Work Programme

of the International Bureau of Weights and Measures

for the four years 2016-2019

Comité international des poids et mesures

TIME METROLOGY

The role of the BIPM in calculating and disseminating TAI/UTC is unique, and the interactions with the wider global community are of a specialist nature with a well-defined community in the field of timing, satellite navigation, geophysics and astronomy. The mission of the BIPM in the field of time is the realization and dissemination of the international time scale, International Atomic Time (TAI). As the uniform time scale it is kept as close as possible to the SI second. Coordinated Universal Time (UTC) is a time scale derived from TAI to provide a reference scale which takes into account the irregular rotation of the earth.

Key activities in Time

New activities are indicated in italics

- **Creating UTC, improving the accuracy and stability of international time references, increasing dissemination and improving accessibility through:**
  - **developing the analysis of data provided by new methods for time and frequency transfer.**
  - **optimizing the algorithms for clock data characterization.**
  - **reducing the delay in the publication of UTC, maintaining adequate extrapolations.**
- ***Contributing to the comparison of optical standards with the highest accuracy over all distances, in view of their future use for the improvement of TAI and as a basis for consideration of a redefinition of the SI second. (New)***
- **Contributing to the provision of a coherent set of space-time references and models for application in space and earth sciences.**

Strategy for time projects

- To calculate, disseminate and improve the world reference time scale through integrating data from atomic clocks and frequency standards maintained and operated at the NMIs (and other participating laboratories),
- To contribute to the investigation of the benefits of a future re-definition of the second and of time-keeping based on optical clocks,
- To promote the importance and benefits to the international telecommunications, astronomy and earth science communities of:
  - UTC
  - frequency measurements traceable to the SI and
  - common space-time references.

Priority activities in the field of Time metrology

The mission of the BIPM in the field of time is the realization and dissemination of the international time scale, International Atomic Time (TAI). As the uniform time scale it is kept as close as possible to the SI second. Coordinated Universal Time (UTC) is a time scale derived from TAI, to provide a reference scale which takes into account the irregular rotation of the earth.

The time scales TAI and UTC are disseminated monthly through BIPM *Circular T*. The *BIPM Annual Report on Time Activities* provides all relevant information, data and results for the year previous to its publication. Reports on time-transfer techniques are also issued regularly.

Other activities related to the time scales are developed in the Department; these contribute to improving the calculation algorithms and increasing knowledge about time transfer techniques.

T-A1 Frequency stability and accuracy of TAI/UTC

Project Code	Name	Deliverables	Resources in: a) Person months b) Operating costs c) Capital investment
T-A1.1	Time transfer for TAI/UTC Provides the differences between two realizations of UTC in contributing laboratories that input data to the key comparison on time CCTF-K001.UTC (monthly BIPM *Circular T*), and to the weekly computation of the rapid UTC (UTCr). *Time/frequency transfer and algorithms are the two key points in the elaboration of a time scale* *Participating laboratories: 73 (2013)*	1) New and refined methods for clock comparison for application on new techniques as implemented in NMIs necessary for the full exploitation of GNSS systems with the calculation of multi-system time links. In parallel, in combination with TWSTFT, this will contribute to the improvement of the uncertainty. Benefits - redundancy of data, impacting on: (a) the reliability of the time links system; (b) the statistical uncertainty of the links; (c) the characterization of clocks; (d) since the time link uncertainty is the major component of the uncertainty of [UTC-UTC(*k*)], enhanced time transfer will impact on the traceability of local realization UTC(*k*) to the SI second; (e) the ultimate impact is on the stability of the time scales. 2) Application of novel methods (beyond GNSS and TWSTFT) of time transfer using optical fibres as they are implemented between contributing laboratories. As in 2013 only one of these links is operational between two UTC laboratories, and we should expect a substantial increase in the mid-term. Deliverable is enhanced time links for TAI, Particularly: (a) increasing the reliability of the time link system by the use of an independent technique; (b) improving the statistical uncertainty of time links to the picosecond; (c) improving the Type B uncertainty (calibration, related to T-A2); (d) since the time link uncertainty is the major component of the uncertainty of [UTC-UTC(*k*)], enhanced time transfer will impact on the traceability of local realization UTC(*k*) to the SI second; (e) the ultimate impact is on the stability of the time scales. 3) Methods based on optical fibre and space techniques for time and frequency transfer with 10^{-18} targeted relative uncertainty for allowing optical clock comparisons. Benefits: when optical clocks are operated over appropriate time intervals, they could be linked keeping their precision to the UTC system and contribute to the	a) 92 pers months + 12 secondee b) 39 k€ c) 32 k€

