Consultative Committee for Time and Frequency

Fifteenth Session

(Sèvres, 20 and 21 June 2001)

Draft Report and **Proposals** from the **CCTF Working Group on the consequences of the global MRA (WGMRA),**

G. de Jong, chairman

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0.0 Preamble.

The content of this contribution has not yet been discussed by the WGMRA members. But the chairman is of the opinion that this is a good starting point for further discussions. It reflects discussions at meetings of APMP TCTF and EUROMET Time Contact Persons. Also attention has been paid to the annexes.

1.0 Introduction

At the 14th CCTF meeting in April 1999 the Working Group on the consequences of the global Mutual Recognition Arrangement (MRA) was created to examine and report on the consequences of the global MRA for the CCTF. The members of this WGMRA are: Dr Rob Douglas (NRC, Canada), Dr Alex Lepek (INPL, Israel), Dr Shin-Ichi Ohshima (NRLM, Japan), Dr Juan Palacio (ROA, Spain), Dr. Donald Sullivan (NIST, USA), while Gerrit de Jong (NMi VSL, Netherlands) was asked to chair this Working Group. This Working Group did not meet, but some documents have been exchanged by e-mail.

2.0 Summary of the MRA

The MRA document is titled as “Mutual recognition of national measurements standards and of measurement certificates issued by national metrology institutes”. The International Committee of Weights and Measures (CIPM) has drawn up the MRA, under the authority given to it in the Meter Convention, for signature by directors of the national metrology institutes (NMIs) of Member States of the Convention.
It is well documented at the web-site of the BIPM (www.bipm.org). It consists of the main MRA dated 14 October 1999 signed for a 4 year period, a Technical supplement and the Appendices A to F.

The **objectives** of the MRA are:
1. to establish the degree of equivalence of national measurement standards maintained by NMIs;
2. to provide for the mutual recognition of calibration and measurement certificates issued by NMIs;
3. thereby to provide governments and other parties with a secure technical foundation for wider agreements related to international trade, commerce and regulatory affairs.
4. statements of the measurement capabilities of each NMI in a database maintained by the BIPM and publicly available on the Web.

The **process** is:
1. international comparisons of measurements, to be known as key comparisons (KC's);
2.supplementary international comparisons of measurements (SC's);
3. quality systems and demonstrations of competence by NMIs.

the **outcome** is:
statements of the measurement capabilities of each NMI in a database maintained by the BIPM and publicly available on the Web.

2.1 Supplement and Appendices of the MRA
Technical supplement: specifies conventions and responsibilities relating to the key comparisons.
Appendix A: contains the growing list of national metrology institutes (NMI's) that have signed the MRA;
Appendix B: contains the key comparisons of quantities that have been carried out and its results (reference values and deviations and associated uncertainties of the participating NMI's);
Appendix C: contains the detailed list of quantities and ranges for which calibration and measurement certificates is recognized by the participating institutes;
Appendix D: is the list of (chosen quantities for) which CIPM and RMO key comparisons will be held;
Appendix E: contains the terms of reference of the Joint Committee of the Regional Metrology Organizations (RMO's) and the BIPM (JCRB);
Appendix F: contains the Guidelines for CIPM key comparisons dated 1 March 1999, see Technical Supplement T.6.

2.2 Some Definitions
Reference value: result from a key comparison, a close approximation to the SI value, but not necessary the best.
Degree of equivalence of a national standard: its deviation from the reference value + the uncertainty at 95% confidence level of this deviation.
CIPM key comparisons (KC's by CC's and BIPM)
RMO key comparisons (KC's by RMO's)

2.3 Responsibilities of the Consultative Committees
Cited from Technical Supplement T.8:
The Consultative Committees have a prime role in choosing and implementing key comparisons and in affirming the validity of the results. Their particular responsibilities are:

a) identify the key comparisons in each field and maintain a current list (Appendix D);

b) initiate and organize, with the collaboration of the BIPM, the execution of key comparisons at intervals to be decided individually for each comparison;

c) review the results of CIPM key comparisons and determine the reference values and degrees of equivalence on the basis of the proposals of the appropriate working groups;

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

e) examine and confirm the results of RMO key and supplementary comparisons and incorporate them in Appendix B and the key comparison database;

f) examine and confirm the results of bilateral key comparisons for entry into Appendix B and the key comparison database.

And also:
g) coordinate the CIPM and the RMO KC's through consultations with the RMO's

h) discuss disputes from MRA + KC's

2.4 Task of RMO's
a) Make proposals to the CC's on the choice of key comparisons;
b) Responsible for carrying out the RMO key comparisons corresponding to CIPM KC's, see Technical Supplement;
c) Participate in JCRB:
d) Responsible for carrying out the RMO supplementary comparisons and other related actions.

2.6 Task of BIPM
Responsible for carrying out the key and supplementary comparisons (see MRA p.29);
Participate in JCRB;
Maintain the database for data of MRA appendix A, B, C, and D as well as publicise the data.

