BIH REPORT

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INTRODUCTION

Before describing the BIH activities on the atomic time scales, I will present the new administrative organization which will be effective from 1988 January 1. This re-organization has its roots in an unsatisfactory decision taken at the end of World War I : a short history of the BIH since its conception in 1919 until the splitting in two different services in 1988 will help in the understanding of a necessary evolution.

The BIH current activity of producing the International Atomic Time TAI and the Universal Coordinated Time UTC has been regularly pursued and considerably improved by the availability of the time comparisons using the GPS. In addition, with an improved statute and an increased staff, we were able to undertake experimental tasks in order to reduce the biases of the time comparisons and we plan to intensify this effort.

We will give an overall view of the present performances of TAI and also, by comparison with some national time scales, show some achievements and problems in the realization of time scales.

REORGANIZATION OF THE BIH ACTIVITIES

At the end of 1987, after 68 years of official operation, the Bureau International de l'Heure (BIH) will cease to exist. That does not mean that the services provided by the BIH have become useless and will disappear. On the contrary, the expansion of the BIH tasks has required a different organization, in order to better serve the interests of the users.

The concept of the BIH has been laid down by General Ferrié at the Bureau des Longitudes (Paris) in 1911, when the development of radio time signals made possible and desirable a worldwide unification of time. In October 1912, the representatives of 16 nations proposed the creation of an International Committee for time and of a central bureau, the BIH. Next year was held a diplomatic conference for preparing an intergovernemental time organization, in many respects similar to the organization settled by the meter convention in 1875. However, the first world war 1914-18 did not allow the ratification of the time convention.

In 1919, different views prevailed, and it was found simpler to establish the BIH as a service of the newly formed International Astronomical Union, IAU, and to locate it at the Paris Observatory (where it had already begun to function non-officially). This situation did not change until 1985. Although truly international by its tasks, the BIH was increasingly supported by the Paris Observatory, at a level of more than 90% of its costs in the recent years. The hybrid statute of the BIH has been a constant source of administrative and financial difficulties, the echoes of which being transmitted by the "IAU Transactions". It is a pity that the statute of an an intergovernemental body, with costs shared by the member states,has not been granted.

When the BIH was founded, time was the rotation of the Earth, and it remained so until the development of operational cesium clocks, in 1955. The role of the BIH was to analyze all the astronomical measures of the mean solar time (shifted by 12h in 1925, and designated as the Universal Time, UT) and to issue the best approximation to it. The dissemination of UT was accomplished by publication of the UT time of emission of radio time signals.

However, the increasing precision in this basic activity requested to know the polar motion, and the BIH began in 1956 to derive its own set of coordinates of the pole from the observations. These coordinates became a major product of the BIH. Subsequently, the development of the space geodesy techniques and of very long base line interferometry for measuring the rotation of the Earth, in the 70's, let to consider the problem of the coordinates of the observing stations in a terrestrial reference frame, and the coordinates of the observed object in a celestial reference frame.

On the other hand, the availability of atomic clocks added a new branch of activities, which was to compute an atomic time scale by averaging the data of atomic frequency standards and atomic clocks. In 1971, the BIH atomic time has been promoted to the function of International Atomic Time (TAI) and has gained a large importance in science, technology and public timing.

The tree of figure 1 shows the development of the BIH activities. The domains encompassed by the BIH are exceedingly large, requiring a staff of 16 persons (scientists and technicians), too heavy for, practically, a single national establishment (the Paris Observatory). It was especially difficult for an astronomical observatory with the statutes of an university to guarantee a sufficient input of scientists for the atomic time. A reorganization was needed : it will be completed on the 1st of January 1988 as follows.

(a) A new "International Earth Rotation Service", IERS, (tentative name) created by the IAU and the International Union of Geodesy and Geophysics will replace the Earth's rotation section of the BIH. The IERS will comprise coordinating centers of each observation technique and specific tasks, and a central bureau. It will also deal with the terrestrial and celestial references. The location of the various components of the IERS is not yet known.