		accuracy of the time scales. 4) Distribution of data, results, comparisons to UTC participants and other relevant users. 5) CCTF-K001.UTC, *Circular T* (*70 participants in 2013, 10 % increase expected*).	
T-A1.2	**Algorithms** Development of new algorithms and upgrading of the algorithms already in use for the provision of time scales at the BIPM (TAI/UTC as in CCTF-K001.UTC - monthly BIPM *Circular T*, in weekly UTCr, in the annual TT(BIPM) and its monthly predictions). *Time/frequency transfer and algorithms are the two key points in the elaboration of a time scale* *Participating laboratories: 73 (2013)*	1) Improved stability by adequate clock frequency prediction and clock weighting. Target is improving the present 3×10^{-16} frequency stability with a target of improving stability by a factor of two. 2) Improved accuracy by use of primary and secondary frequency standard measurements and procedure for frequency steering. The target is improving the present frequency accuracy (few parts in 10^{-16}) with a target of improving accuracy by a factor of two. 3) Distribution of data, results, comparisons to UTC participants and other relevant users (data distributed – some 200 data/results per day by ftp plus large numbers of web consultations). 4) Generation of TT(BIPM): a coordinated time calculated at the BIPM for scientific applications requiring long-term stability. TT(BIPM) has applications in some fields of astronomy (pulsar timing for the construction of a dynamic time scale), in space research, etc. Its algorithm is similar to that for TAI, but with a major role for the primary frequency standards. The introduction of secondary standards (optical clocks) will demand changes in the algorithm, with impact on the long-term stability and accuracy. TT(BIPM) is published in January every year for (year-1), with monthly extrapolations for the current year.	a) 48 pers months + 12 secondee b) 34 k€ c) 12 k€
T-A1.3	**Rapid UTC** *Participating laboratories: 40 (2013)*	1) Publication of UTCr, rapid UTC providing weekly access to a UTC Rapid solution for better synchronization of local realizations of UTC(*k*) in contributing laboratories, particularly enabling NMIs to improve the UTC(*k*) serving as a reference for GNSS time steering (*40 participants in 2013, 100 % increase expected over the programme*).	a) 36 pers months b) 6 k€ c) 22 k€

T-A2 Characterization of delays in GNSS equipment operated in TAI/UTC contributing laboratories

All laboratories that contribute to UTC are equipped with GNSS time receivers to provide data for the comparison of their clocks (T-A1). The comparison between the local clock and the clock in the satellite is carried out within the receiver located in the laboratory, whilst the signal from the satellite arrives at the antenna and has a path delay until it reaches the comparison point. As a consequence, the measurement of the delay is essential to the stability and accuracy of the UTC time links system. The BIPM has centralized the characterization of GNSS equipment delays in contributing laboratories since it is part of the actions necessary for the provision of UTC. The activity is mostly referred to as "*calibration of GNSS receiver equipment in laboratories*".

The result of a "*calibration*" is part of the data used for the calculation of time links for TAI/UTC (T-A1).

Project Code	**Name**	**Deliverables**	**Resources in:** **a) Person months** **b) Operating costs** **c) Capital investment**
T-A2.1	**Maintenance of BIPM travelling receivers and procedures for calibration** The equipment in the BIPM Time laboratory is principally used for maintaining the BIPM travelling standard receivers. The ensemble of receivers consists of equipment similar to that installed in the contributing laboratories. Some of the equipment is used for travelling, whilst other equipment remains in the laboratory to act as the reference during a campaign. An atomic clock providing the local time reference is necessary. In parallel, the Time Department develops strategies for delay characterization based on different geometries, data acquisition processes and statistical treatment of measurements.	1) Characterization of equipment compatible with those operated in NMIs. 2) Reliable/redundant travelling and fixed-reference standards. 3) Guidance documents and support for contributing NMIs. 4) Technical protocols for calibration. 5) Methods of calibration aimed at improving the time link uncertainty, which remains the largest component of the uncertainty of *UTC-UTC*(*k*). The target is improving the present 5 ns value of the Type B uncertainty by a factor of at least 2.	a) 20 pers months b) 0 k€ c) 170 k€