2.7 Participation in KC's
CIPM KC's: NMIis that are labs with highest technical competence and experience (normally the CC members), and other labs nominated by their NMI and designated responsible for national measurements standards.
RMO KC's and Supplemental Comparisons (SC's): all RMO members having technical competence to the comparison subject

2.8 Calibration Measurement Capability (CMC) see T.7, declarations on calibration measurement capabilities of NMIs accredited according ISO 17025, to be sent to RMO, then to JCRB for review, and finally entered into Appendix C at the BIPM data base.

2.9 Actions to be taken at CCTF meetings

a) identify the key comparisons in the field of Time and maintain a current list (Appendix D);
b) initiate and organize, with the collaboration of the BIPM, the execution of key comparisons at intervals to be decided individually for each comparison;
c) review the results of CIPM key comparisons and determine the reference values and degrees of equivalence on the basis of the proposals of the appropriate working groups;

3.0 Present process for the calculation of TAI, UTC and UTC-UTC(k)

Each participating institute sends to the BIPM: files containing UTC(k) - clock(i) per 5 days, UTC(k)- T(GPS) for each satellite as indicated on the schedules issued by the BIPM, and/or TWSTFT(k)-TWSTFT(l) following an agreed schedule (i.e.3 days per week).
Also, if appropriate, about once per month, data which contains additional information from accuracy evaluations of primary time standards (PTS).

Output products of the monthly BIPM calculations are: the time scale differences UTC- UTC(k) per 5 d, the relative frequency difference between TAI and EAL, the scale interval of TAI (some times referred to as the rate of TAI or the TAI frequency), expressed in the SI unit of time and its uncertainty, and the rates of the individual clocks with respect to the rate of UTC, all from the average over the recent 30d.
For the BIPM time scale calculations fixed delay corrections per lab k are used for GPS and TWSTFT from (differential) delay calibration trips in the past. The results of these calibrations and its uncertainty have been published by the BIPM in technical reports.
For the SI unit of time calculations these delays are assumed to be stable, any changes are attributed to the clock stability.

4.0 Report

On the subject the implementation of MRA in the field of time and frequency has been discussed at RMO's EUROMET and APMP. Comments also have been received from the BIPM Time Section and from PTB. The annexes show the principal contributions for this report section.

-The conclusion is that the present work of the Time Section of the BIPM is appreciated. The present practice of calculating EAL, TAI and UTC and publication in BIPM circular T is sufficient and is the clear candidate for a CCTF KC. No RMO KC seems to be needed now.

-Participation in the CCTF KC's of not only the best primary clocks but also of UTC(k)s.

-At present uncertainty statements of UTC-UTC(k) are missing, they should be determined and added.

-TAI/UTC could be used as KC reference value, for time epoch (time scale) as well as for time interval (the scale interval unit of TAI/UTC), the SI second.

-The average scale interval unit deviation of UTC(k) over a period of time t can be calculated by taking the first derivative of UTC-UTC(k): dt = d(UTC-UTC(k))/t.

-The average deviation of the "frequency" of UTC(k) df over a period of time t can be derived from UTC-UTC(k) from the first difference of UTC-UTC(k) over that period of time: df = -d(UTC-UTC(k))/t

-Also the problem of the participation of clocks and time scales of non-members of the Meter Convention was addressed.

- For the calculation and stating of the uncertainty of UTC(k) and its derivatives one or more averaging periods of time should be agreed.

5.0 Proposals

5.1 Choices for CCTTF KC's

The following quantities for CCTF Key Comparisons can be identified:
1. Time epoch: TAI, UTC, UTC(k)
2. Time interval unit: scale unit of TAI, UTC, UTC(k), the SI second [s]
3. Rate: first derivative of UTC and TAI, rate of clocks,[s/s]
4. Frequency: inverse of the rate, [Hz/Hz]

By comparing the locally generated time scale UTC(k) with the UTC (or TAI) reference time scale as Key Comparison Reference Value (KCRV), the degree of equivalence of the local realization of UTC, of the SI second as well as of rate and frequency can be determined. So TAI is the best choice for the main CCTF KC.

Uncertainties per quantity:
1: Uncertainty of delay values + stability of (clock link to UTC(k), Transfer Link from UTC(k) to EAL, EAL to TAI link)
2, 3, 4: Stability of (clock link to UTC(k), Transfer Link from UTC(k) to EAL, EAL to TAI link)

5.2 Key Comparison on TAI

The procedure of the calculation of TAI is the responsibility of the permanent CCTF Working Group on TAI. The clock data, time transfer link data are provided by the NMIs to BIPM. The calculations and the publications of the results are performed by the BIPM. The KCRV is TAI/UTC. The annual report including the degrees of equivalence of the yearly KC should be agreed by the CCTF members and will then be published in the Annual Report of the BIPM Time section and filed in the BIPM database for MRA Appendix B.

The EAL to TAI link is determined by the BIPM from the evaluation of the best primary standards for the SI second. The deviation and uncertainty of TAI is determined following the CCTF Recommendations (1999). No new action is proposed.

The difference TAI-UTC (DTAI) is a constant integer number of seconds decided by the IERS and it does not change the uncertainty of UTC.

