Time and Frequency: A Bibliography of NBS Literature Published July 1955-December 1970
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**THE INSTITUTE FOR BASIC STANDARDS** provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of a Center for Radiation Research, an Office of Measurement Services and the following divisions:


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**THE OFFICE FOR INFORMATION PROGRAMS** promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal Government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System; provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world, and directs the public information activities of the Bureau. The Office consists of the following organizational units:


\textsuperscript{1} Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.

\textsuperscript{2} Part of the Center for Radiation Research.

\textsuperscript{3} Located at Boulder, Colorado 80302.
Time and Frequency:
A Bibliography of NBS Literature

Published July 1955—December 1970

B. E. Blair

Time and Frequency Division
Institute for Basic Standards
National Bureau of Standards
Boulder, Colorado 80302
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TIME AND FREQUENCY:  
A BIBLIOGRAPHY OF NBS LITERATURE  
PUBLISHED JULY 1955—DECEMBER 1970

B. E. Blair

This publication gives bibliographic references to NBS time and frequency papers (principally those of the Time and Frequency Division or its predecessor sections) published over the past 15 years. The NBS material is classified under five general sections: Time and Frequency Standards; Time Scales, Time; Distribution/Reception of Time and Frequency Signals; Statistics of Time and Frequency Analyses, Frequency Stability; and General, Summary, and Status Reports. An additional section lists outside publications which describe the use of NBS time and frequency services or illustrate their varied use in seismic research, industrial practice, navigation, and propagation studies, among others. The bibliography documents past progress, will aid access to available literature, and gives an indication of the present direction, scope, and status of NBS time and frequency research.

Key words: Atomic clocks; atomic standards; clock dissemination; crystal oscillators; definition of second; flicker noise; frequency; frequency stability; lasers; length standards; measurement standards; spectral density; standard frequency broadcasts; speed of light; statistics of time/frequency measurements; time; time/frequency dissemination; time scales; timing (HF, LF, satellite, TV, VLF); wavelength standards; WWV; WWVB; WWVH; WWVL.

Introduction

This bibliography lists NBS papers and reports in the field of time and frequency under five categories and by fiscal year, published from June 1955 through December 1970. The cited work is principally that of the Time and Frequency Division; however, important related work in the time and frequency area by other NBS personnel also is listed. We include an NBS author index as well as a selected listing of non-NBS written articles about our work. This latter section gives a sampling of reports and papers which describe and illustrate, for instance, instrumentation methods for comparability to NBS time and frequency standards, the use of the NBS radio broadcasts and services, and the scope and depth of such usage.

The contents of this bibliographic listing exemplify the extent and character of work performed by the Time and Frequency Division. (The listing is in the form of an NBS Special Publication which we plan to update periodically.) The Division welcomes questions and provides consultation services on matters relating to time and frequency. Appendix I shows the section structure and responsibilities of the Division. Appendix II indicates the various time and frequency broadcast notices, bulletins, HF prediction notices, etc., available to the public on the basis of need.

To aid in the location of the source material, there has been a vigorous attempt to list complete references in consistent form, using accepted journal title abbreviations as given in the 1961 Chemical Abstracts—Lists of Publications or the 1966 Revised and Enlarged Word Abbreviation List for USASI Z39.5-1963—American Standard for Periodical Title Abbreviations. Most of the bibliographic listings can be seen at public or university libraries. NBS Technical Notes and papers with a USGPO notation are available, for the price shown, from:

Superintendent of Documents  
U. S. Government Printing Office  
Washington, D. C. 20402

A listing with a Libr. Congr. notation is available as follows:

The Library of Congress  
Washington, D. C. 20540

Photocopying is done also by the Library for research purposes, under certain specified conditions. Any out-of-print Bureau documents can generally be obtained by such photoduplication, as well as single articles in a publication, such as proceedings of a conference. Complete information about these services are available from the Photoduplication Service Group of the Library of Congress. Papers with an AD accession number and a NTIS notation are available from the National Technical Information Service as follows:
Limited reprints of some listed research articles and reports are available from:

Secretary to the Chief
Time and Frequency Division
National Bureau of Standards
Boulder, Colo. 80302
(Telephone: 303-447-1000, ext. 3294)
This section is concerned with studies on primary time and frequency standards at NBS since 1955. The studies embrace low temperature crystal oscillators; development, construction, and evaluation of atomic beam frequency standards assembled at the NBS laboratories (including ammonia masers, cesium, thallium, and hydrogen beam standards); evaluation of commercial atomic frequency standards, such as rubidium, cesium, and hydrogen standards; evaluation of errors in atomic frequency standards; development of low noise electronics; theoretical research on atomic beam resonances and hydrogen spin-exchange; stabilization of laser frequencies; and refinement of measurements of the speed of light.

