U. S. NAVAL OBSERVATORY
WASHINGTON, D. C. 20390

62L
2400
Ser 910
17 Jul 1969

From: Superintendent, U. S. Naval Observatory
To: Distribution List

Subj: DoD Precise Time and Time Interval (PTTI) Conference; report on

Ref: (a) DoD Instruction 4630.4 of 22 Jun 1966
(b) NAVOBSY ltr 62 2400 ser 355 of 20 Mar 1969

Encl: (1) Conference Report
(2) List of Attendees

1. Reference (a) authorized the U. S. Naval Observatory to conduct a conference for Precise Time and Time Interval (PTTI) requirements. Reference (b) announced the convening of subject conference. The conference was convened and adjourned on 28 April 1969.

2. Enclosure (1) [with attachments 1-4] and enclosure (2) forward and provide the pertinent data discussed at the conference.

3. It is requested that comments and recommendations on the information contained in enclosure (1) be submitted to the Superintendent (Attn: PTTI Operations Officer), U. S. Naval Observatory, Washington, D.C. 20390.

J. Maury Werth

J. MAURY WERTH

Distribution List:
All Conference Attendees [encl (2)]

REPORT ON
PTTI CONFERENCE

U. S. Naval Observatory
28 April 1969

I. Captain J. Maury Werth, USN, Superintendent of the U. S. Naval Observatory, opened the meeting with a welcome and explanation of the purpose of the conference to the attendees [Attachment (1)].

II. The technical program convened with a talk by Dr. G. M. R. Winkler, Director, Time Service Division, U. S. Naval Observatory, on "Present and Future Time Synchronization Methods" [Attachment (2)].

Messrs. P. F. MacDoran and F. Borncamp of the Jet Propulsion Laboratory, Pasadena, California, continued the session with discussions on "Precise Time and Frequency Requirements for the Deep Space Network" [Attachment (3)].

Mr. L. N. Bodily, representing the Hewlett-Packard Company, Palo Alto, California, spoke on the maintenance problems existing with cesium beam standards [Attachment (4)].

III. Concepts:

The Naval Observatory submitted to the attendees for comments, a plan wherein the Naval Observatory would be:

a. A central source for pooling PTTI synchronization clock trips to effect economy.

b. Responsible for the standardization of PTTI techniques and procedures.

c. A central source for PTTI problems and advice.

d. Responsible for the establishment of Time Reference Substations.

A central source for coordinating all agencies' clock trips was suggested to avoid two or more teams visiting the same area at approximately the same time. In coordinating visits, one team could perform a commitment for another agency, deleting a separate requirement, and effecting a cost reduction in travel and per diem. To accomplish a satisfactory coordination program, a standard method for time transfers and phase measurements must be performed by all clock teams. A procedure of this nature was submitted to the attendees for their comments [NAVOBSY ltr 62 2400 Ser 550 of 24 Apr 1969 (copies provided to all addressees during conference)].

Encl (1) to NAVOBSY ltr 62L
2400 Ser 910 of 17 Jul 1969

As demands increase for atomic standards and clocks, so do the problems. The Naval Observatory is in the best position to assist and to provide advice to users and potential users. It was recommended that organizations having experiences or problems contact the Time Service Division, U. S. Naval Observatory.

The Naval Observatory will establish Time Reference Substations in various countries, certifying their accuracy by performing frequent clock visits. These substations could be visited by local or visiting agencies requiring their services.

During the conference a survey was performed to determine from the attendees their precise time requirements. The results were:

Number of Organizations	Accuracy
2	milliseconds
1	400.0 μsec
2	100.0 μsec
2	50.0 μsec
1	25.0 μsec
3	10.0 μsec
4	5.0 μsec
11	1.0 μsec
1	0.2 μsec
1	10.0 nanosec

IV. A training program sponsored by the U. S. Naval Observatory was scheduled at the Hewlett-Packard Company, Rockville, Maryland, 9-13 June. The course will cover theory and application, and checkout and maintenance of cesium beam standards and clocks. Applications will be accepted from all organizations requiring such training.

Courses of instruction in LORAN-C monitoring techniques are being planned and will be conducted at the Naval Observatory in the near future. Personnel interested should contact the Time Service Division, U.S. Naval Observatory.

V. The meeting adjourned with the conference objective and milestones listed as:

a. Closer coordination between user agencies and the Naval Observatory on time synchronization related matters.

b. A central source for coordination of clock trips.

c. Annual conference on updating of requirements.

