# THE BUREAU INTERNATIONAL DE L'HEURE

Humphry M. Smith, Chairman, Directing Board

Differences of longitude between observatories, hitherto restricted to rare exercises involving transport of chronometers, became practicable in the mid-1840's with the spread of the electric telegraph system, but a new era of international co-operation resulted from the successful pioneer experiments early in 1899 when radio signals from Dover, England, were received across the Channel at Boulogne, France. (1) It was soon realised that radio signals could be used, not only for the determination of longitude, but also for the dissemination of time. In September 1903 the U.S. Navy began short-range low-power transmissions from Navesink, New Jersey, (2) and in January 1905 inaugurated regular broadcasts at midday.(3) Experimental services commenced in Germany (Norddeich) in 1907 and in June 1910 details of a regular service were announced officially by the Reichs-Marine-Amts. In France the Bureau des Longitudes resolved in 1908 "that a service of time signals be installed as soon as possible at the Eiffel Tower as an experimental service for the determination of longitudes", and work started in January 1910. It was interrupted when some equipment was put out of action by the flooding of the Seine, and a regular service from the new installation commenced officially on 23 May 1910 "as much in respect of time as in the determination of longitudes". (4)

It is surely appropriate to commend the perspicacity of the Bureau des Longitudes in realizing that positive action should be taken to rationalize radio time signal emissions on a world-wide basis, and to acknowledge their initiative in arranging a conference in Paris in October 1912 "to study ways of effecting practical unification of time, and to prepare a plan for the organization of an international time service able to meet all needs". (5) Sixteen nations were represented, and following lengthy discussions, proposed the establishment of a "Commission International de l'Heure" to secure unification of radio time signals; to ensure the universal use of GMT; to create an executive organization, the Bureau International de l'Heure (BIH) in Paris, with the task of co-ordinating results from observatories and to deduce the most exact time. Discussion of the results was to be undertaken by the Association géodesique internationale at Potsdam.

At a further meeting held the following year, (6) formal statutes of the organization, renamed the Association International de l'Heure, were drawn up, (7) but were never ratified owing to the outbreak of war in Europe in 1914. Despite many difficulties, the BIH continued to operate, under the direction of B. Baillaud, with the invaluable support of General Ferrié. In 1918 the Royal Society in London called an Inter-Allies Conference of Scientific Academies for the reconstitution of the international scientific organizations which had existed pre-war. It was proposed to form national committees which would be federated in an international council. At a further session, held in Paris later the same year, an executive committee was formed, and at a third session in Brussels in July 1919, formal statutes were adopted. One result was the creation of the International Astronomical Union (IAU), which included in its 32 commissions, number 31, the Commission de l'Heure. (8) The original statutes were taken as a model, and new regulations were drawn up to bring the Time Commission and the BIH under the auspices of the IAU. (9) It was pointed out, however, that the 1913 conference "included only 15 astronomers out of 54 delegates, the remainder being administrators, technicians and others. Consequently the authority of the Commission is more limited". Under the IAU, the field of activity was restricted to astronomical affairs, and ... "it is not in a position to give authoritative opinion upon matters of administrative convenience of different States, as to the needs of seafarers or on technical questions of electrical engineering ..." (10). It was probably a remanent effect of this attitude which subsequently led such organizations as the International Radio Scientific Union (URSI) and the International Radio Consultative Committee (CCIR) to take the initiative in questions involving radio time signal emissions.

When B. Baillaud became President of the Union, G. Bigourdan was appointed Director of the BIH (1 January 1920 until 31 December 1928). From 1929 to 1965, the Director of the Paris Observatory was "ex officio" Director of the BIH, and a "Chef des Services" was appointed.

| | Director | Chef des Services |
|---|---|---|
| Jan. 1929 - Oct. 1929 | H. Deslandres | A Lambert |
| Oct. 1929 - 1944 | E Esclangon | " " |
| 1945 - Sept. 1963 | A Danjon | N Stoyko |
| Oct. 1963 - Sep. 1964 | F Denisse | " " |
| Oct. 1964 - 1965 | " " | B Guinot |

In addition to correlating data on astronomical observations of time, and on radio time signals, the BIH sponsored an international longitude operation in 1926, followed by a further programme seven years later. The results were published: (11) Some anomalous values were revised, and international co-operation was facilitated. In 1937 combined BIH data were employed in the determination of the seasonal fluctuation in the rotation of the Earth; (12) the amplitude obtained was less than had been deduced earlier, (13) although subsequent investigations gave an even smaller value. (14) Other research carried out at the BIH was concerned with geophysical phenomena.

