approuvée par le CIPM comme représentation secondaire de la seconde) ;

- la transition optique non perturbée $4s\ {}^2S_{1/2} - 3d\ {}^2D_{5/2}$ de l'ion de $^{40}Ca^+$, à la fréquence de f_{40Ca+} = 411 042 129 776 395 Hz avec une incertitude-type relative estimée de $1{,}5 \times 10^{-14}$;

- la transition optique non perturbée 1S – 2S de l'atome neutre de ^1H, à la fréquence de f_{1H} = 1 233 030 706 593 518 Hz avec une incertitude-type relative estimée de $1{,}2 \times 10^{-14}$.

  Remarque : Cette fréquence correspond à la moitié de l'écart en énergie entre les états 1S et 2S ;

- la transition optique non perturbée $5s^2\ {}^1S_0 - 5s5p\ {}^3P_0$ de l'atome neutre de ^{87}Sr, à la fréquence de f_{87Sr} = 429 228 004 229 873,4 Hz avec une incertitude-type relative estimée de 1×10^{-15} (cette radiation a déjà été approuvée par le CIPM comme représentation secondaire de la seconde) ;

- la transition optique non perturbée $6s^2\ {}^1S_0 - 6s6p\ {}^3P_0$ de l'atome neutre de ^{171}Yb, à la fréquence de f_{171Yb} = 518 295 836 590 865,0 Hz avec une incertitude-type relative estimée de $2{,}7 \times 10^{-15}$.

  Il est recommandé que le CIPM approuve cette radiation comme représentation secondaire de la seconde ;

- la transition quantique hyperfine non perturbée de l'état fondamental de l'atome de ^{87}Rb, à la fréquence de f_{87Rb} = 6 834 682 610,904 312 Hz avec une incertitude-type relative estimée de $1{,}3 \times 10^{-15}$ (cette radiation a déjà été approuvée par le CIPM comme représentation secondaire de la seconde).

Remarque : La valeur de l'incertitude-type est supposée correspondre à un niveau de confiance de 68 %. Toutefois, étant donné le nombre très limité de résultats disponibles, il se peut que, rétrospectivement, cela ne s'avère pas exact.

et requiert l'approbation du CIPM.

RECOMMANDATION CCTF 2 (2012) :

Concernant l'amélioration et la maintenance des services fournis par le Département du temps du BIPM sur internet

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

considérant

- que le Bureau international des poids et mesures (BIPM) a amélioré de façon constante et par divers moyens la visibilité des informations qu'il fournit dans le domaine du temps et des fréquences, notamment en permettant leur téléchargement à partir du site internet du BIPM, ces informations comprenant :
    - les données horaires obtenues à partir d'étalons primaires et secondaires,
    - les données opérationnelles de comparaisons de temps,
    - les données de sauvegarde de comparaisons de temps,
    - les versions corrigées, traitées, synthétisées et combinées des données précédemment mentionnées,
    - les rapports sur les étalonnages des équipements de comparaison de temps,
    - les échelles de temps et autres produits créés à partir des données précédemment mentionnées,
    - les produits intermédiaires nécessaires à la création des produits officiels du BIPM,
    - les produits et données associés à des projets spécifiques, expérimentaux, et/ou non officiels, tels que le Temps universel coordonné rapide (UTCr),
    - d'autres publications,
- que ces informations sont fréquemment utilisées dans le cadre d'études, qu'elles soient officielles, non officielles, publiées, informelles ou pédagogiques,
- que ces informations sont utilisées par les fabricants souhaitant évaluer et améliorer la qualité de leurs produits,
- que la diffusion publique de ces informations est très utile à la communauté du temps et des fréquences, et qu'elle est essentielle pour améliorer le Temps universel coordonné (UTC),
- que des informations détaillées concernant l'infrastructure mise en œuvre pour conserver le temps sont très utiles aux laboratoires lorsqu'ils réalisent pour la première fois leur UTC local,
- que le Département du temps du BIPM a récemment distribué un questionnaire afin de recueillir des avis sur les services qu'il fournit sur internet et qu'il a créé une base de données donnant accès (avec protection par mot de passe) à des descriptions de l'infrastructure mise en œuvre par les laboratoires participant au calcul de l'UTC pour conserver le temps,