Over this 15-year period, the accuracy of primary frequency standards has improved from about 1 part in 10^8 to some 5 parts in 10^{13} (1σ). The rigorous evaluation of the cesium beam standard at NBS, along with similar studies at other national laboratories, contributed to the 13th General Conference of Weights and Measures defining, in 1967, the international unit of time—the second—based on a cesium resonance frequency. For the future, studies indicate that frequency accuracies of a few parts in 10^{14} are within reach of today’s research capabilities. An exciting consequence of further work envisions a single Standard for frequency, time, and length, from which other units of measurement can be derived. This approach would specify a numerical value for the speed of light (previous best experimental value) and, since length measurements could be referred back to a frequency standard, there would be no need for a separate length standard.
SECTION A

TIME AND FREQUENCY STANDARDS

July 1955 - June 1956


[A-2] NBS, "Constant temperature oven for quartz crystal oscillator," NAT. BUR. STAND, (U. S.), TECH. NEWS BULL., 40, No. 4, p. 59 (USGPO, $0.15, April 1956).


July 1956 - June 1957


July 1957 - June 1958


1. Letters in parentheses indicate applicability to additional sections.
July 1958 - June 1959


July 1959 - June 1960


July 1960 - June 1961


NBS, "Atomic frequency standards," NAT. BUR. STAND. (U. S.), TECH. NEWS BULL., 45, No. 1, pp. 8-10 (USGPO, $0.15, January 1961).


July 1961 - June 1962


July 1962 - June 1963

July 1963 - June 1964


NBS, "Standards and calibration--Precision of the U.S. frequency standard," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 48, No. 2, pp. 31-32 (USGPO, $0.15, February 1964).

July 1964 - June 1965


NBS, "Frequency stability calibration of signal sources," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 49, No. 6, p. 89 (USGPO, $0.15, June 1965).

July 1965 - June 1966


July 1967 - June 1968


July 1968 - June 1969


July 1969 - June 1970


July 1970 - June 1971


SECTION B

TIME SCALES, TIME

The reports and papers in this section span a period of time which experienced three different definitions of the basic unit of time—the second—with some four to five orders of magnitude improvement. In 1955 the International Astronomical Union approved a prototype time unit, the Ephemeris second, to supplant the less precise mean solar or UT second. The International Committee of Weights and Measures adopted this refined standard in 1956, and the General Conference of Weights and Measures gave formal approval to the Ephemeris second in 1960. Concurrently, with the advent of atomic frequency standards, it was apparent that an even more refined unit of time—an atomic second—could be defined. As a consequence, the International Committee of Weights and Measures (CIPM) established in 1956 a Consultative Committee for the Definition of the Second (CCDS) which held four meetings in Paris (1957, 1961, 1963, and 1967). Dr. F. W. Brown represented NBS at the first meeting and entered into initial discussions as recorded in Comité Consultatif Pour La Définition De La Seconde 1re Session, 1957 (Minutes of the First Meeting), pages 1-32 (Gauthier-Villars, Paris, France, 1958). In 1964 the General Conference of Weights and Measures authorized the International Committee of Weights and Measures to define a provisional atomic second based on the cesium transition frequency.

The 13th General Conference of Weights and Measures, in 1967, defined the unit of time in the International System of units as follows:

"The second is the duration of
9 192 631 770
periods of the radiation
corresponding to the transition
between two hyperfine levels
of the ground state of the
atom of cesium 133."

Since navigators, astronomers, and others require earth or UT time, studies continue for optimizing and striking a compromise between the needs of both kinds of time. There is also anticipation that future research will further refine the present definition of the second.