(b) The responsibility of the International Atomic Time will be given to the Bureau International des Poids et Mesures, BIPM, where it will get a truly intergovernemental support. In preparation for this transfer, the time section of the BIH has been moved to BIPM in 1985.

(c) The Universal Coordinated Time, UTC, which is TAI corrected for an integral

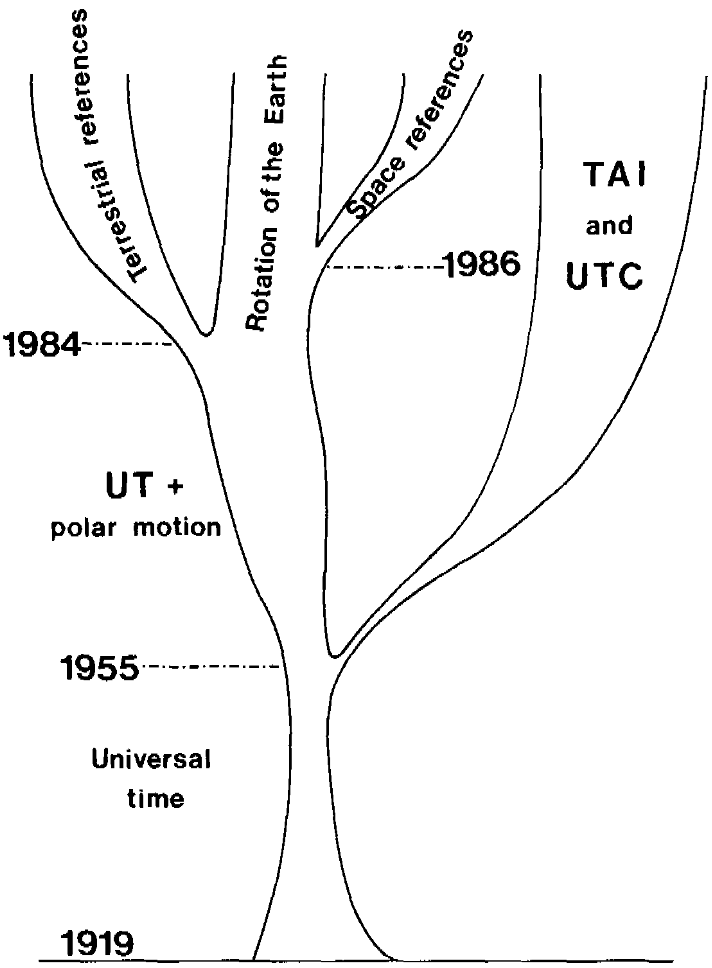

Fig. 1. Evolution of the BIH activities

number of seconds, is of course established together with TAI at BIPM. But the responsibility of deciding and announcing the occurence of leap seconds will be given to the IERS.

Finally, after 77 years, the wish of the BIH founders that the unification ot time be the task of an intergovernemental body will be fulfilled. Practically, the changeover of responsibility implies no changes of scientific policy and the users of the BIH services on atomic time will hardly notice it. However a first consequence of the transfer to BIPM is an increase of the staff and the possibility of undertaking new researches and actions as shown in the followings.

This presentation will be restricted to the present activities of the BIH/BIPM on the atomic time scales.

THE SERVICES PROVIDED BY THE BIH/BIPM.

The BIH/BIPM establishes the time scales TAI and UTC and provides the primary means to disseminate them. Hoping that nobody here has problems in getting the second, I will consider only the decimal part and, therefore TAI and UTC as equivalent.