- que les progrès à venir continueront à être accueillis favorablement,

recommande au Comité international des poids et mesures (CIPM) d'accroître les ressources allouées au Département du temps du BIPM afin que ses services fondés sur l'utilisation d'internet dans le domaine du temps et des fréquences puissent continuer à être améliorés et maintenus de façon à :

- recueillir chaque année des commentaires généraux et spécifiques concernant les informations qui devraient être mises à disposition, la structure des fichiers proposés sur internet, leur nomenclature et toute autre documentation, afin de prendre en compte ces commentaires,
- rassembler des informations, de différents types et nouvelles, sur la configuration historique et les performances observées des équipements commerciaux d'intérêt, tels qu'amplificateurs, étalons de fréquences et équipements de comparaisons de temps, qu'ils soient primaires ou redondants, transmises par les laboratoires en mesure de fournir ce type de données.

RECOMMANDATION CCTF 3 (2012) :
Calcul et publication d'un UTC rapide (UTCr) de façon régulière

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

considérant

- que le Bureau international des poids et mesures (BIPM) a conduit avec succès une expérience pilote visant à produire chaque semaine depuis janvier 2012 une évaluation rapide du Temps universel coordonné (UTC), dénommée « UTC rapide » ou « UTCr »,
- qu'un grand nombre de laboratoires participant au calcul de l'UTC envoient également des données au BIPM pour le calcul de l'UTCr,
- que les laboratoires participant au calcul de l'UTC souhaitent que l'UTCr devienne un produit permanent du BIPM, publié de façon régulière une fois par semaine,

notant

- que le fait de contribuer à l'UTCr permet aux laboratoires du temps de mieux piloter leur réalisation locale UTC(*k*) sur l'échelle de référence UTC,
- que les membres du personnel du Département du temps du BIPM doivent continuer à assurer la publication mensuelle de la *Circulaire T* du BIPM, qui constitue le seul moyen d'établir la traçabilité des réalisations locales UTC(*k)* à l'UTC,
- que la production et la publication de l'UTCr, de façon régulière et dans les délais, imposent des contraintes de temps significatives aux membres du personnel du Département du temps du BIPM et requièrent un moyen de dissémination fiable,

recommande au BIPM

- de poursuivre le projet pilote d'évaluation de l'UTCr et de présenter un rapport au Groupe de travail du CCTF sur le Temps atomique international (TAI) en 2013 afin que la possibilité de transformer l'UTCr en un produit courant opérationnel soit examinée,
- de continuer à disséminer l'UTCr en veillant à ce que les données soient publiées en temps voulu, dans un format approprié et définitif, de façon à ce que l'utilisation généralisée de l'UTCr soit soutenue et encouragée,

recommande par ailleurs au Comité international des poids et mesures (CIPM)

- que des efforts soient déployés afin d'améliorer les équipements du BIPM nécessaires à l'échange, au calcul et à la distribution des données,
- que les ressources humaines nécessaires pour assurer le calcul et la publication de l'UTCr de façon régulière soient maintenues.