PTTI CONFERENCE
U. S. Naval Observatory
28 April 1969

ATTENDEE LIST

JCS

LTC F. L. Jensen
CAPT C. E. Rich, USN

AFCRL

CAPT D. G. Abby
MAJ J. A. Cook

AFTAC

CAPT R. M. Couch
CAPT W. J. S. McGuire
L. H. Shennill

AGMC

J. F. Barnaba
T. Howell

HQ MAC

CAPT L. D. Beers

USAECOM

T. J. Kesolits

USASCA

S. Pomerantz

USATOPOCOM

Wm. Allen
Dr. A. A. Baldini
R. A. Gouker
J. D. Love
H. E. Petry
Dr. F. W. Rohde

WSMR

J. Giacomo
E. Grant

OPNAV

M. Morelli
CDR E. F. Stacy

NAVASTROGRU

P. J. Norton
R. R. Smith

COMNAVCOMM

LT C. R. Craver

NAVELECSYSCOM

LCDR G. P. Asche
T. Lieberman

NAVOBSY

H. N. Acrivos
LCDR B. M. Atwood
R. M. Boyd
Dr. R. G. Hall
J. D. Lavanceau
J. O. McNeece
K. Putkovich
Dr. K. A. Strand

NRL

J. A. Bowman
V. R. Gayler
R. R. Stone, Jr.

HQ USMC

MAJ T. J. Cronin, Jr.
MAJ G. S. Prescott

FAA

J. L. Brennan
R. M. Buck

USCG

LT C. E. Potts
R. Sponar

USC&GS

W. J. Blackburn

NASA

A. R. Chi
H. S. Fosque
D. Kaufmann
G. S. Rall
F. Stetina

NBS

J. Jespersen

EG&G, Inc.

J. Rennie

HP

L. N. Bodily
R. W. Cornes

JHU/APL

C. A. Dunnell
B. W. Shaw
P. E. P. White

JPL

F. Borncamp
P. F. MacDoran

Western Electric

B. E. Porter

Encl (2) to NAVOBSY ltr 62L
2400 Ser 910 of 17 Jul 1969

PTTI CONFERENCE
U. S. Naval Observatory
28 April 1969

INTRODUCTION AND WELCOME
by
Captain J. Maury Werth

Welcome, gentlemen, to the U. S. Naval Observatory.

I am Captain Werth, Superintendent of the Observatory. It is gratifying to see so many of you here today. The facilities of the Naval Observatory are at your disposal--and we hope that you can go back to your offices with a feeling that the time was well spent.

In February 1965, the Department of Defense delegated sole management and control responsibility to the U. S. Naval Observatory for Precise Time and Time Interval (known to most of you as PTTI). The scope of the Naval Observatory's operations were thereby enlarged from a supporting service for the Navy to a role as single manager for PTTI within the Department of Defense, and for its components and contractors. In June 1965, the Secretary of the Navy directed the Observatory to maintain adequate facilities to carry out its assigned responsibilities. By the first part of 1966, the Observatory had its Precise Time Synchronization Service in operation as one means of insuring worldwide uniformity in precise operational timing functions.

This conference is the first of what we hope will be a series of conferences of this nature. They will be designed to reveal if we are meeting all of the requirements and to determine what we can do better than we are doing now. Today--we would like to cover four general areas:

1. To establish a sound working relationship between the Naval Observatory and each DoD component, contractor, and other interested agencies.

2. Review existing PTTI requirements and examine possible future requirements. This step should enable us to establish the overall needs of the DoD and to be able to formulate the means for strong support services more economically. This is important in light of the ever-increasing budget reduction programs affecting all of our organizations.

3. To provide advice and guidance to all PTTI users.

Attachment (1)

4. To promote and establish the means for maintaining operational uniformity of PTTI functions.

This is a large order of business.....but, we believe that this is the beginning of a program that will benefit all concerned.

Now, may I introduce our PTTI Operations Officer, Mr. Harold Acrivos. He will fill you in on the details----and will be your Naval Observatory contact in all matters relating to Precise Time and Time Interval in the future.

PTTI CONFERENCE
U. S. Naval Observatory
28 April 1969

Summary of Comments
by
G. M. R. Winkler

on
PRESENT AND FUTURE
TIME SYNCHRONIZATION METHODS

1. Our operational requirements exist in three main areas:

Clock time (UTC)

Synchronization

Astronomical time (UT).