At the International Telecommunication and Radio Conferences, Atlantic City, 1947 (15) a series of frequencies was allocated for standard frequency services, and in Appendix B of the associated Radio Regulations the International Telecommunication Union (ITU) expressed the opinion that:- "The addition of time signals superimposed on these same broadcasts is also highly useful and should be included, if possible." (16) Among the proposals submitted to Study Group 3 (SG3) of the CCIR for consideration at the meeting in Stockholm in 1948 was a draft recommendation implementing the Atlantic City initiative, (17) and incorporating representations by the French administration that "The co-ordination of time signals falls within the competence of the International Committee for Time; The determination of Universal Time ... falls within the competence of the International Committee for Time... the organization in charge of international co-ordination of standard frequency transmissions can only be the CCIR or a special subcommittee constituted by the CCIR." (18) The adopted Recommendation No 18 specifically requires (para 12) "that Study Group No 7" (which took over these responsibilities from SG/3) "seek the co-operation of the International Committee of Time in the provision of the time service". (19)

At the Royal Greenwich Observatory, (RGO), the astronomical observations of time had been corrected for the effects of polar variation since 1948, and for the seasonal fluctuation since October 1949, thus providing a quasi-smooth time system "Provisional Uniform Time" (PUT). (20) By 1955 the BIH found that four independent systems of correction had come into use among participating observatories, and the resultant problems were discussed by the IAU in 1955, (21). Following subsequent correspondence, a report was prepared by N. Stoyko (Chef des Services, BIH), in October 1955 setting out the plans for the introduction of UT0, UT1 and UT2, and for the inauguration of the Service International Rapide des Latitudes (SIR) to compute current extrapolations of the polar motion to be used in the formation of UT1. Initially the SIR was located in Turin, but this led to some delays and the work was undertaken at the BIH. The number of stations furnishing data increased from 4 (1956) to 33 (1965). (22)

Another significant innovation took place in 1955. Following development work in the United States, where the National Bureau of Standards had built an ammonia molecular clock in 1948, (23) and caesium beam standards had been constructed, (24) - in one case running for six weeks in 1954 with an accuracy of $\pm 1$ in $10^9$, L. Essen and J. Parry at the National Physical Laboratory (NPL) brought an atomic standard into regular use in 1955. The caesium transition frequency was determined as 9 192 631 830 $\pm$ 10 in terms of PUT. (25) The atomic standard was then used for the calibration of quartz clocks employed in the formation of the Greenwich Atomic Time scale (GA). The data were also made available to the BIH where A and N Stoyko determined the progressive retardation in the rate of rotation of the Earth. (26) Measures made with the NPL standard were then compared with data from the US Naval Observatory over the period 1955 - 1958, and the caesium frequency in terms of the second of ephemeris time furnished the now-familiar figure of 9 192 631 770. The BIH atomic time scale A3, with initial epoch 1955, based on the results from three independent standards, NPL (England); Neuchâtel (Switzerland); NBS (USA) was formed from 1 January 1958 (20 h UT) using phase comparisons on VLF and LF. (28,29) This continued until near the end of 1968, when a few participating establishments started regular reception of the pulses of the Loran-C navigation system, and direct time comparisons became feasible.

A further significant advance arose from the pilot scheme for international co-operation which was inaugurated between the USA and UK on 1 January 1961. (30) In this scheme the radio time signals followed the uniform rate of Atomic Time, AT, but since the scale interval of AT had been chosen to conform to that of ET, it was necessary to apply an extrapolated frequency offset, reassessed annually to maintain approximate agreement with Earth rotational time, UT. If an excessive departure developed owing to an unforeseen change in the rate of rotation of the Earth, a step adjustment was applied to the radio signals. The principle of maintaining a constant rate, with step adjustments, had been in use in the UK since 1944, and had become more effective with the introduction of atomic standards. The USA/UK co-ordination operated through the informal mutual agreement of the observatories concerned, but other authorities found it advantageous to synchronize with the USA/UK system. Following discussions at the IAU in 1961 (31) the CCIR recommended in 1963 that all time signal emissions should conform to the co-ordinated system, (now designated UTC), and that the BIH should undertake the responsibility of promulgating the frequency offsets (in units of 50 parts in $10^{10}$) and the dates and times of step adjustments (in units of 0.1 s). (32) This action was confirmed by the IAU in 1964. (33).