RECOMMANDATION CCTF 4 (2012) :

Sur la mise à niveau des équipements des systèmes globaux de navigation par satellite (GNSS) utilisés dans les laboratoires de temps contribuant au Temps universel coordonné (UTC) vers des systèmes de réception multifréquences et multiconstellations et leur étalonnage

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

considérant

- que les étalons atomiques de fréquence ont atteint une stabilité et une exactitude sans précédent et que d'autres progrès dans ce domaine sont en cours,
- que le fait de pouvoir comparer ces étalons afin de réaliser l'UTC dépend de l'exactitude et de la précision des méthodes de comparaisons de temps fondées sur des équipements du GNSS,
- que les données des satellites du Global Positioning System (GPS) jouent un rôle important dans les comparaisons de temps et de fréquences,
- que la constellation du GLONASS est désormais terminée et qu'une modernisation du système GLONASS est en cours,
- que le déploiement de la constellation européenne de Galileo a commencé en 2011 et devrait s'achever ces prochaines années,
- que la République populaire de Chine a commencé à lancer des satellites BeiDou/COMPASS dans le cadre d'applications régionales et que la constellation BeiDou/COMPASS déployée au niveau international sera opérationnelle dans les années à venir,
- que les incertitudes résultant de l'étalonnage des équipements des laboratoires de temps ont un impact significatif sur les comparaisons internationales de temps et, plus particulièrement, sur l'exactitude du calcul de l'UTC,
- que des comparaisons de temps fondées sur les mesures de code et de phase des porteuses aux deux fréquences du GPS sont utilisées pour certaines liaisons horaires dans le calcul de l'UTC,

notant

- que les coûts associés à l'acquisition, l'installation, la mise en œuvre et l'entretien des équipements sont inférieurs au prix d'achat d'un étalon de fréquence au césium,
- que de nombreux logiciels capables de traiter les données de mesure de code et de phase des porteuses à deux fréquences existent ou sont en cours d'élaboration,
- que certains de ces algorithmes permettent déjà de combiner les données des systèmes du GPS et du GLONASS,

recommande

- aux laboratoires participant au calcul de l'UTC de mettre à niveau leurs équipements afin de passer à des systèmes de réception multifréquences et multiconstellations permettant d'effectuer des mesures de code et des mesures de phase des porteuses,
- aux organismes mettant au point des logiciels pour les comparaisons de temps de mettre à niveau leurs solutions multirécepteurs et multiconstellations,
- au BIPM d'élaborer en collaboration avec les organisations régionales de métrologie des directives concernant l'étalonnage des nouveaux équipements multifréquences et multiconstellations,
- au BIPM de continuer à organiser et conduire, dans les laboratoires, des campagnes de mesure des retards de ces nouveaux équipements du GNSS, avec le soutien des organisations régionales de métrologie pour ce qui concerne les comparaisons régionales,
- à l'ensemble des laboratoires, et en particulier à ceux jouant un rôle unique dans le calcul du Temps atomique international (TAI) tels que les laboratoires pivots et ceux contribuant directement à la Section 5 de la *Circulaire T* du BIPM, de fournir des données obtenues à partir d'au moins trois récepteurs GNSS traçables à leur réalisation locale de l'UTC, ce qui permettrait de vérifier la stabilité des retards de leurs équipements.

RECOMMANDATION CCTF 5 (2012) :

Déploiement des réseaux de comparaisons de temps et de fréquences par fibre optique à l'échelle continentale et soutien vis-à-vis des études sur l'amélioration des comparaisons horaires intercontinentales

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

considérant

- que l'exactitude et la stabilité des étalons optiques de fréquence mis au point dans des laboratoires partout dans le monde ne cessent de s'améliorer,
- qu'il est nécessaire d'effectuer des comparaisons régulières des étalons optiques de fréquence car elles jouent un rôle essentiel dans la préparation d'une redéfinition de la seconde, ainsi que dans d'autres applications telles que la participation au calcul des échelles de temps,
- que les techniques de comparaison de temps et de fréquences utilisées de façon courante dans le monde entier afin de produire le Temps atomique international (TAI) ne présentent pas une stabilité suffisante pour comparer les étalons optiques de fréquence les plus performants,
- qu'il a été démontré que les liaisons par fibre optique permettent de réaliser des comparaisons des étalons de fréquence parmi les plus performants avec la stabilité requise, sur des distances de l'ordre de 1000 km,
- que les liaisons par fibre optique améliorent la robustesse des réseaux de comparaisons de temps et de fréquences car ces liaisons sont indépendantes des systèmes globaux de navigation par satellite (GNSS) et des méthodes de comparaison de temps et de fréquences par aller et retour sur satellite,
- que certains projets de recherche sont mis en œuvre afin d'étudier d'autres méthodes de comparaisons de temps et de fréquences qui permettraient d'améliorer de façon significative les comparaisons intercontinentales,