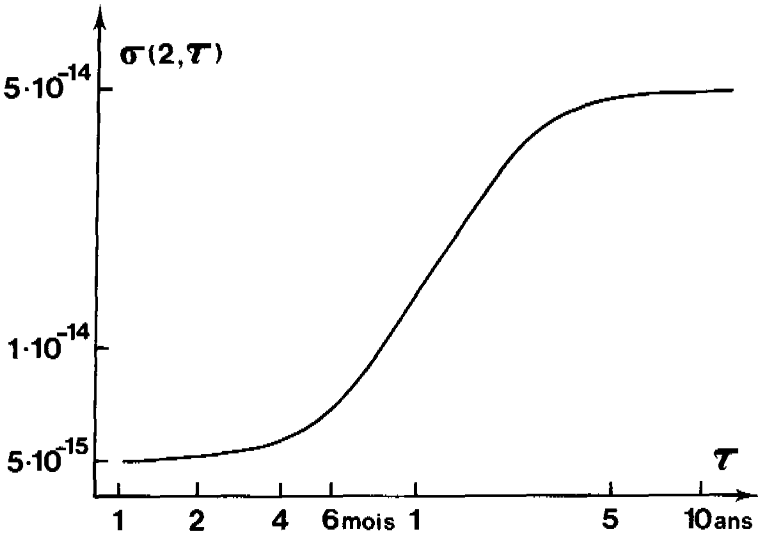

Fig. 2. Frequency stability of TAI

Definition of TAI

TAI is a realized approximation of an ideal time scale, which should be obtained by adding ideal SI second. This definition is complemented to take into account relativistic effects that will not be discussed here, although they matter in practice.

Realization of TAI and UTC

TAI is realized in three steps :

(a) A stability algorithm processes the readings of many atomic clocks, in order to form an average intermediate time scale, with a high reliability. This algorithm emphazises the long term stability (sample time over 2 months).

(b) With the data of the most accurate primary frequency standards, the duration of the second of the intermediate time scale is evaluated.

(c) TAI is derived from the intermediate time scale, using a frequency correction, according to a smooth "steering" process, in order to maintain the conformity of its second with the realization of the SI second by the primary standards. The steering is seldom brought into operation. For instance, since 1984 February 29, there is a constant frequency offset between the intermediate time scale and TAI.

The extent of the participation to TAI evaluation is given by Table I. To my knowledge, all the countries belonging the necessary equipment are members of the TAI club. The most recent recent members are India and Israel.

The frequency stability of TAI supposed as being the output of a fictitious clock is given by figure 2. This evaluation assumes, of course, that the present level of noise of the instruments does not change. It is somewhat hypothetical for τ over 1 year, but shows that the degradation of the stability by random walk frequency noise is limited, on account of the frequency steering.

Table I. Participation to the TAI and UTC evaluation and dissemination in August 1986.

Number of participating clocks	192
including : 175 industrial cesium clocks 6 laboratory primary cesium clocks 11 hydrogen masers	
Number of primary frequency standards	10
Number of participating laboratories	49
Number of participating countries	23
Number of national master clocks for which "TAI - clock" or "UTC - clock" is published	37

The duration of the TAI second seems to be maintained, on averages over at least two months, within the limits of $1 \pm 5 \times 10^{-14}$.

Dissemination of TAI and UTC

The primary dissemination of TAI and UTC is the publication of corrections to be added to the readings of the master clocks of the participating laboratories. These corrections are issued at 10-day intervals in BIH monthly circulars (sent by mail and available in files of the General Electric Mark 3 Service). Their uncertainties are discussed in the following section.

Thus the user who needs to date an event in TAI and UTC with the highest accuracy must first have a time link with the master clock of a national laboratory of the TAI system, then to apply the BIH corrections. Usually, for convenience, these master clocks are maintained close to UTC ($\pm 5 \mu s$, for instance)

The large number of participating laboratories serves several purposes :

- to ensure the viability of TAI and UTC,
- to optimize the stability and accuracy by appropriate statistics,
- to offer numerous possibilities of access to TAI and UTC and therefore to favour the unification of time.

But this organization entirely rests upon the possibility of precise and accurate distant clock comparisons.