2. Specifications of Clocks (fundamental terms):

a. Accuracy refers to a statistical measure (rms value, 1 sigma) of agreement of the output frequencies of a sample of frequency standards with the frequency of the standard clock time scales of the U. S. Naval Observatory.

b. Stability is the statistical measure (1 sigma) of frequency deviations from the standards average frequency under specified conditions of operations.

c. Resettability or reproducibility is a measure of precision of controls and prescribed adjustments after the standards have been turned off.

3. Performance of Modern Clocks:

A simple statistical model cannot do complete justice to requirements of planning for practical deployment of clocks. Another much simplified description could be as follows for cesium beam clocks: Phase deviations occur randomly around a rather uniform performance which will last from a few days to 100 days in the best case. The increasing age of beam tubes will be reflected in a gradual increase of these (phase) fluctuations. They range from 10 nanoseconds (1 sigma per day) up to several hundred nanoseconds. The uniform performance is interrupted by irreversible changes in average frequency which may amount to up to 4×10^{-12} (for the

HP 5061). In all cases which were investigated at the Naval Observatory the effective "C" field had changed. Frequent adjustments and changes affecting the standards will increase the probability of such "permanent" frequency changes.

For all practicable purposes, the cesium beam clock is the only clock readily available with a performance allowing a sub-microsecond synchronization under operational conditions. Data on the performance of portable clocks, together with experience in the operation of cesium beam clocks in the laboratory, indicate that it is entirely sufficient to synchronize once per week in order to maintain such microsecond internal system synchronization. The data which proved that this is possible are: (a) the RMS closure errors of the U. S. Naval Observatory's four portable clocks in more than 30 trips of 20 to 30 days' duration (one microsecond); and, (b) the range of RMS deviations from a linear performance of the U. S. Naval Observatory's cesium beam clocks (between 55 nanoseconds to one microsecond RMS for a 100-day interval with a daily sampling). In order to provide sufficient reliability, a minimum redundancy of 3 to 4 clocks in a timing center is necessary. At the same time, this redundancy will invariably improve the available precision by revealing sudden frequency changes of any one standard.

The question of averaging of phase and frequency in an automatic combiner versus computer evaluation of independently running clocks must be decided individually according to requirements. Most applications in conjunction with an existing computer will be better off by having the computer average and monitor the individually operating clocks. On the other hand, in the absence of such a computer, operational convenience may dictate the use of an additional phase combiner.

4. Cost Effectiveness of Precision Clocks:

A Cost Effectiveness (CE) figure can be derived roughly by taking into account relative estimates of performance, cost, etc.

For example:

CE Elements	Hydrogen Maser	Cesium Beam	Rubidium Vapor Cell	Quartz Crystal
Cost Initial	5.00	1	0.5	0.10
Support	10.00	1	0.5	0.10
Stability	10.00	1	0.1	0.01
Reliability	0.20	1	1.0	10.00
$CE = \frac{Rel \times Stab}{Cost \times Supt}$	0.04	1	0.4	10.00

This must be extended according to application to include further elements as weight, power consumption, volume, environmental sensitivity (H-maser is about 40 times more sensitive to magnetic field changes than is CS, the quartz crystal sensitivity is zero), temperature coefficient, pressure coefficient (altitude), etc.

5. International Aspects of Clock Time Scales:

Improved international cooperation, centrally coordinated by the Bureau International de l'Heure (B.I.H.) is being promoted at the present time. A considerable improvement in the operations of the coordinated clock time scale, UTC, will be necessary for the realization of precision sub-microsecond worldwide timing. Steps for such an improvement on an international basis have been taken (CCIR Interim Meeting Document No. 70). Our proposal calls for the abolishment of frequency offsets and for steps of 1 second in the future UTC system. The navigators are not prepared to accept this as yet.

6. Time Distribution Policy:

It is necessary to review basic principles and concepts, to establish values and to scrutinize goals in order to evaluate the many possibilities which exist or have been proposed for long distance synchronization. Should there be one single time reference or several independent systems? Today one single reference is the only feasible approach from a purely economical point of view.

However, cost versus redundancy and the status of a proposed method in the research and development cycle are additional important points. Up to now, precision timing has been provided (with the notable exception of WWV) as a piggyback operation superimposed as a secondary mission to navigation and communication services. I believe that this principle of economy is still far from being exhausted.

This method of using electronic navigation services is also the only method which allows timing of moving clocks economically and silently.

Our general principle in timing must be to operate major systems and timing centers (Time Reference Substations) in a well coordinated way but still sufficiently independent so that they can survive a complete loss of communications and control for a considerable time without excessive systems degradation.