The uncertainties of UTC-UTC(k) should be determined and published. The delays in the GPS, Glonass and/or TWSTFT equipment has to be determined along with its uncertainty. In the past the BIPM has taken this task (see last Rapport BIPM-98/7) and BIPM still uses corrections based on past calibrations. Further action is needed, see 5.3.

The value and its uncertainty of the link of the clocks at each NMI k to UTC(k) should be determined by each NMI and is not a subject for CCTF KC.

5.3 Supplemental Comparison on Equipment delay
In addition to the CCTF KC on TAI, the delay in GPS, Glonass and TWSTFT instrumentation should regularly (at least once per year) be determined (i.e. by means of a calibration trip) for the calculation of UTC-UTC(k) and its uncertainty.
BIPM still uses corrections based on past calibrations. CCTF should decide how this should be continued. During a calibration trip, the delay of a circulating receiver or other calibration equipment could act as an agreed reference value KCRV. These calibration trips can be performed as Supplemental Comparisons or as Key Comparison by CCTF, BIPM and/or RMOs. Studies are recommended to improve the uncertainties of time transfer links.

5.4 Naming of CCTF KC and SC
Following the naming conventions, a possible name of the yearly CCTF KC can be:
CCTF-Kyyyy.TAI CCTF-K2001.TAI, etc. where yyyy is the calendar year;
or: CCTF-Kyyyy.UTC, CCTF-K2001.UTC, etc..

Names of (yearly) calibration trips as CCTF Supplemental Comparisons:
CCTF-Syyyy.TWCAL, CCTF-S2001.TWCAL,
CCTF-Syyyy.GPSCAL, CCTF-S2001.GPSCAL,

In stead of “CCTF” in these names, BIPM (or the RMO) could be chosen.

5.5 Participation of Non-Members
A NMI from countries or economies that are not member of the Meter Convention, may become Associate of the CGPM. Then the NMi is entitled to participate through their RMO by signing a declaration appended to the MRA.
If in one economy more than one institute is now participating in the TAI calculations, one institute may have signed the MRA on behalf of all, and the names of the other institutes being attached to the MRA document. (Note: for me it is not clear if then all institutes in a country may participate.)

5.6 MRA appendix C, CMC tables
In the RMOs much discussion takes place about what subjects should become entries to be filled in the CMC. See example from EUROMET Time Contact Persons Meeting in Annex 5 (Note: should this be discussed/coordinated at the CCTF?)

6.0 Conclusion

(note: to be drawn after the discussion at the CCTF)

7.0 Annexes 1 to 5

Annex 1

Key Comparisons in the Field of Time and Frequency: a Proposal

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Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

The text of the CIPM-MRA gives rather clear indications about the procedures to be followed in order to obtain the technical basis for equivalence of national measurement standards maintained by NMIs. In general terms, it has to be found out to what external individual standards are consistent with the key comparison reference values.

In the field of time and frequency the Co-ordinated Universal Time UTC represents a world-wide recognised time and frequency reference. The procedures to establish UTC should not be altered unless very stringent requirements have been identified. This is to our opinion not the case. The terms in the CIPM-MRA should thus be interpreted with as much freedom as possible.

UTC shall be regarded as the reference for two quantities, time-unit and time epoch. The determination of UTC has been well described in the literature. What has been missing is a detailed (in terms of the requirements enlisted in the GUM) description and publication of how the scale unit and its uncertainty are determined, based on the comparisons against primary frequency standards. In response of Recommendation S2 and S3 of the 14^{th} Session of the CCTF this information will soon become available.

What has also been missing is the uncertainty of time differences UTC-UTC(k) of the contributing laboratories k. This value may vary considerably, depending on the calibration of local time comparison equipment in the laboratories k. Most probably, the BIPM has traditionally taken care of the time comparison links of individual laboratories. It may become necessary to undertake calibration exercises for some laboratories which today are listed in the UTC-UTC(k) tables of the Circular T.

The following agreements and procedures are proposed:

1) The scale unit of UTC and TAI, based on primary standards, is recognised as the reference value for the quantities frequency and time interval. The determination of the TAI scale unit is continued in the usual way by comparisons of TAI with primary frequency standards which realise the SI second with a specified uncertainty. These comparisons are key comparisons. Data treatment should continue along the traditional lines to ensure continuity and reliability. The uncertainties in the determination of the TAI scale unit shall be made transparent as detailed in the Recommendation S2 and S3 of the 14^{th} CCTF.

2) Laboratories k which maintain time scales UTC(k) in close agreement with UTC should compare their time scales to UTC by appropriate means. This means that they should, for the time being, provide data UTC(k)-T(GPS) in the format as recommended by the CCTF.

If calibration of the receiver delays is available with an uncertainty $\sigma_t(k)$, the laboratory can thus demonstrate equivalence of its time scale and UTC within the respective uncertainty. The deviation UTC-UTC(k) and its uncertainty composed of $\sigma_t(k)$ and the intrinsic uncertainty of UTC should be published in the Circular T of the BIPM Time Section.