THE ROLE OF THE TIME COMPARISONS AT BIH

This role is twofold : in the establishment of TAI/UTC and in its dissemination.

(a) For the statistics in the TAI algorithm, we use frequency samples of the clocks and primary standards. These samples should not be spoiled by the uncertainties of the time comparisons. Fortunately, the required long term stability of TAI makes possible the use of averaging times of one to two months, which reduce to an acceptable level the random noise of the time comparisons, even with the LORAN-C and television methods. On the other hand, a time link which involves an unknown, but constant, delay does not forbid the participation of a clock and of a frequency standard to TAI.

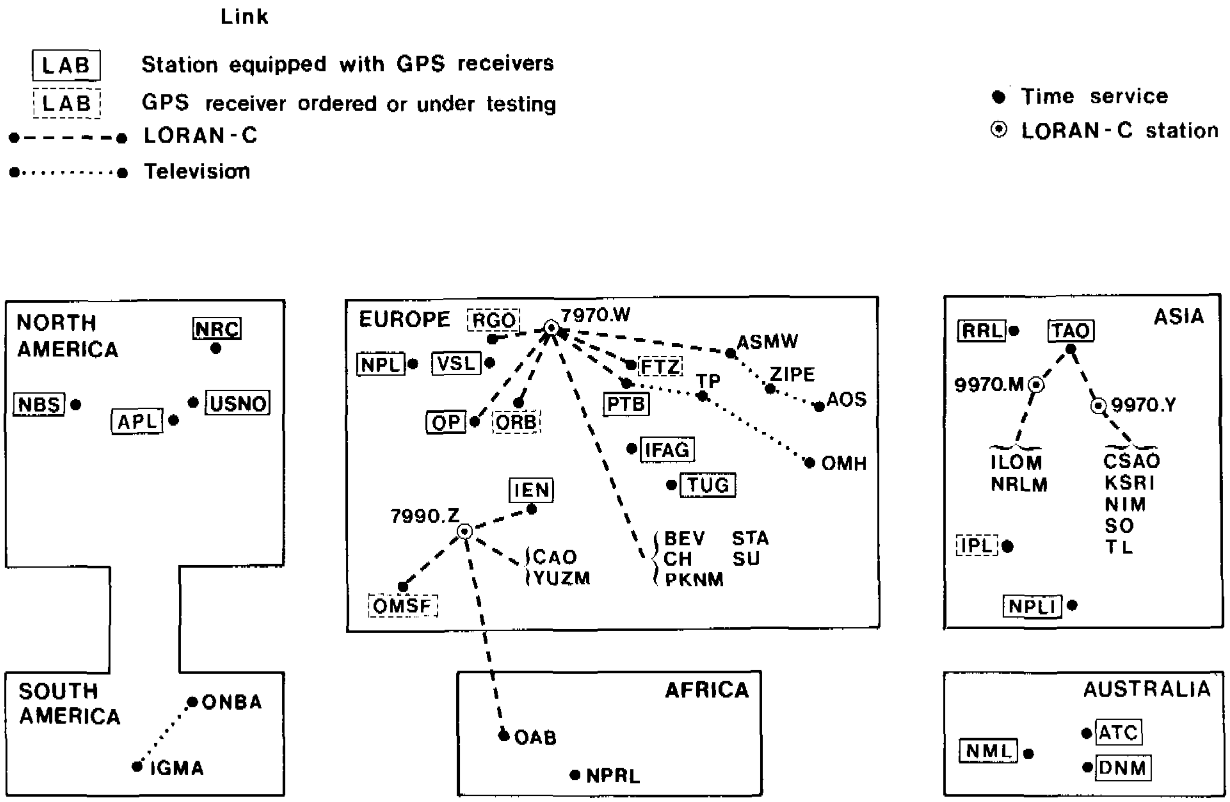

Fig. 3. Time comparison network used by the BIH (Aug. 1986)

(b) As stated before, the primary dissemination of TAI is made by the publication of clock corrections. Let us suppose that the same event is dated by two different master clocks in different laboratories A and B. After adding the TAI clock corrections, the two laboratories should assign the same TAI date to the event. In practice it is not strictly true, and the difference reflects the lack of precision and of accuracy of the time link between A and B. Thus, the precision and accuracy of time comparison impose a limit to the ultimate precision of reading of TAI.