The Naval Observatory maintains excellent international relations with many timing centers. It is requested, however, to visit these, and particularly the Paris Observatory, only in emergencies.

7. Distribution Systems:

a. LORAN-C. All chains will be equipped with Cs beam clocks. 1 pps identification from (synchronized) master stations can be used with extremely simple equipment. Antenna delay deserves more attention for timing than has been necessary up to now. Cycle identification is the only real problem--also in very great distance skywave applications (6,000 Mi).

b. OMEGA. The Omega system will become operational by 1972 and will be capable of disseminating clock time with a precision of approximately 1 μs (computer-receivers). Less sophisticated users will obtain timing to 5 μs in the absence of major ionospheric disturbances (all daylight path).

c. Fly-over. In the interest of early standardization the Naval Observatory needs to know how many ground stations may become necessary. One obstacle has been cleared--frequency allocation.

8. The U. S. Naval Observatory must be kept informed of requirements and R&D efforts. Only in this way can we function as the central focal point of activities.

PTTI CONFERENCE
U. S. Naval Observatory
28 April 1969

Summary of Comments
by
L. N. Bodily
Hewlett-Packard Company

on
MAINTENANCE PROBLEMS EXISTING WITH THE CESIUM BEAM STANDARDS

Cesium beam standard operation, performance characteristics, reliability and maintenance were briefly discussed.

Possible end-of-life mechanisms for the cesium beam tube were outlined and discussed:

1) Cesium source depletion--present tubes have adequate supply for in excess of five years operation;

2) Vacuum pump failure--this is an infrequent catestrophic type failure and results in tube pressure rise and resultant beam scattering;

3) Saturation of cesium getters--this gives rise to secondary cesium emission which results in a degraded signal-to-noise performance.

End of life is indicated when the desired signal output is less than that necessary to maintain lock with the electronics or when the signal-to-background ratio degrades to less than 1:1. Periodic measurement of signal to background is the most reliable method to determine tube performance.

Present field performance data indicate cesium tube life is now in excess of three years and continues to increase.

One failure mechanism in the electronic circuitry which is difficult to detect is an intermittent short of an integrating capacitor associated with the operation amplifier. When the control voltage of the flywheel oscillator is set to zero, the control loop can fail and the high stability of the oscillator will maintain the output frequency of the standard less than the logic limit necessary to give an alarm indication. One possible technique to detect this condition is to offset the control voltage to the oscillator to such a value that the logic error limits are actuated with interruption of normal control loop operation (±20 "Control" meter reading).

Attachment (3)

Frequency adjustment of the cesium beam standard by adjustment of the C-field should be done on the basis of extended time interval measurements rather than frequency comparisons with portable clocks. Temperature and magnetic field effects upon the portable clock can result in errors in frequency setting based on the frequency comparison technique in the order of parts in 10 to the 12.

PTTI CONFERENCE
U. S. Naval Observatory
28 April 1969

Outline of Comments
by

F. Borncamp and P. F. MacDoran
Jet Propulsion Laboratory

on

PRECISE TIME AND FREQUENCY REQUIREMENTS FOR THE DEEP SPACE NETWORK

Part I. REQUIREMENTS

Peter F. MacDoran
Navigational Accuracy Group
Systems Analysis Research Section
Jet Propulsion Laboratory

1. SPECTRUM OF REQUIREMENTS
   - A. Internal Agreement Between Observing Stations
   - B. Relationship of Observer to the Universe
2. INFORMATION CONTENT OF DOPPLER TRACKING
3. BALANCED ERROR SOURCES STRATEGY
4. TRACKING SITUATIONS OF INTEREST
   - A. Planetary Orbiters
   - B. Cruise and Encounter Navigation
   - C. Scientific Applications
5. EFFECTS OF UT-ONE UNCERTAINTIES
6. ECONOMIC BENEFITS OF TIME SYNCHRONIZATION FOR DATA REDUCTION
7. SUMMARY

Attachment (4)

Part II. OPERATIONAL EFFORTS TO MEET THESE REQUIREMENTS

Franz Borncamp
Systems Data Analysis Group
Deep Space Instrumentation Facility Operations Section
Jet Propulsion Laboratory

1. PROBLEMS OF MAINTAINING PRECISE TIME IN A GLOBAL NET

2. LIMITATIONS OF THE CURRENT SYSTEM (TIME AND FREQUENCY)

   A. Frequency Standards
   B. Frequency Distribution
   C. VLF Data

3. FUTURE INTERNAL IMPROVEMENTS

   A. A New Clock System FTS-2
   B. Hydrogen Masers
   C. Lunar Bounce Timing System
   D. Microwave Time Distribution System