recommande

- aux laboratoires nationaux de métrologie, aux fournisseurs de réseaux à fibre optique, aux agences spatiales, aux gouvernements nationaux, aux organisations régionales de métrologie, au Comité international des poids et mesures (CIPM), à l'Union internationale des télécommunications (UIT) et aux autres organismes concernés :
    - de poursuivre avec vigueur le déploiement des réseaux de comparaisons de temps et de fréquences par fibre optique à l'échelle continentale,
    - d'encourager et de soutenir activement les travaux de recherche visant à améliorer de façon significative les comparaisons de temps et de fréquences sur des distances intercontinentales,
    - de se consulter et de coordonner leurs actions afin d'accéder aux infrastructures nécessaires pour mettre en oeuvre les nouvelles méthodes de comparaisons de

temps et de fréquences, et afin d'identifier les synergies de ces infrastructures avec d'autres applications,

- au BIPM de participer activement à ces avancées, notamment en préparant les données de comparaisons d'horloges effectuées à l'aide des nouvelles méthodes de comparaisons de temps et de fréquences afin que ces données puissent être utilisées pour la réalisation des échelles de temps.

RECOMMANDATION CCTF 6 (2012) :

Contribution du Comité consultatif du temps et des fréquences (CCTF) à l’obtention d’une échelle de temps de référence continue

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

ayant examiné

les termes de la Résolution 653 (CMR-12) intitulée « Avenir de l'échelle de temps universel coordonné », adoptée par la Conférence mondiale des radiocommunications (CMR) en 2012, qui invite la CMR de l'Union internationale des télécommunications (UIT) en 2015

> *« à envisager la possibilité d'obtenir une échelle de temps de référence continue, en modifiant le temps UTC ou en utilisant une autre méthode, et à prendre les mesures voulues à cet égard, compte tenu des études de l'UIT-R*[1] *»*

et prie le secrétaire général de l'Union internationale des télécommunications

> *« de porter [la Résolution 653] à l'attention des organisations concernées, telles que [...] la Conférence générale des poids et mesures (CGPM), le Comité consultatif du temps et des fréquences (CCTF), le Bureau international des poids et mesures (BIPM) [...]* »,

recommande que les points suivants soient pris en compte dans la mise en œuvre d'une échelle de temps continue

1. il est possible d'obtenir une échelle de temps continue : le BIPM réalise et maintient une telle échelle de temps,
2. l'UTC sans discontinuités dues à l’insertion de secondes intercalaires constitue une échelle de temps de référence continue,
3. les concepts de continuité et d'uniformité doivent s’appliquer <u>strictement</u> aux échelles de temps de référence,
4. l'unité d'une grandeur métrologique quelle qu’elle soit est unique, c'est pourquoi une échelle de temps spécifique devrait être unique,
5. lors de la redéfinition d’une grandeur métrologique, l’invariance de son unité doit être assurée ; en ce qui concerne la seconde du Système international d'unités (SI), l'échelle correspondante doit être continue et uniforme,
6. le terme « coordonné » dans « Temps universel coordonné » implique que les laboratoires nationaux de métrologie coordonnent leurs efforts pour l’établir, et ne se réfère en rien à la direction du Soleil par rapport à une position donnée à la surface de la Terre,

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[1] Union internationale des télécommunications – secteur Radiocommunications