The network of time comparisons used by BIH in August 1986 is shown by figure 3. The GPS is predominant and the LORAN-C is only used for a few regional links, where it can be very good. The comparisons using the public television are still employed in Eastern Europe.

Concerning the GPS, the time comparisons are organized using the common view approach, as suggested by the NBS. One should reach an accuracy of about 10 ns. But it is not realized in practice. The discrepancies are mainly due to wrong corrections for the instrumental delays and cable delays, and also to bad shape of local pulses, errors of the geodetic coordinates of the antennas, etc. In order to reduce these errors, the NBS and the BIH have organized jointly a visit of the US and european laboratories last October, with a portable GPS receiver used as a standard for calibrating the delays. The first results of this joint effort are presented during this PTTI Conference (by Davis, Lewandowski and Weiss). Up to now the NBS has prepared the common view tracking schedule of the

GPS satellites. This responsibility has been transferred to BIH, following the suggestion made by NBS.

Concerning the remaining LORAN-C links, we have brought several improvements : organization of simultaneous receptions of the same emissions, better processing, study of seasonal effects. In some cases we have found that the LORAN-C agrees to ± 35 ns (one sigma) with the GPS, over about 1000 km, on 10-day averages.

As a consequence of the use of GPS and of the improvement of the LORAN-C, the precision of reading of TAI as it is obtained, and as it can be expected after precise calibration is :

	obtained (one sigma)	expected
For GPS equipped laboratories	50 ns	10 ns
For LORAN-C equipped laboratories	150 ns	40 ns

Much accuracy can still be gained. The BIH/BIPM will intensify the efforts in the removal of biases.

TAI AND LOCAL INDEPENDANT ATOMIC TIME SCALES

Eleven laboratories compute atomic time scales, which are independent from each other. It exists :

(a) national time scales, based on the clocks of several laboratories in each country (DDR, France, Switzerland);
(b) laboratory time scales, for laboratories belonging a sufficient number of industrial cesium clocks or hydrogen masers (NBS, RGO, RRL, SO, SU, USNO) ;
(c) scales produced by a single high quality "primary" clock, i.e. a frequency primary standard running continuously as a clock (NRC, PTB).

The purpose of these time scales, usually denoted by TA(lab), where lab is the acronym of the laboratory, is to provide a very stable reference with much shorter delays than TAI.

The comparison of these time scales between themselves and with TAI reveals interesting features and shows the possibilities and the limitations of the atomic time scales. Figure 4 is drawn with real data although I kept anonymity.

The scale TA(lab A) is given by a single primary cesium standard and is practically independent of TAI since it enters in the TAI computations for about 1% of the total weight. One observes

- a mean frequency difference over 2.6 years

$$f\ (TAI) - f\ (TA(lab\ A)) = 3.0 \times 10^{-14}$$

- an annual term with a peak to peak amplitude of about 300 ns.

After removal of the linear and annual term (fig. 5) the agreement of the two time scales is good ; the mean annual frequency difference varying of only 1.3×10^{-14} on the 2.6-year interval. This shows how good a single laboratory cesium clock can be. In addition there are reasons to believe that the annual term is due to the environmental effects on industrial clocks which affects TAI,