3) If no calibration is available, the difference UTC-UTC(k) still allows for the laboratories (k) to demonstrate the equivalence of their frequency standards and the rate of UTC. The quantity d[UTC-UTC(k)] / dt may be calculated form the published time-differences. Its uncertainty composes of components due to

- the uncertainty $\sigma_f(k)$ which reflects the anticipated or known temporal delay changes of the receiver delays for the respective time interval,

- the uncertainty $\sigma_a(k)$ due to the anticipated or known temporal frequency instability of the local frequency standard employed to realise UTC(k).

The comparisons UTC-UTC(k) may play the role of key comparisons, defined in the CIPM-MRA, if the uncertainty components are known. It should be the task of the laboratories to evaluate these uncertainty components, and they should be published in the Annual Report of the BIPM Time Section.

Annex 2

2nd TCTF meeting
at CRL, Tokyo
Nov. 1, 2000

Report of CIPM(CCTF) and RMO key comparisons

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Shin-ichi Ohshima, and Yasuhiro Nakadan
National Research Laboratory of Metrology

1. Status of CIPM key comparison in the field of T&F
A working group (WG) on the key comparison of T&F was set up at the last CCTF meeting in April 1999. This WG is going to discuss the CIPM key comparison and will make a recommendation on the method and procedure to be used for the comparison within one year.

The WG is chaired by Dr. G. de Jong from the NMi Van Swinden Laboratorium of The Netherlands and other members are four specialists including Dr. S. Ohshima (NRLM, Japan) who is the representative for the Asia Pacific region.

The method and the procedure to be used for the RMO key comparison of T&F should be compatible with that of CIPM. The member institutes of APMP can contribute to the establishment of the procedure for CIPM key comparison by discussing this issue within APMP and by expressing their opinions to the CCTF WG.

The following are tentative opinions that were offered by the members of two Japanese national measurement institutes on T&F, CRL and NRLM.

2. Basic consensus on CIPM key comparison of Japanese national measurement institutes
Regarding T&F,

1) Not only the primary frequency standards but the UTC(k) should be included in the CIPM key comparison.
2) An effective CIPM key comparison for T&F has actually already been established for the construction of the TAI, among the T&F institutes, and the BIPM published data via *Circular-T* and its Time Section Annual Report.
3) Regarding the key comparison reference value for T&F, the frequency of the UTC calculated by the BIPM should be adopted.
4) The uncertainty of the frequency of the UTC(k) should be evaluated by both the uncertainty of the UTC itself and the data for the UTC(k) - UTC and/or the TA(k) - TAI of *Circular-T* by the BIPM
5) Further discussion of the evaluation method to determine the uncertainty of the frequency of the UTC(k) should be made.

For example,
- i) data length
- ii) uncertainty calculation method
  - a) uncertainty = standard deviation of the UTC(k) around the UTC
  - b) uncertainty = standard deviation of the UTC(k) around the mean frequency offset from the UTC
- iii) an other method?

Some calculated examples of the uncertainty of the UTC(k) are attached to this report.

3. RMO key comparison

(1) Concept of RMO key comparison for T&F

General conditions for RMO key comparison are as follows (from Global MRA document);

a) links with the CIPM key comparisons provide adequate redundancy through the participation of a sufficient number of laboratories in both sets of comparisons to ensure that links to the key comparison reference values are established with acceptably low uncertainty;

b) the procedures used in regional comparisons, and the evaluation of the results and uncertainties, are compatible with those used in the CIPM key comparisons;

c) the timing of RMO key comparisons is coordinated with, and is at least as frequent as, those of the CIPM key comparisons;

d) the results of RMO key comparisons are carefully evaluated by the RMO, which also tales responsibility for ensuring that the proper procedures have been followed, and then the results are submitted for publication and to the relevant CC incorporation in Appendix B and the key comparison data base.

In the case of T&F,
if the method for the daily-time transfer for the construction of the TAI is adopted as the CIPM key comparison,

i) it is not reasonable to apply the same method used for CIPM key comparison as RMO key comparison by RMO itself, because it imposes a large amount of work on RMO.

ii) if the national institutes under the APMP can use the same procedure for international time transfer for the TAI, it is better that they send the data to the BIPM and they calculate the UTC(k) - UTC for all institutes sending data.

The above opinion means that in the case of T&F it is not effective and reasonable to separate the CIPM and the RMO key comparisons.

(2) Supplement comparison

The bilateral or multilateral comparison performed among the RMO institutes by methods other than the time transfer for construction of the TAI should be considered as a "supplement comparison".

(3) Problems to be solved

i) Can the BIPM accept the additional institutes' data and process the data to calculate the UTC(k) - UTC for all institutes ?

ii) The new institutes joining the CIPM key comparison should have the equipment and man power to perform the daily task of time transferring.

4. Conclusion

The opinions described in this report are the results of discussion between only members of Japanese national measurement institutes involved in T&F. Therefore, further discussions with APMP institutes are welcome and we, the TCTF of APMP, must contribute our opinions to the CCTF WG on key comparison.

Example of uncertainty evaluation of UTC(k) vs. UTC

Figure 1 shows the time differences between the UTC(k) and the UTC over three years obtained from the *Circular-T* published by the BIPM. In this figure, five major T&F institutes in Asia Pacific region are plotted.