T-A2.2	**Realization of delay measurement campaigns for pivot laboratories (G1 labs)** The BIPM organizes and realizes travelling standard visits among the contributing laboratories for measuring the (relative) delays in GNSS equipment. The measurements are analysed and processed at the BIPM and the result forms part of the data used for the time links calculation. Absolute determination of delays is made using the BIPM/CNES calibrator.	Typically two characterization campaigns (requiring the sending of BIPM travelling system without staff) to each of approximately 15 contributing laboratories (G1 labs) during the programme: 1) Regular assessment of the values of the Type B uncertainty of time links via periodic calibration of GNSS equipment in a selected group of NMIs (potential "pivot" laboratories, laboratories in regions where RMOs are not active or organized). 2) Evolving Protocols for calibration. 3) Improved link accuracy from 5 ns to 2 ns. 4) Input data for time links used in CCTF-K001.UTC, BIPM *Circular T* and rapid UTC.	a) 18 pers months + 12 secondee b) 30 k€ c) 0 k€
T-A2.3	**Coordinating with the RMOs for campaigns of G2 laboratories (labs which are not pivot labs) and linking results to the BIPM G1 reference** RMOs organize regional calibration campaigns with their own travelling equipment supporting the BIPM in the maintenance of time link system stability. The BIPM provides guidance to RMOs, establishes priorities and interacts with them for the coordination of the campaigns. The BIPM validates the results of the RMOs' calibrations, makes the link to the BIPM system and decides on the results to be used for TAI/UTC.	1) Provision of Guidelines for the calibrations, including technical instructions for RMOs and protocols for linking their calibrations to the BIPM time link system. 2) Regular assessment of the values of the Type B uncertainty of time links via periodical calibration of GNSS equipment in a set of laboratories as defined by the BIPM for approximately 60 contributing laboratories. 3) Improved link accuracy from 5 ns to 2 ns 4) Generating Input data for time links used in CCTF-K001.UTC, BIPM *Circular T* and rapid UTC.	a) 10 pers months b) 0 k€ c) 0 k€

T-A3 Use of very accurate frequency standards - Secondary representations of the second

This activity should be considered of common interest to time and length metrology. The application of frequency combs, traditionally related to the length comparisons, is now expanding into the field of time metrology.

Project Code	Name	Deliverables	Resources in: **a) Person months** **b) Operating costs** **c) Capital investment**
T-A3.1	**Time and frequency transfer techniques for highly accurate optical standards** Study and implementation of techniques. Cooperation with different sectors is planned (French space agency, NMIs)	1) Comparison of optical standards with ~10^{-18} relative uncertainty over short and long baselines. This includes continental links via optical fibres and intercontinental comparisons using enhanced TW links and one-way space techniques. 2) Contributing to the discussion on the redefinition of the second (2018 onwards).	a) 30 pers months +12 secondee b) 30 k€ c) 0 k€
T-A3.2	**Maintenance of equipment** The equipment will serve (a) to study the physics related to the transfer techniques; (b) to develop competency for the statistical treatment of measures for application in time scale construction; (c) to characterize their uncertainties, including calibration. Equipment consists of: Frequency combs and terminals for advanced time transfer using microwave links; H-maser for providing the frequency reference.	1) Evaluation of the use of microwave links as a possible candidate for future high level optical clock comparisons based on a comparison of Space-Earth and Earth-Earth Comparison of atomic clocks, within the ACES. Activities will be in cooperation with the French Space Agency (CNES). 2) Comparison of optical standards with ~10^{-18} fractional uncertainty over short and long baselines. 3) Improved time link accuracy. 4) Contributing to the discussion on the redefinition of the second (2018 onwards).	a) 18 pers months b) 0 k€ c) 350 k€

Additional activities in the field of Time Metrology - not covered by the adopted budget

T-A3.3	**Frequency comb validation** Assuring the correct validation of the increasing number of frequency combs in NMIs at accuracy levels aiming to meet both time and length requirements, taking particular note of the emergence of optical clocks	Organising a comparison of NMI frequency combs based on the existing BIPM frequency comb (estimated for maximum of 5 node NMIs for length, and up to 10 NMIs for frequency) Target is parts in 10^{18} (driven by frequency needs), - 10^{16} sufficient for length	a) 12 pers months b) 20 k€ c) 10 k€