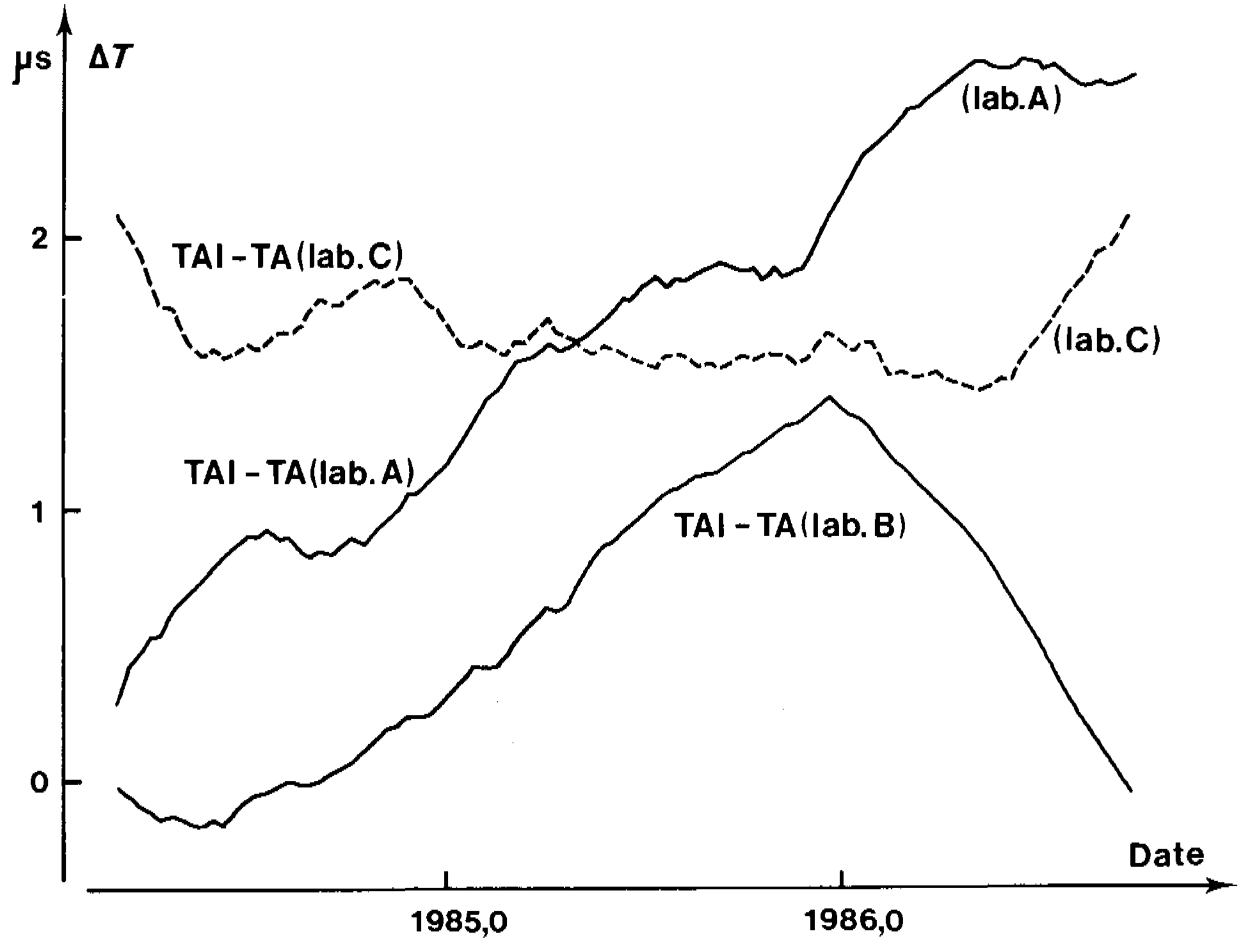

Fig. 4. Comparison of local independent atomic time scales with TAI (see text). The origins of the ΔT are arbitrary.