NBS participation in such far reaching endeavors as time unit definitions, coordination of UT and AT, development of a national and/or international time scale, and research into methods for synchronizing time scales, is shown in the scope, depth, and variety of applicable subjects listed in this section.
SECTION B

TIME SCALES, TIME

July 1955 - June 1956

[B-1] (C)

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[B-2] (A)

July 1957 - June 1958

NONE

July 1958 - June 1959

NONE

July 1959 - June 1960

NONE

July 1960 - June 1961

[B-4] (C)

July 1961 - June 1962


July 1962 - June 1963


July 1963 - June 1964


July 1964 - June 1965


July 1965 - June 1966


July 1966 - June 1967


July 1967 - June 1968


July 1968 - June 1969


July 1969 - June 1970


July 1970 - June 1971

SECTION C

DISTRIBUTION/RECEPTION OF TIME AND FREQUENCY SIGNALS

NBS contributions to the topic of this section were, in the middle 1950's, through the HF standard frequency broadcasts of WWV and WWVH with received precisions of some parts in 10^7 from day to day. LF broadcasts were commenced at 60 kHz (KK2XEI—later WWVB) in 1956 from a site at the Boulder Laboratories. Only radiating about a watt of power, this 60 kHz broadcast was used by Prof. Pierce at Harvard University to intercompare NBS and NPL (England) frequency standards to several parts in 10^9. Concurrently with the LF studies, it became apparent that VLF signals also could be broadcast with precision. NBS studies, along with others, gave impetus to the adoption, in December 1959, of the 20 kHz standard frequency band by the International Radio Conference for the International Telecommunications Union (ITU). After a 3-month period of construction, NBS commenced broadcasting a 20 kHz standard frequency from WWVL at a site some 18 airline kms west of Boulder. The success of these two low frequency transmissions on an experimental basis led to the development and construction of more powerful stations at Ft. Collins, Colorado in 1963. This section of the bibliography includes papers which describe the NBS broadcasts and give their characteristics, use, special experiments, and levels of received precision. The improvement in frequency standards during this period of time contributed immensely to the precision of signals broadcast. The NBS contribution to Loran-C, although not a direct time and frequency involvement, is also listed.

As time and frequency dissemination advanced to meet more stringent goals, the use of satellites and commercial TV enabled μ second, or better, timing. The future includes providing a more powerful and effective WWVH on Kauai, Hawaii in July 1971, revising the format of the HF broadcasts for greater utility of use, and refining the satellite and TV experiments; long-range plans include WWV-type transmissions from synchronous satellites and time synchronizations through long-base interferometry (LBI) measurements.
SECTION C

DISTRIBUTION/RECEPTION OF TIME AND FREQUENCY SIGNALS

July 1955 - June 1956

[C-1] NBS, "Standard frequencies and time signals WWV and WWVH," NAT. BUR. STAND. (U.S.), LETT. CIRC. 1023, 14 pages (June 1956), (Superseded by MISC. PUBL. 236, December 1960).

July 1956 - June 1957


July 1957 - June 1958


[Note: These notices were published monthly thereafter thru October 1968--PROC. IEEE (Letters), 56, No. 10, pp. 1759-1760 (October 1968).]


[C-7] NBS, "Standard musical pitch," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 41, No. 8, pp. 120-121 (USGPO, $0.15, August 1957).

July 1958 - June 1959

NONE

July 1959 - June 1960


J. RES. NAT. BUR. STAND. (ENG. AND INSTRUM.), 64C, No. 2, pp. 159-165 (April-June 1960).


July 1960 - June 1961


IRE TRANS. SPACE ELECT. AND TELEMETRY, SET-6, No. 3-4, pp. 138-146 (December 1960).


NBS, "New standard frequency broadcasts," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 44, No. 7, pp. 120-121 (USGPO, $0.15, July 1960).


July 1961 - June 1962


July 1962 - June 1963


July 1963 - June 1964


[C-34] (B) NBS, "NBS low-frequency station WWVB to broadcast international unit of time," NAT, BUR, STAND, (U.S.), TECH, NEWS BULL., 49, No. 2, p. 27 (USGPO, $0.15, February 1965).

July 1965 - June 1966


[C-41] (B) NBS, "WWVB adds time code to broadcasts," NAT, BUR. STAND, (U.S.), TECH. NEWS BULL., 50, No. 1, pp. 15-16 (USGPO, $0.15, January 1966).

July 1966 - June 1967


July 1967 - June 1968

[C-50] JESPERSEN, J. L., "Signal design for time dissemination: some aspects," NAT. BUR. STAND. (U.S.), TECH. NOTE 357, 38 pages (USGPO, $0.30, November 1967).