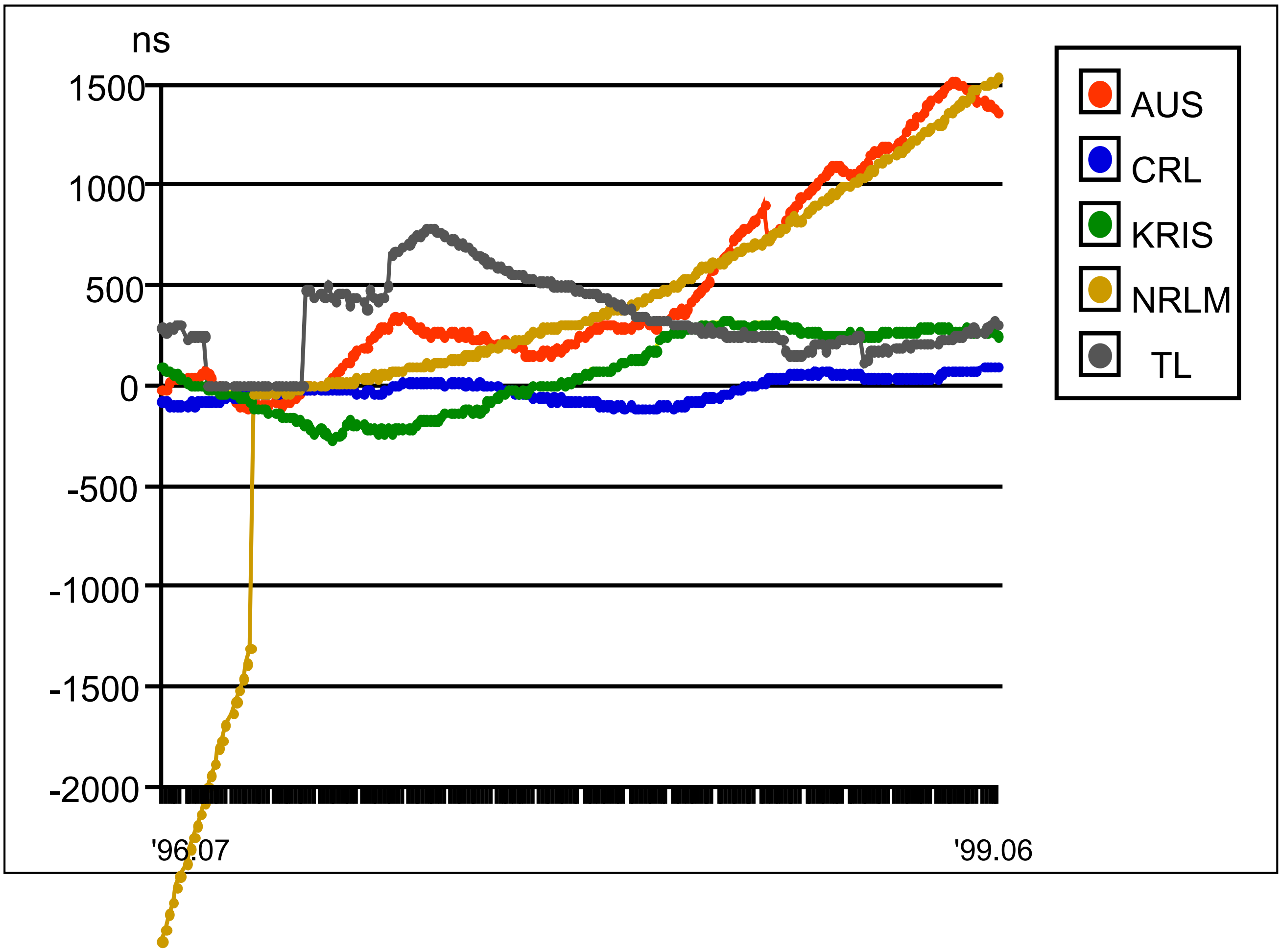
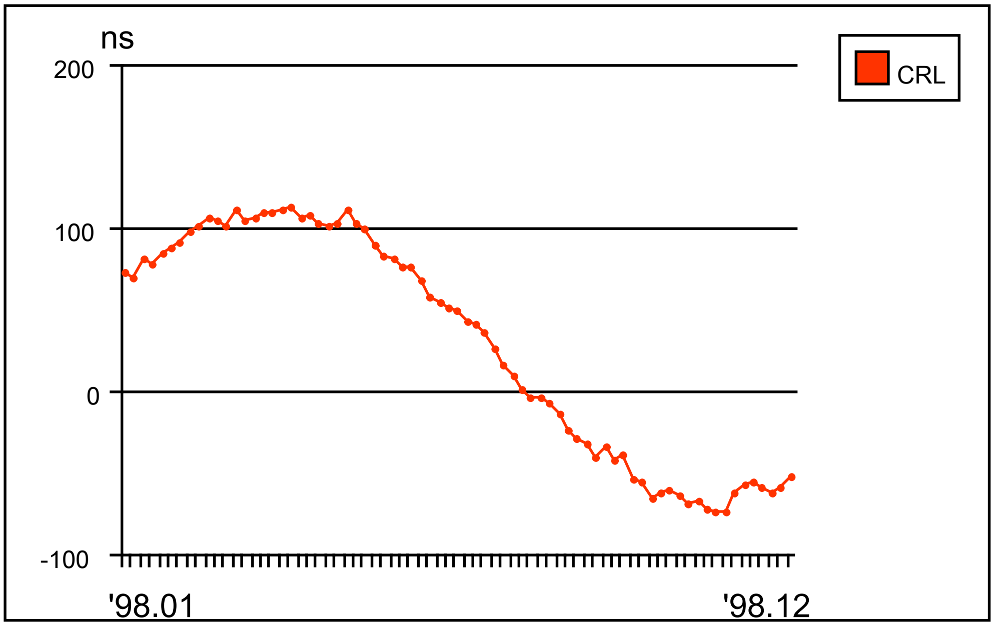
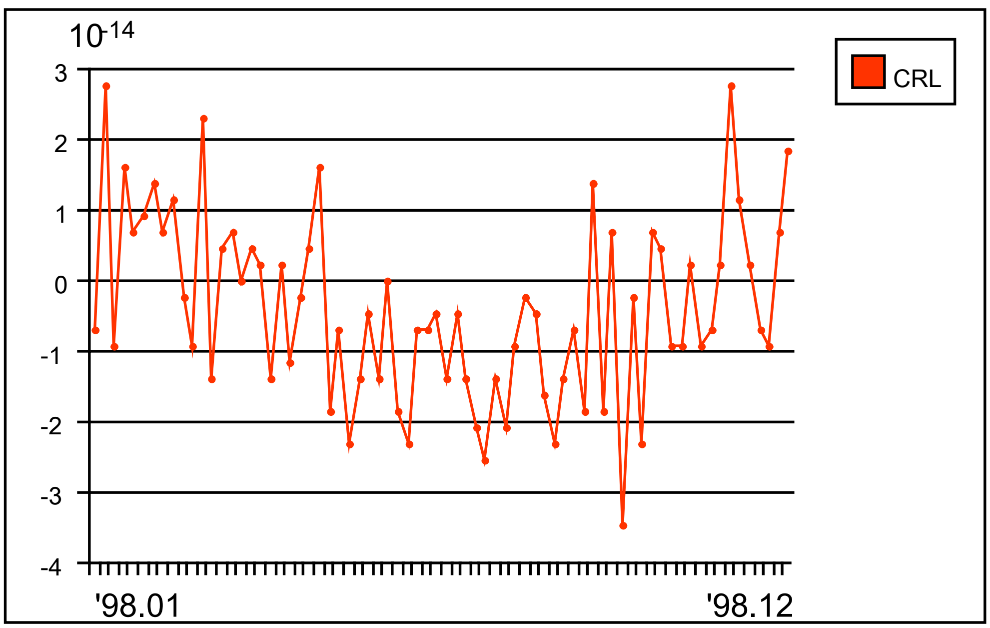