7. le terme « universel » dans « Temps universel coordonné » signifie que l'échelle de temps doit être utilisée partout dans le monde,
8. la dénomination « Temps universel coordonné » doit être conservée dans le cas d'une nouvelle définition de l'UTC sans insertion de secondes intercalaires,
9. l'angle UT1 qui permet de relier les systèmes de référence terrestres et célestes ne doit pas être considéré comme une échelle de temps mais comme l'angle qui caractérise la rotation irrégulière de la Terre,
10. le Service international de la rotation terrestre et des systèmes de référence (IERS) permet d'accéder à UT1 en temps réel en mettant régulièrement à disposition des prédictions de UT1 - UTC avec une précision 100 000 fois supérieure à l'approximation brute UT1 = UTC actuellement établie en faisant correspondre UTC à UT1 à 0,9 seconde près,
11. il est nécessaire d'encourager une dissémination plus large d'UT1 - UTC,

recommande par ailleurs

au Comité international des poids et mesures (CIPM) et à l'Union internationale des télécommunications - secteur Radiocommunications (UIT-R) d'examiner la possibilité de former un groupe de travail commun afin d'étudier comment coordonner les actions qui seront nécessaires pour définir une échelle de temps continue de référence mondiale.

RECOMMENDATION CCTF 1 (2012):
Updates to the list of standard frequencies

The Consultative Committee for Time and Frequency (CCTF),

considering that

- a common list of "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second" has been established,
- the CCL-CCTF Frequency Standards Working Group (FSWG) has reviewed several candidates for inclusion into the list,

recommends

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

- the unperturbed optical transition $3s^2\ {}^1S_0 - 3s3p\ {}^3P_0$ of the $^{27}Al^+$ ion with a frequency of f_{27Al+} = 1 121 015 393 207 857.3 Hz and an estimated relative standard uncertainty of 1.9×10^{-15}.

  This radiation is recommended to be endorsed by the CIPM as a secondary representation of the second;
- the unperturbed optical transition $5d^{10}6s\ {}^2S_{1/2} - 5d\ {}^96s^2\ {}^2D_{5/2}$ of the $^{199}Hg^+$ ion with a frequency of f_{199Hg+} = 1 064 721 609 899 145.3 Hz and an estimated relative standard uncertainty of 1.9×10^{-15} (this radiation is already endorsed by the CIPM as a secondary representation of the second);
- the unperturbed optical transition $6s^2\ {}^1S_0 - 6s6p\ {}^3P_0$ of the ^{199}Hg neutral atom with a frequency of f_{199Hg} = 1 128 575 290 808 162 Hz and an estimated relative standard uncertainty of 1.7×10^{-14};
- the unperturbed optical transition $6s\ {}^2S_{1/2} - 4f\ {}^{13}6s^2\ {}^2F_{7/2}$ of the $^{171}Yb^+$ ion with a frequency of f_{171Yb+} (octupole) = 642 121 496 772 645.6 Hz and an estimated relative standard uncertainty of 1.3×10^{-15}.

  This radiation is recommended to be endorsed by the CIPM as a secondary representation of the second;
- the unperturbed optical transition $6s\ {}^2S_{1/2}$ (F = 0, m_F = 0) – $5d\ {}^2D_{3/2}$ (F = 2, m_F = 0) of the $^{171}Yb^+$ ion with a frequency of f_{171Yb+} (quadrupole) = 688 358 979 309 307.1 Hz and an estimated relative standard uncertainty of 3×10^{-15} (this radiation is already endorsed by the CIPM as a secondary representation of the second);
- the unperturbed optical transition $5s\ {}^2S_{1/2} - 4d\ {}^2D_{5/2}$ of the $^{88}Sr^+$ ion with a frequency of f_{88Sr+} = 444 779 044 095 485.3 Hz and an estimated relative standard uncertainty of 4.0×10^{-15} (this radiation is already endorsed by the CIPM as a secondary representation of the second);

- the unperturbed optical transition $4s\ ^2S_{1/2} - 3d\ ^2D_{5/2}$ of the $^{40}Ca^+$ ion with a frequency of f_{40Ca+} = 411 042 129 776 395 Hz and an estimated relative standard uncertainty of 1.5×10^{-14};
- the unperturbed optical transition 1S – 2S of the ^1H neutral atom with a frequency of f_{1H} = 1 233 030 706 593 518 Hz and an estimated relative standard uncertainty of 1.2×10^{-14}.