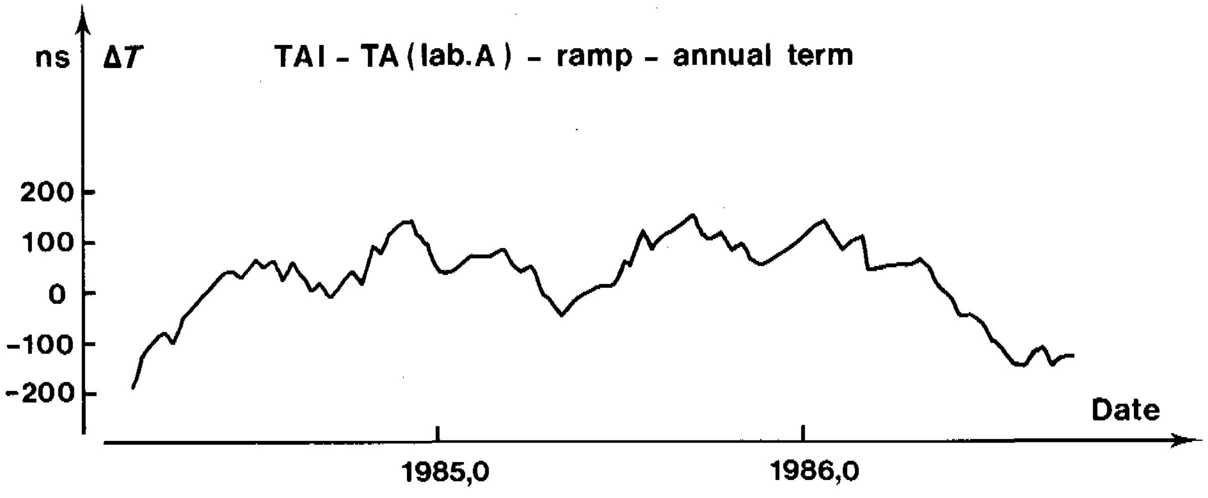

Fig. 5. Comparison of the data of a primary clock (see text) with TAI, after removal of a frequency bias an a periodic annual term.

as well as other time scales based on these instruments.

The time scale TA(lab B) is based on a large number of industrial cesium clocks of a single laboratory. As the frequency accuracy of this scale does not matter, a linear function of time was removed. An interesting feature is the sharp frequency change, by 9.7 x 10^{-14} which occurred between the 20th and the 30th of December 1985. Otherwise, the time scale behave extremely well. This type of accident frequently occurs with time scales which are the output of stability algorithms. The algorithms are optimized for random noise. But real clocks have also non-random frequency variations. The better detection of wrong clock behaviour and subsequent action could be an important factor for the improvement of time scales.

The national time scale TA(lab C) is based on a number of industrial cesium clocks which is about three times smaller than for lab B. In addition it involves distant time comparisons. With respect to lab B, the noise increases noticeably.

This brief comparison of time scales call for additional remarks.

. The fine resolution of GPS time comparison offers new possibilities of a better understanding of the clocks and time scales behaviour.

. We consider now as large disturbances effects which are below 1 x 10^{-13} in relative frequency.

. When the utmost long term stability and accuracy is needed, for instance for the studies of the pulsar timing, it might be interesting to test various time scales : TAI and national time scales ; this is made possible by the publication by the BIH of the differences TAI - TA(lab). It should be possible also to build in retrospect an improved time scale, after correction of defects which were not noticed in the quasi-real time production of time scales.

ACKNOWLEDGEMENTS

The BIH/BIPM work continues with the help of all the laboratories which generously contribute data, and provide many facilities. We express our thanks to them.

ACRONYMS OF THE LABORATORIES IN THIS TEXT

NBS	National Bureau of Standards, Boulder, USA
NRC	National Research Council, Ottawa, Canada
RGO	Royal Greenwich Observatory, Herstmonceux, U.K.
RRL	Radio Research Laboratory, Tokyo, Japan
SO	Shanghaï Observatory, People's Republic of China
SU	Gosstandart, Moscou, USSR
USNO	US Naval Observatory, Washington, USA.