Fig. 1. UTC - UTC(k) of main institutes over three years.



(a) Time difference UTC – UTC(CRL) in 1998



(b) Normalized frequency departure of UTC(CRL) against UTC

Fig. 2. Time difference and normalized frequency departure of UTC(CRL) against the UTC.

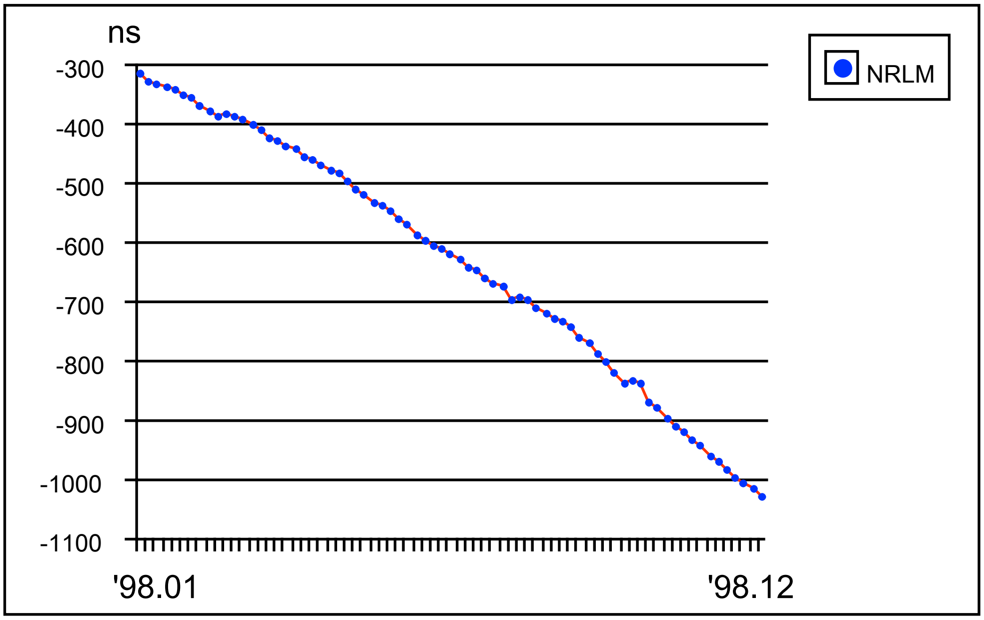
The UTC(CRL) was generated by using a micro-phase stepper to control its frequency. Figure 2 shows the time difference and normalized frequency departure of the UTC(CRL) against the UTC during 1998.