Executive Secretaries and other international liaisons in science departments

Project Code	Name	Deliverables	Resources in: **a) Person months** **b) Operating costs** **c) Capital investment**
CM-A1	**Coordination and Support to the CCM** (Mass and Related Quantities)	Provision of the CCM Executive Secretary, general support to the CC and WGs plus specifically support for: 1) Two CCM meetings: 2) Four annual meetings of CCM working groups 3) Coordinate review of CC and RMO comparison reports before publication 4) Coordinate review of CC and RMO comparison reports before publication 5) Related liaisons with RMOs.	a) 16 pers months b) 4.3 k€ c) 0 k€
CE-A1.1	**Coordination and Support to the CCEM** (Electricity and Magnetism)	Provision of the CCEM Executive Secretary, general support to the CC and WGs plus specifically support for: 1) Two CCEM meetings 2) Four annual meetings of CCEM working groups (12 meetings) 3) Coordinate review of CC and RMO comparison reports before publication 4) Related liaisons with RMOs.	a) 14 pers months b) 8.4 k€ c) 0 k€
CE-A1.2	**Coordination and Support to the CCPR** (Photometry and Radiometry)	Provision of the CCPR Executive Secretary, general support to the CC and WGs plus specifically support for: 1) Two CCPR meetings 2) Four annual meetings of CCPR working groups (12 meetings) 3) Related liaison with International Commission on Illumination (CIE) and RMOs 4) Coordinate review of CC and RMO comparison reports before publication 5) Related liaisons with RMOs.	a) 6 pers months b) 2 k€ c) 0 k€
CT-A1.1	**Coordination and promotion of SI time activities for the advancement in the development of time scales** Activities within the scope of/linking to/cooperating with: - ITU - IGS - ICG - Space agencies operating GNSS - NMIs	1) TAI/UTC/TT(BIPM)/ maintenance 2) GNSS time transfer 3) GNSS coordination 4) Support to GNSS system times 5) Time and frequency transfer methods.	a) 24 pers months b) 120 k€ c) 0 k€

CT-A1.2	**Coordination and promotion of SI time activities for scientific applications** Activities within the scope of/linking to/cooperating with: - IERS - IAU - IUGG/IAG - URSI	1) Space-time references, IERS Conventions 2) Timescales for astronomy/TT(BIPM)/Pulsar timescales 3) Time references for geodetic and geophysical applications Geodetic references.	a) 16 pers months b) 50 k€ c) 0 k€
CT-A1.3	**Coordination and Support to the CCTF** (Time and Frequency)	Provision of the CCTF Executive Secretary, general support to the CC and WGs plus specifically support for: 1) Coordination between NMIs for the maintenance of UTC 2) Monitoring and validation of the BIPM Time Department activities and plans 3) Development of strategic plans 4) Key comparisons in time and frequency 5) Recommendation of standard frequencies as secondary representations of the second 6) Secretariat of CCTF and WGs 7) Participation in WGs.	a) 16 pers months b) 25 k€ c) 0 k€
CT-A1.4	**Coordination and Support to the CCL** (Length)	Provision of the CCL Executive Secretary. Support for: 1) CCL Meetings 2) Coordination between NMIs for length related activities 3) Development of strategic plans 4) Key comparisons in length, support to comparisons of stabilized lasers piloted by NMIs 5) Recommendation of standard frequencies for the practical realization of the metre 6) Participation in WGs	a) 4 pers months b) 5 k€ c) 0 k€
CQM-A1.1	**Coordination and Support to the CCQM** (Amount of Substance: Metrology in Chemistry)	Provision of the CCQM Executive Secretary. Support for: 1) Four CCQM Plenary Meetings 2) Nine CCQM working groups (36 Meetings) 3) Participate in the pool of experts reviewing CC and RMO comparison and pilot study reports before publication 4) Development of strategic plans 5) Related liaisons with RMOs.	a) 22 pers months b) 42 k€ c) 0 k€
CQM-A1.2	**Coordination of JCTLM Activities**	Support for: 1) JCTLM Executive and WGs (eight meetings) 2) JCTLM Database entry/nomination review process Maintenance of: JCTLM Database.	a) 26 pers months b) 52 k€ c) 0 k€
CQM-A1.3	**Liaison and coordination activities**	Liaison activities with: IUPAC; ISO TC 212, IFCC, WMO, WHO, WADA, Codex, ISO TC 146.	a) 12 pers months b) 18 k€ c) 0 k€