It is perhaps fitting at this stage to pay tribute to the work of N. Stoyko, who joined the BIH 1 November 1924, and carried on the work after the arrest of A. Lambert 21 August 1943 (died in Germany 15 August 1944). Confirmation of his position as Chef des Services was granted in 1945, and he served with distinction in this capacity for nearly twenty years. It was with a real sense of personal loss that we heard of his death on 14 September 1976.

In 1965 the BIH was reorganized in order to conform with the statutes of the Federation of Astronomical and Geophysical Services. The Director of the Paris Observatory was no longer the ex-officio Director of the BIH, and B. Guinot became Director of the BIH. A Directing Board was formed, with two representatives of the IAU, one each from the IUGG and URSI, and an observer from CCIR: the Director BIH was also a member ex officio. (34) In the past, much of the work of the BIH had consisted of publishing extensive tables of times of reception of an ever-increasing number of radio time signals. Due to difficulties in ensuring prompt receipt of data from some observatories, the definitive results only became available many months in arrear. With most authorities maintaining closer controls and conforming to the co-ordinated system, individual reception times were now of less interest. Other changes were seen to be advantageous, and the various publications were rationalized and a much accelerated publishing schedule was introduced. Operational procedures were modernised, and greater use made of computer techniques.

By 1968 considerable dissatisfaction was being expressed concerning the frequency offset, which caused the intervals between successive time signal pulses to depart from the second; moreover some world-wide radio navigation and communication systems experienced great practical difficulties in making simultaneous adjustments to the adopted frequency offset. The CCIR set up an International Working Party, IWP 7/1, to explore the possibility of eliminating the offset and making one-second step adjustments (the latter generally involved no physical readjustment, but could be applied arithmetically.) (35) In view of the wide repercussions of the proposed changes, efforts were made to publicise the conflicting requirements and to invite opinions on possible solutions (36).

In 1969 the Loran-C radio-navigation chains made practicable time comparisons between observatories on a regular basis to a higher accuracy than had been possible using VLF and LF phase measures. The former BIH scale of atomic time A3 was succeeded by TA (BIH), formed from the seven independent scales of the Physicalisch-Technische Bundesanstalt (PTB); US Naval Observatory (USNO); TA (F), a mean of the standards at three French establishments; Royal Greenwich Observatory (RGO); National Research Council (of Canada) (NRC); US National Bureau of Standards (NBS); Observatory of Neuchâtel (ON), all being linked through the Loran-C network. (37)

A recommendation of CCIR Study Group 7 in 1969, endorsed by the Plenary Assembly in 1970, (38) proposed the removal of the inconvenient offset from the co-ordinated radio time signals and, with the concurrence of the International Marine Consultative Organisation (IMCO) (38a), to substitute one-second step adjustments. Details were specified in Recommendation 517, (39) and the new UTC system was brought into operation by the BIH following an initial adjustment on 1 January 1972.

In the process of introducing new international units as the basis for measurements, the International Committee of Weights and Measures (CIPM) was concerned by the unsatisfactory situation in which one of the basic units, the second, was defined as a specified fraction of a time interval, the day, which was known to be variable in length. In 1956 there was little choice: atomic standards of frequency (and time interval) were rare and might still be regarded as unproven; the only alternative unit was the second of ephemeris time (ET) which, by definition, is invariable. (40) It was soon realised that the choice was an unfortunate one, as ET can only be determined in arrear, and then only with insufficient accuracy for most modern needs. By 1964 it was realised that atomic standards could be used to make the ET second accessible. (41) Because of its convenience and superior accuracy, the atomic definition of the second was formally adopted in 1968. (42) The next task was to define and to maintain an international reference scale of time, so the CIPM recalled their consultative committee (CCDS) to examine the problems and make recommendations. The CCDS had little hesitation in proposing that the exist-scale of the BIH should be accorded formal recognition, (43) despite the fact that the BIH is a service of FAGS (and thus indirectly under the auspices of the International Council of Scientific Unions (ICSU) whereas the CIPM is an inter-Governmental organization. The 14th General Conference of Weights and Measures endorsed this arrangement; (44) a representative of the CIPM was invited to assist the Directing Board of the BIH, and a member of the staff of the International Bureau of Weights and Measures has been attached to the BIH to participate in the additional tasks involved. Discussions continue in the CCIR concerning the UTC system of radio time signals (particularly on time codes) (45) and in the CCDS (particularly on the national legal implications of the use of UTC). (46) In addition, these organizations, together with the IAU and other interested parties, are concerned with the manner in which the conflicting requirements of stability, and conformity of the scale unit with the consensus of primary laboratory standards, can be best resolved.