  Note: This frequency corresponds to half of the energy difference between the 1S and 2S states;
- the unperturbed optical transition $5s^2\ ^1S_0 - 5s5p\ ^3P_0$ of the ^{87}Sr neutral atom with a frequency of f_{87Sr} = 429 228 004 229 873.4 Hz and an estimated 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 $6s^2\ ^1S_0 - 6s6p\ ^3P_0$ of the ^{171}Yb neutral atom with a frequency of f_{171Yb} = 518 295 836 590 865.0 Hz and an estimated relative standard uncertainty of 2.7×10^{-15}.

  This radiation is recommended to be endorsed by the CIPM as a secondary representation of the second;
- the unperturbed ground-state hyperfine transition of ^{87}Rb with a frequency of f_{87Rb} = 6 834 682 610.904 312 Hz and an estimated relative standard uncertainty of 1.3×10^{-15} (this radiation is already endorsed by the CIPM as a secondary representation of the second).

Note: The value of the standard uncertainty is assumed to correspond to a confidence level of 68 %. However, given the very limited number of available data there is a possibility that in hindsight this might not prove to be exact.

and asks the CIPM for approval.

RECOMMENDATION CCTF 2 (2012):

On improved internet services provided by the BIPM Time Department and their maintenance

The Consultative Committee for Time and Frequency (CCTF),

considering that

- the International Bureau of Weights and Measures (BIPM) has steadily improved the visibility of its time and frequency information in numerous ways, including via downloads from the BIPM website. This information includes:
  - Clock data from both primary and secondary standards,
  - Operational time transfer data,
  - Backup time transfer data,
  - Corrected, processed, reduced and combined forms of the above data,
  - Reports of time transfer calibrations,
  - Time scales and other products generated from the above,
  - Intermediate products used in the creation of official BIPM products,
  - Products and data of special, experimental, and/or unofficial projects, for example rapid Coordinated Universal Time (UTCr),
  - Other publications,
- the information is frequently used for official, unofficial, published, informal and pedagogical studies,
- the information is used by manufacturers seeking to assess and improve the quality of their products,
- the public dissemination of information is very useful to the time and frequency community, and to the improvement of Coordinated Universal Time (UTC) itself,
- detailed information on timekeeping infrastructure is very useful to laboratories when they begin to realize UTC for the first time,
- the BIPM Time Department recently circulated a questionnaire that solicited advice about the BIPM's web services, and created a database structure for password-protected distribution of descriptions of the timing infrastructure of contributing laboratories,
- future improvements will continue to be well-received,

recommends to the International Committee for Weights and Measures (CIPM) that increased resources be allocated to the BIPM Time Department so that time and frequency internet services can continue to be improved and maintained so that

- annual requests could be made for both general and specific comments on the information that should be made available, the internet file structure, nomenclature, and documentation, and those comments responded to,

- additional and different types of data on the historical configuration of, and the observed performance of, relevant commercial equipment such as amplifiers, frequency standards, and time transfer hardware, both primary and redundant, could be gathered from laboratories that are able to supply the information.