July 1968 - June 1969


July 1969 - June 1970


SECTION D

STATISTICS OF TIME AND FREQUENCY ANALYSES, FREQUENCY STABILITY

This section includes NBS papers on such subjects as power spectrum, oscillator noise effects, flicker noise, stability of frequency generators, and statistics of atomic frequency standards. Specific NBS work and publications in this general subject area did not appear until the late 1950's. Impetus to the study of the definition and measurement of short-term frequency stability was given by the joint IEEE-NASA Symposium in 1964, from which evolved a Special Issue of the IEEE PROCEEDINGS in February 1966. NBS contributions to these studies are noted in this listing. Some specific characterizations or definitions of frequency stability have now been crystallized by the Subcommitte on Frequency Stability of the Frequency and Time Technical Committee (IEEE Group on Instrumentation and Measurement). The initial publication of this work is NBS TECH. NOTE 394, co-authored by 11 Subcommittee members.
SECTION D

STATISTICS OF TIME AND FREQUENCY ANALYSES; MEASUREMENTS

July 1959 - July 1960


July 1960 - June 1961


July 1961 - June 1962

NONE

July 1962 - June 1963


July 1963 - June 1964


July 1964 - June 1965


July 1965 - June 1966


July 1966 - June 1967


July 1967 - June 1968


July 1968 - June 1969

[D-14] BARNES, J. A., "Tables of bias functions, $B_1$ and $B_2$, for variances based on finite samples of processes with power law spectral densities," NAT. BUR. STAND. (U. S.), TECH. NOTE 375, 37 pages (USGPO, $0.50, January 1969).


[D-16] POWERS, R. S., and SNYDER, W. F. (Eds.), "Radio-frequency measurements in the NBS Institute for Basic Standards" (Time and Frequency Sections only), NAT. BUR. STAND. (U. S.), TECH. NOTE 373, pp. 1 to 12-1 (USGPO, $1.00, June 1969).


IEEE TRANS. INSTRUM. AND MEAS., IM-20, No. 2 (May 1971).
SECTION E

GENERAL, SUMMARY, AND STATUS REPORTS

This section includes (1) reviews of progress, developments, etc., in the general area of time and frequency for given time periods, prepared for the International Body of URSI—Commission 1; (2) conference or summary reports showing the progress of time and frequency projects; (3) status reports of time and frequency activities at a given time; and (4) reports or papers which show how time and frequency functions fit into the overall NBS mission of providing a central basis for the National Measurement System.
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GENERAL, SUMMARY AND STATUS REPORTS

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July 1958 - June 1959


July 1959 - June 1960

NONE

July 1960 - June 1961


July 1961 - June 1962

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SECTION G

NBS TIME AND FREQUENCY SERVICES
OUTSIDE PUBLICATIONS

In this section appear some important articles which are non-NBS affiliated, yet are related to NBS services. These papers describe the NBS standards and facilities, show methods and techniques for using the NBS time and frequency services, and document some of the many ways in which the NBS outputs in time and frequency are used. These NBS services impact on a range of activities which includes the timing of seismic events; providing a time reference for both telemetering data from “clusters” of seismic stations throughout the western U.S. and automatically processing earthquake data on an electronic computer; accurate timing for telephone distribution in many of our major cities; frequency synchronizaton of electric power utilities throughout the U.S. and Canada; frequency and time synchronizaton of standards laboratories; contributions to an international time scale as determined by the B.I.H.; time service station for USNO clock reference; and specialized research and propagation studies. Such a varied range of activities provides a cross section of the NBS time and frequency user. The aggregate body of users includes government agencies (U.S. Geological Survey, U.S. Coast & Geodetic Survey, NASA, U.S. Navy, U.S. Air Force, U.S. Army), diverse university research units, Woods Hole Oceanographic group, Jet Propulsion Laboratory, Douglas Aircraft Co., Canadian Pacific Railway, Bell Telephone Co., power utilities in the U.S. and Canada, time and frequency equipment manufacturers, amateur radio operators, and scientific and technical industries.