From this graph, we obtained the following values for the UTC(CRL);

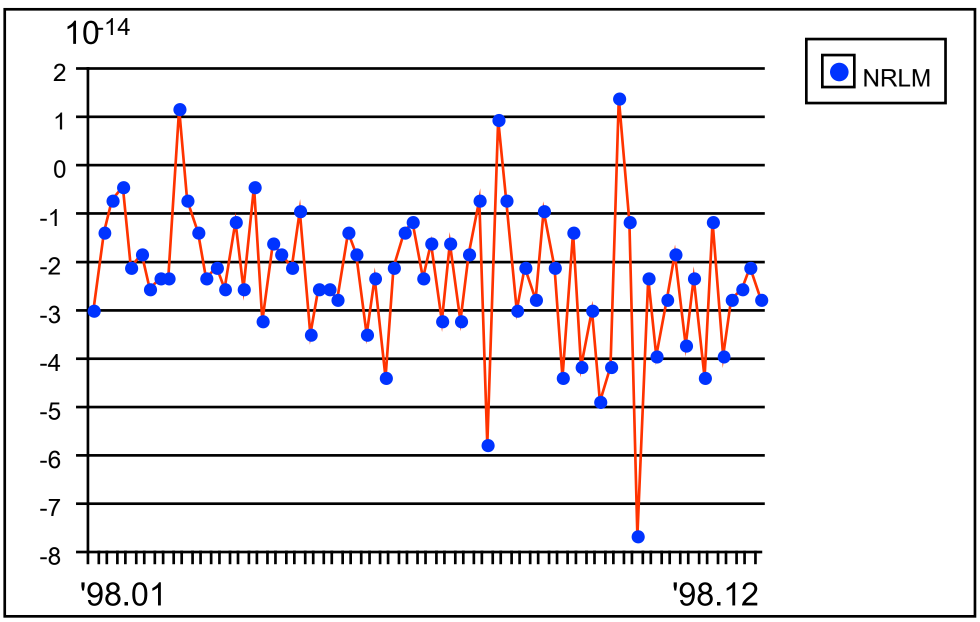
Mean normalized frequency departure was 0.40×10^{-14} : one year average.

Standard deviation from the UTC frequency was 1.36×10^{-14}.

Standard deviation from the mean normalized frequency departure was 1.30×10^{-14}.



(a) Time difference UTC – UTC(NRLM) in 1998



(b) Normalized frequency departure of the UTC(NRLM) against the UTC

Fig. 3. Time difference and normalized frequency departure of the UTC(NRLM) against the UTC.

UTC(NRLM) was generated by the "master clock method" using a single atomic clock. Figure 3 shows the time difference and normalized frequency departure of the UTC(NRLM) against the UTC during 1998.

Mean normalized frequency departure was 2.29×10^{-14} one-year average.
Standard deviation from the UTC frequency was 2.71×10^{-14}.
Standard deviation from mean normalized frequency departure was 1.45×10^{-14}.
Standard deviation of normalized frequency after linear fit was 1.36×10^{-14}.

Annex 3

Sèvres, 21 March 2001

Dear Dr de Jong,

As I have promised when we met at Neuchâtel, I will try to give you an overview of the present situation which may help you and the working group you chair on your discussions on key comparisons in our domain.

Monthly Circular T provides the information on time scales calculated with laboratory data contributions. We receive the following information from labs:

- Clock data
- Link data
- PFS data

On the basis of this data we calculate the differences [UTC – UTC(k)] and [TAI-TA(k)] which are published in tables 1 and 2 of Circular T. Data used in the calculation (clock and link data) have no stated uncertainties up to now.

The evaluation of primary frequency standards leads to the individual values of the fractional deviation of the scale unit of TAI relative to the SI unit (“d”), and from them we perform the BIPM estimation. The uncertainties are given as the combination of four components

- the one taking into account systematic effects (type B)
- the one raised from the PFS instability (type A)
- the uncertainty of the link between the PFS and the lab clock participating in TAI (if it corresponds)
- the uncertainty of the link to TAI

Uncertainties assigned to PFS follow the CCTF recommendations (1999).

Circular T also lists the values of the coefficients to calculate [UTC – GPS time] and [UTC – GLONASS time]. They are respectively derived from [UTC-UTC(OP)] and [UTC(OP)-GPS time], and [UTC-UTC(VSL)] and [UTC(VSL)-GLONASS time]. In both cases a global estimation of the uncertainty of the daily values of the coefficients is given. For each daily value the standard deviation is listed.