RECOMMENDATION CCTF 3 (2012):

Regular calculation and publication of rapid UTC (UTCr)

The Consultative Committee for Time and Frequency (CCTF),

considering that

- the International Bureau of Weights and Measures (BIPM) has been successfully conducting a pilot experiment for producing a rapid Coordinated Universal Time (UTC) solution (rapid UTC or UTCr) on a weekly basis since January 2012,
- a large number of laboratories that contribute to the computation of UTC also contribute data to UTCr,
- the UTC contributing laboratories want UTCr to become a permanent product from the BIPM, respecting a regular weekly publication schedule,

noting that

- by contributing to UTCr, time laboratories can better steer their respective UTC(*k*) to the reference UTC,
- the staff of the BIPM Time Department must continue to assure the monthly publication of BIPM *Circular T*, which is the only way of making local realizations UTC(*k*) traceable to UTC,
- the timely and regular production and publication of UTCr imposes real time constraints on the staff of the BIPM Time Department and requires a reliable means of dissemination,

recommends to the BIPM that

- the evaluation of UTCr as a pilot project continues and that a report is sent to the CCTF Working Group on TAI[1] (WGTAI) in 2013 to discuss the possibility of transforming UTCr into a routine operational product,
- the dissemination of UTCr is pursued by ensuring timely availability of the results in a suitable and definitive format, so that widespread use of UTCr is supported and encouraged,

[1] International Atomic Time (TAI)

further recommends to the International Committee for Weights and Measures (CIPM) that

- efforts be made to improve the equipment at the BIPM involved in data exchange, calculation and distribution of results,
- the human resources necessary for assuring the regular computation and publication of UTCr be maintained.

RECOMMENDATION CCTF 4 (2012):

Concerning the upgrade and calibration of global navigation satellite systems (GNSS) equipment in the timing laboratories contributing to Coordinated Universal Time (UTC) towards multi-frequency, multi-constellation receiving systems

The Consultative Committee for Time and Frequency (CCTF),

considering that

- atomic frequency standards have achieved unprecedented stability and accuracy, and that further advances in this field are under way,
- the ability to compare these standards for the realization of UTC is dependent on the accuracy and precision of time transfer methods based on GNSS,
- data from Global Positioning System (GPS) satellites plays an important role in time and frequency transfer,
- the GLONASS constellation is now complete and a modernization of the GLONASS system is under way,
- deployment of the European Galileo constellation started in 2011 and should be completed in the coming years,
- the People’s Republic of China has started launching BeiDou/COMPASS satellites for regional applications, and the global constellation will be operational in the coming years,
- present uncertainties in the calibration of equipment at timing laboratories currently have a significant impact on international time transfer in general and on the accuracy of the computation of UTC in particular,
- GPS time transfer based on dual-frequency code and carrier-phase data is used in the operational computation of UTC for some time links,

noting that

- the costs associated with equipment acquisition, installation, operation, and maintenance are less than the purchase price of a single caesium frequency standard,
- many software algorithms using dual-frequency code and carrier-phase data are either available or under active development,
- some of these algorithms already allow for the combination of GPS and GLONASS data,

recommends that

- the laboratories contributing to UTC upgrade their equipment towards multi-frequency, multi-constellation receiving systems providing code- and carrier-phase measurements,
- institutions developing software algorithms for time transfer work to upgrade their multi-constellation and multi-receiver solutions,
- the BIPM in collaboration with the regional metrology organizations (RMOs) develops calibration guidelines for new multi-frequency, multi-constellation equipment,
- the BIPM continues to organize and run campaigns to measure delays of this new GNSS equipment in laboratories, with the support of the RMOs within the frame of regional comparisons,
- all laboratories, especially those playing a unique role in International Atomic Time (TAI) computations, such as pivot laboratories and those contributing directly to Section 5 of the BIPM *Circular T*, to supply data from at least three GNSS receivers traceable to their local realization of UTC; this would help verify the stability of their hardware delays.