4. DESIRED EXTERNAL REFERENCE UTILIZATION

   A. VLF
   B. NBS-USNO Synchronization

DATA SHEET
for
PRECISE TIME MEASUREMENTS

Date ____________________

1. Names of personnel making measurements: ________________________________

____

2. Location of measurement: ____

____

3. Address(es) to which calibration certification(s) should be sent: ______

____

4. Designation of clock measured: ____

   a. Oscillator model number: ____________________ Ser. # ______________
   b. Clock model number: ________________________ Ser. # ______________

5. Designation of reference clock: ____

   a. Oscillator model number: ____________________ Ser.# ______________
   b. Clock model number: ________________________ Ser.# ______________

6. Displayed time of day check between measured and reference clocks. Compare the readings of the two clocks separately and check if found to agree:

   Hours ________ Minutes _________ Seconds _________ Record any difference.

7. Time marker to 100 kHz zero crossover measurement:

   a. Ref. clock pulse trigger polarity, level, and slope: _______________
   b. Ref. osc. 100 kHz positive going crossover check: _________________
      (Ascertain zero voltage counter trigger level before making measurement.)

   Date: ______________________ Time (UTC): ______________________
   UTC (USNO PC# ________) - UTC (USNO Cs# ________) = __________ microseconds

8. Time marker difference measurements:

   a. Mea. clock pulse trig. voltage polarity and slope: _________________
   b. Ref. clock pulse trig. voltage polarity and slope: _________________

   Date: ______________________ Time (UTC): ______________________
   UTC (________________) - UTC (________________) = __________ microseconds

   Date: ______________________ Time (UTC): ______________________
   UTC (________________) - UTC (________________) = __________ microseconds

   Date: ______________________ Time (UTC): ______________________
   UTC (________________) - UTC (________________) = __________ microseconds

(Rev. 9/69)

9. If photo is available, attach it to chis sheet and record the following: (Photo must be identified on back by activity and clock designation.)

Oscilloscope settings:

Sensitivity: ________________ volts/cm

Sweep: ______________________ μs/cm

10. If photo is not available, sketch pulse and enter remarks below:

11. Measured clock pulse characteristics:

Amplitude: ______________________ volts, into: ________ ohms

Polarity: ______________________, rise time: ________________ μs

Pulse length: ____________________ μs

DATA SHEET
for
PRECISE TIME MEASUREMENTS

Date ____________________

1. Names of personnel making measurements: ____________________

____

2. Location of measurement: ____________________

____

3. Address(es) to which calibration certification(s) should be sent: ________

____

4. Designation of clock measured: ____________________

   a. Oscillator model number: ____________________ Ser. # ____________
   b. Clock model number: ____________________ Ser. # ____________

5. Designation of reference clock: ____________________

   a. Oscillator model number: ____________________ Ser.# ____________
   b. Clock model number: ____________________ Ser.# ____________

6. Displayed time of day check between measured and reference clocks. Compare the readings of the two clocks separately and check if found to agree:

   Hours ________ Minutes ________ Seconds ________ Record any difference.

7. Time marker to 100 kHz zero crossover measurement:

   a. Ref. clock pulse trigger polarity, level, and slope: ____________
   b. Ref. osc. 100 kHz positive going crossover check: ____________
      (Ascertain zero voltage counter trigger level before making measurement.)

   Date: ____________________ Time (UTC): ____________________
   UTC (USNO PC#________) - UTC (USNO Cs#________) = __________ microseconds

8. Time marker difference measurements:

   a. Mea. clock pulse trig. voltage polarity and slope: ____________
   b. Ref. clock pulse trig. voltage polarity and slope: ____________

   Date: ____________________ Time (UTC): ____________________
   UTC (______________) - UTC (______________) = __________ microseconds

   Date: ____________________ Time (UTC): ____________________
   UTC (______________) - UTC (______________) = __________ microseconds

   Date: ____________________ Time (UTC): ____________________
   UTC (______________) - UTC (______________) = __________ microseconds

(Rev. 9/69)

9. If photo is available, attach it to this sheet and record the following: (Photo must be identified on back by activity and clock designation.)