This is the situation at present. Let us think now about the key comparisons. From the Mutual Recognition Arrangement (MRA) we can resume that:

The key comparisons have been *chosen to test the principal techniques in each field of metrology*. They also fulfil the other essential function of international comparisons: *to check the estimated accuracy of independent primary realizations of the units of the SI.*

There exist three types of key comparisons:

1. *CIPM key comparisons*: those executed by a Consultative Committee (CC) of the BIPM leading to a key comparison reference value (KCRV);
2. *RMO key comparisons*: those executed by a RMO (Regional Metrologic Organization). Note that only key comparisons carried out by a CC of the CIPM lead to a KCRV. For a key comparison carried out by a RMO the link to the KCRV is obtained by reference to the results from those institutes which have also taken part in the CIPM key comparison;
3. *Supplementary comparisons*: those are carried out by the CC, the RMOs and the BIPM to meet specific needs not covered by the key comparisons, including comparisons to support confidence in calibration and measurement certificates.

For each key comparison the following information is included:

- Individual values for each institute participating in the comparison together with their declared uncertainties;
- The key comparison reference value with its associated uncertainty;
- For each institute, the deviation from the key comparison reference value and the uncertainty in the deviation (at a 95% level of confidence), i.e. its degree of equivalence.
- The degrees of equivalence between the standards of each of the participating institutes.

Considering the objectives of key comparisons, the individual estimations of d could be considered as key comparisons since they serve to check the estimated accuracy of independent primary realizations of the time unit of the SI (?). This is a main point to be discussed within the WG. Which is the role of the BIPM estimation of d? Could it be considered as a KCRV?

Some areas perform CIPM, RMO and supplementary key comparisons, which are included in the key comparisons data base, or in process to be included. Quite often the heads of section meet to exchange their experience concerning this issue, which is rather new for all. Even if we have not yet started with key comparisons in time and frequency, these meetings allow me to gather useful information for the future. Maurice Cox, mathematician and statistician from the NPL is at the BIPM for two weeks; he has a large experience on key comparisons and he could give us some advice. I am trying to fix a date to have a discussion of the physicists of the time section with him, he can perhaps guide us in answering the questions of the previous paragraph. I will let you know the result, since it might contribute to the WG preparation for the CCTF.

With my best regards,
Felicitas Arias

Annex 4

Sèvres, 26 March 2001

Dear Dr de Jong,

This letter complements the one I e-mailed you last week concerning key comparisons. I made clear some points concerning key comparisons reference values (KCRVs) and degrees of equivalence.

- A KCRV can be (a) a value which is calculated from a CIPM key comparison, (b) a value which is adopted. In our case, the second of the SI could be the KCRV (adopted). A KCRV has an associated uncertainty.
- The evaluations of PFS give the deviation *d*, that is the deviation from the KCRV and the uncertainty of the deviation. This is the *degree of equivalence* of each institute.
- There BIPM estimation of *d*, evaluated from the individual PFS estimations. Can it be considered a *degree of equivalence* for the BIPM ? I am not sure, since it is not issued from an individual evaluation as in the laboratories.

I hope that the WG will have an advise on this points.

Best regards,
Felicitas

Annex 5 EUROMET CMC Example

NMI:Example						**Date:dd mm yy**			
Time and frequency									
Calibration or Measurement Service			**Measurand Level or Range**			**Measurement Conditions/Independent Variable**		**Expanded Uncertainty**	
Quantity	Instrument or Artifact	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units
[redacted]	Standard clocks	Time interval meas. relative to UTC(k)	0	1	s	1 PPS pulse amplitude	> 1V (50 Ω)	a	ns
	Standard clocks	Remote time interval meas. via GPS relative to UTC(k)	0	1	s	1 PPS pulse amplitude	> 1V (50 Ω)	a	ns
Time interval	Clocks and pulse generators	Time interval meas.	0	1000 *	s	1 PPS pulse amplitude /trigger error	> 1V(50 Ω)/not include in exp.unc.	**	pS
Time interval	Stopwatches (manually operated)	Time interval generation	1*	86400*	s			**	s
Time interval	Stopwatches (electrically operated)	Time interval generation	$1 \cdot 10^{-5*}$	86400*	s	Input sensitivity	< 1V	**	µs
Frequency	Frequency standards	Direct Measurement Average	1	1	MHz	Averaging Time / Amplitude	1 day >0.5 V	1,00E-07	Hz
Frequency	Frequency standards	Phase/time meas.	1	1	MHz	Meas. Time / Amplitude	1 day >0.5 V	1,00E-07	Hz
Frequency	Frequency standards	Phase/time meas.	5	5	MHz	Averaging Time/ Amplitude	86400 s >0.5 V	1E-13 x freq	Hz
Frequency	Frequency standards	Phase/time meas.	10	10	MHz	Averaging Time/ Amplitude	86400 s >0.5 V	1,00E-13	Hz / Hz
Frequency	Frequency generators	Frequency meas.	0,001*	$1.3 \cdot 10^{9*}$	Hz	Averaging Time/ Amplitude	86400 s >0.05 V	c	Fract.Feq.Dev. * fo
Frequency	Frequency standards	Remote phase/time meas. GPS	*	*	MHz	Averaging Time	86400 s	c	
Frequency	Frequency standards	Remote phase/time meas. TV Link	*	*	MHz	Averaging Time	86400 s	c	