RECOMMENDATION CCTF 5 (2012):

Development of continental-scale optical fibre time and frequency transfer networks and support to studies of improved methods for intercontinental clock comparisons

The Consultative Committee for Time and Frequency (CCTF),

considering

- the continuing reduction in the uncertainty and instability of optical frequency standards developed in institutes around the world,
- the need for regular comparisons between these standards, as an essential part of the preparation for a redefinition of the second and for other applications such as contributions to time scales,
- that the stabilities of time and frequency transfer techniques currently and routinely used for comparisons around the world, i.e. for the production of International Atomic Time (TAI), are insufficient for comparisons between the best optical frequency standards,
- the demonstrated capability of optical fibre links to realize frequency comparisons with the stability required for the best frequency standards, over distances of the order of 1000 km,
- that optical fibre links improve the robustness of time and frequency transfer networks since they are independent of the global navigation satellite system (GNSS) and two-way satellite time and frequency transfer (TWSTFT) methods,
- the existence of research projects concerning alternative time and frequency transfer methods with the potential to significantly improve intercontinental comparisons,

recommends that

- national metrology institutes (NMIs), optical fibre network providers, space agencies, national governments, regional metrology organizations (RMOs), the International Committee for Weights and Measures (CIPM), International Telecommunications Union (ITU) and other relevant bodies:
    - vigorously pursue the development of continental-scale optical fibre time and frequency transfer networks,
    - actively encourage and support research aimed at significantly improving time and frequency transfer over intercontinental distances,
    - consult and coordinate with each other on access to the necessary infrastructures for new time and frequency transfer methods and on synergies with other applications of these infrastructures,
- the BIPM participates actively in these developments, notably by making preparations for exploiting, in time scale realization, clock comparison data issued from new time and frequency transfer methods.

RECOMMENDATION CCTF 6 (2012)

A contribution from the Consultative Committee on Time and Frequency (CCTF) on achieving a continuous reference time scale

The CCTF, having analyzed the terms of WRC-12 Resolution 653 adopted by the World Radiocommunication Conference (WRC) 2012 on the Future of Coordinated Universal Time (UTC) which invites the ITU WRC 2015 to

> "*consider the feasibility of achieving a continuous reference time-scale, whether by the modification of UTC or some other method and take appropriate action, taking into account ITU-R studies*,"

and instructs the ITU Secretary-General

> "*to bring this Resolution to the attention of relevant organizations such … the General Conference on Weights and Measures (CGPM), the Consultative Committee for Time and Frequency (CCTF), the Bureau International des Poids et Mesures (BIPM) …*"

Recommends that the following facts be recognized in the implementation of a continuous time scale:

1. a continuous time scale is indeed achievable, and that it has been realized and maintained by the International Bureau of Weights and Measures;
2. a continuous reference time scale corresponds to UTC without leap second discontinuities;
3. the concepts of continuity and uniformity should be applied <u>strictly</u> in a reference time scale;
4. the unit for any quantity in metrology is unique, and as such, a single time scale should also be unique;
5. in the event of a redefinition of any quantity in metrology, the unit should be invariant, and particularly for the second of the Système International the respective scale should be continuous and uniform;
6. the name "Coordinated Universal Time" be maintained in the case of a redefinition of UTC without leap second adjustments;
7. the term "Universal" in "Coordinated Universal Time" implies that the time scale is to be used throughout the world;
8. the term "Coordinated" in "Coordinated Universal Time" implies coordination among National Metrology Institutes and not a relationship to the direction of the Sun from a position on the surface of the Earth;
9. the angle UT1 used to relate celestial and terrestrial reference systems should not be considered as a time scale, but as the angle that characterizes the variable rotation of the Earth;

10. the International Earth Rotation and Reference Systems Service (IERS) provides a means of accessing UT1 in real-time by means of routinely available predictions of UT1-UTC with precision 100 000 times better that the coarse approximation UT1 = UTC currently provided by means of coding UTC to match UT1 within 0.9 second;
11. a wider dissemination of UT1-UTC is to be encouraged;

and further recommends

that the International Committee for Weights and Measures (CIPM) and the International Telecommunication Union – Radiocommunication Sector (ITU-R) consider the formation of a joint working group to study the possibility of coordinating future actions in the definition of the continuous world-reference time scale.