Among the important advances that have been made under the Direction of B. Guinot, the first concerns the international scale of atomic time, now designated by the language-independent acronym TAI. Because of (a) some doubt as to the strict independence of the seven constituent atomic scales, which vitiated statistical methods for the combination of data, and (b) the desire to include information from the maximum number of establishments possessing atomic clocks and adequate means for comparing them internationally, since August 1973 participants have communicated data from individual clocks. An algorithm (47) in which the clocks are objectively weighted according to their recent performance, has been devised, and is now being modified to take account of the measures made at the three standards laboratories:- PTB; NRC and NBS. A step adjustment in frequency (rate) is scheduled for 1 January 1977, and a modified algorithm will seek to achieve stability of rate while maintaining the time interval of TAI (and of UTC) in accord with the consensus of the determinations of the primary laboratory standards.

Another advance has been made in the formation of the BIH definitive scale of UT1. An improved impersonal method of weighting the astronomical observations was introduced in 1971 resulting in a significant enhancement of accuracy. (48). In order to meet the special needs of the space programme in the navigation of deep-space probes, a rapid service was inaugurated: each collaborating observatory reduced the observations quickly and communicated the results to the BIH by radio or Telex. The data were correlated and communicated to the Jet Propulsion Laboratory with minimum delay. The success of the programme (which was carried out with financial assistance from NASA), permitted trajectory correction manoeuvres (reported by letter Fliegel, JPL, to Guinot, BIH, 9 April 1974) as follows:- "Mariner 10 encountered Mercury within 60 km of the predicted aiming point, with the most accurately determined orbit achieved so far .... Improvement in JPL operations since the inception of the BIH Rapid Service has been dramatic. Uncertainties in UT1 are no longer considered to be a dominant source of error in navigation ..."

A notable contribution to astronomical and geophysical research in recent years has been the availability in machine-readable form of the collated observational data received from all participating organizations. It is unfortunate that this facility is not widely known, and that some research has been carried out using unsuitable data. In all applications where errors associated with a particular station might be significant, the BIH data should be employed. It was with the aid of such material that it was demonstrated that tidal waves and the diurnal nutation significantly increased the scatter of astronomical observations of time: the appropriate corrections were tabulated in the BIH Annual Report for 1971. (49)

In 1972 the published values of the coordinates of the pole incorporated data supplied by the Dahlgren Polar Monitoring Service (DPMS) of the US Naval Weapons Laboratory and based on Doppler satellite observations. (50).

The many developments of the past 15 years, and particularly the added responsibilities of the BIH for the reference scale of atomic time, were considered by the IAU in 1976, and new terms of reference have been recommended. (See Appendix A).

It will be apparent that under a succession of devoted Directors the BIH has amply fulfilled the hopes of the farsighted scientists who were responsible for its foundation in 1912/1913. The emergence of newer techniques of radio astronomy, laser tracking, VLBI and Doppler ranging of artificial satellites confirm the belief that further progress may be anticipated with confidence, and that the Bureau is held in the highest esteem and merits continued support, both scientific and financial.

## APPENDIX A

Revised terms of Reference of BIH
Adopted by IAU General Assembly 2 September 1976

The functions of the BIH shall be

(a) to establish the scale of the International Atomic Time TAI, in accordance with the decisions of the 14th Conférence Générale des Poids et Mesures and in conjunction with the Bureau International des Poids et Measures;
(b) to establish, from all relevant data, and to publish the current values of the Universal Time and of the angular velocity of the Earth's rotation and, in addition, the operational coordinates of the pole used for this purpose;
(c) to implement the system of the Coordinated Universal Time UTC by the distribution of all necessary information for the coordination of time-signal emissions and the synchronization of clocks on the UTC scale;
(d) to distribute information important for scientific users of time, and to supply on request the available data on the subject of time;
(e) to perform scientific research as necessary for the improvement of the service.

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