Oscilloscope settings:

Sensitivity: ________________ volts/cm

Sweep: ______________________ μs/cm

10. If photo is not available, sketch pulse and enter remarks below:

11. Measured clock pulse characteristics:

Amplitude: ______________________ volts, into: ________ ohms

Polarity: ______________________, rise time: ________________ μs

Pulse length: ____________________ μs

U. S. NAVAL OBSERVATORY
WASHINGTON, D.C. 20390

LIST OF TIME SERVICE PUBLICATIONS

The U. S. Naval Observatory Time Service publications, described on the enclosed list, are available upon request. The description of the publications concerning time and frequency services is intended for your use and should not be returned. Return this sheet only to:

Superintendent
Attention: Time Service Division
U. S. Naval Observatory
Washington, D. C. 20390

Publications (and number of copies of each) required are:

1. ______	6. N/A	11. ______
2. ______	7. ______	12. N/A
3. ______	8. ______	13. N/A
4. ______	9. ______	14. ______
5. ______	10. ______	15. ______

Mailing address:

Organization ______________________________

Attention ______________________________

Address ______________________________

____

City/State/Zip ______________________________

Telephone numbers:

Commercial ______________ Ext. ______________

AUTOVON/IDS ______________

Any comments, suggestions, or recommendations pertaining to Time Service are welcome.

J. MAURY WERTH
Superintendent

19 March 1969

U. S. NAVAL OBSERVATORY
WASHINGTON, D.C. 20390

<u>Time Service Publications</u>
(This form is for your retention)

___Series 1. LIST OF WORLDWIDE VLF AND HF TRANSMISSIONS suitable for Precise Time Measurements. Includes: Call sign, geographic location, frequencies, radiated power, etc.

Will be available in the near future.

___Series 2. SCHEDULE OF U. S. NAVY TIME SIGNAL TRANSMISSIONS in VLF and HF bands. Includes: Times of broadcast, frequencies, etc.

___Series 3. SCHEDULE OF U. S. NAVY VLF TRANSMISSIONS, including OMEGA System. Includes: Location, frequencies, power radiated, maintenance periods, type of transmission, etc.

___Series 4. DAILY RELATIVE PHASE VALUES (Issued weekly). Includes: Observed phase and time differences between VLF, LF, Omega, and Loran-C stations and the USNO Master Clock.

___Series 4A. Instructions for use of phase value bulletins and TWX.

___Series 5. DAILY TELETYPE MESSAGES (sent every working day). Includes: Daily relative phase and time differences between USNO Master Clock and VLF, LF, Omega, and Loran-C stations. Propagation disturbances and notices of immediate concern for precision timekeeping.

NOTE: The need to receive the Daily Teletype Messages must be established in writing to the:

Superintendent
U. S. Naval Observatory
Washington, D. C. 20390.

Requests on file at the USNO do <u>not</u> need to be re-submitted.

___Series 6. Time Service Internal Mailing.

___Series 7. PRELIMINARY TIMES AND COORDINATES OF THE POLE (issued weekly). Includes: UT2 - UTC predicted 2 weeks in advance; time differences between USNO Master Clock and UTC, UT0, UT1, UT2, and A.1; provisional coordinates of the pole.

___Series 8. TIME SERVICE ANNOUNCEMENTS OF B.I.H. ADOPTED OFFSET from Nominal Frequency and Time Adjustments.

(OVER)

___Series 9. TIME SERVICE ANNOUNCEMENTS PERTAINING TO LORAN-C. Includes: Change in transmissions and repetition rates, times of coincidence (NULL) ephemeris tables, coordinates and emission delays, general information, etc.

___Series 10. ASTRONOMICAL PROGRAMS (issued when available). Includes: Information pertaining to results, catalogs, papers, etc. of the Photographic Zenith Tube (PZT), Danjon Astrolabe, and Dual-Rate Moon Position Camera.

___Series 11. TIME SERVICE BULLETINS. Includes: Time differences between coordinated stations and the UT2 Time Scale; earth's seasonal and polar variations (as observed at Washington and Florida); Provisional coordinates of the pole; adopted UT2 - A.1, etc.

___Series 12. Time Service Internal Mailing.

___Series 13. Time Service Internal Mailing

___Series 14. TIME SERVICE GENERAL ANNOUNCEMENTS: Includes: General information pertaining to time determination, measurement, and dissemination.

Should be of interest to all Time Service Addressees.

___Series 15. BUREAU INTERNATIONAL de l'HEURE (B.I.H.) Circular D: Heure Définitive et Coordonnées du Pôle à 0^h TU: Includes: Coordinates of the pole; UT2 - UTC, UT1 - UTC, and TA(AT) - UTC; UTC - Signal.

NOTE: USNO Time Service will distribute Circular D of the B.I.H. to U. S. addressees only.