This listing is a sample of outside publications which attempts to show the scope and depth of NBS time and frequency involvement in science and technology. It cannot be all-inclusive; however, we welcome recommendations for noteworthy accessions, as well as documentation of additional uses of our time and frequency services. The references include some manufacturers’ literature; their inclusion, though, is to show overall techniques and methods of time and frequency measurement and in no way is an NBS endorsement of commercial equipment. The outline structure of this section is as follows:
G I. Description of NBS frequency standards, broadcasts, and receiving systems.

G II. How to use NBS time and frequency broadcasts.

G III. Varied uses of NBS time and frequency services.
   a. Commercial-radio frequency stabilization
   b. Geophysical event timing
   c. Intercomparison of frequency standards, time scales
   d. Local laboratory synchronization
      (1) General synchronization
      (2) Within laboratory distribution
   e. Navigation
   f. Portable clock comparisons
   g. Power industry frequency synchronization
   h. Propagation studies
   i. Research experiments
   j. Timing
      (1) Local
      (2) Telephone company
SECTION G
NBS TIME AND FREQUENCY SERVICES--OUTSIDE PUBLICATIONS

G-1 - Description of NBS Frequency Standards, Broadcasts and Receiving Systems


G-2 - How to Use NBS Time and Frequency Services


G-3 - Varied Uses of NBS Time and Frequency Services

(a) Commercial-radio frequency stabilization


(b) Geophysical event timing


(c) Intercomparison of frequency standards, time scales


Note: This publication describes: 1. the B. I. H. system of time measurement, 2. formation of atomic time (B. I. H) including weight factors of international laboratories, 3. coordinated universal time and time signals from worldwide standard frequency and time broadcasts and 4. history of polar motion from 1964.00 to 1969.95.


(d) Local laboratory synchronization

1) General synchronization


2) Within laboratory distribution


(e) Navigation


(f) Portable clock comparisons


Note: This announcement denotes NBS, Boulder, Colo. among other laboratories, as a USNO time reference station at which precise time measurements can be made and related to the USNO master clock to about ±2.5 microseconds.


(g) Power industry frequency synchronization


(h) Propagation studies


(i) Research experiments


(j) Timing

1) Local


2) Telephone Company

APPENDIX I

STRUCTURE OF NBS TIME AND FREQUENCY DIVISION

The Time and Frequency Division, one of eleven technical divisions in the NBS Institute for Basic Standards, is located at Boulder, Colorado, 80302, and consists of three Sections as follows:

Section 273.01 Frequency-Time Dissemination Research
Pursues research on new and improved methods for dissemination of frequency and time standards, including radio (HF, MF, LF, and VLF signals), satellites, television timing, portable clocks, and other advanced techniques.

Section 273.02 Frequency-Time Broadcast Services
Operates four NBS standard frequency radio stations—three located at Ft. Collins, Colorado, and one HF station, WWVH, located at Maui, Hawaii. (WWVH will relocate to Kauai, Hawaii on or about July 1, 1971.) The three Ft. Collins stations include (1) WWV, which transmits in 6 HF bands, (2) WWVB, which transmits a 60 kHz signal, and (3) WWVL, an experimental VLF broadcast, nominally at 20 kHz. Evaluates, modifies, and develops new or better techniques for improving the accuracy and/or coverage of the NBS standard frequency and time broadcasts.

Section 273.04 Atomic Frequency and Time Standards
Operates, maintains, and improves the primary NBS Frequency and Time Standards. Performs research and development on cesium beams, hydrogen beams, and other potential quantum electronic frequency standards, low noise electronics, and statistical analyses and model techniques for evaluating time and frequency data. Also provides frequency and time calibrations to users requiring traceability to the NBS standards.
APPENDIX II

NBS TIME/FREQUENCY BROADCAST NOTICES, BULLETINS, HF PREDICTION METHODS

1. Information on the NBS standard frequency and time broadcasts is given monthly in the NAT. BUR. STAND. (U.S.), TECH. NEWS BULL. (USGPO, $3.00/yr.) since January 1967.

2. The Frequency-Time Broadcast Services Section publishes a monthly bulletin which includes time scale information, daily phase deviations of NBS and non-NBS stations, daily television time transfer measurements, outages of NBS radio broadcasts, advance announcements concerning phase adjustments, offsets or alterations of broadcast formats, etc. Users of NBS radio broadcasts, who require such information on the basis of need, should address a request to:

Chief, Frequency-Time Broadcast Services Section, 273.02
Time and Frequency Division
National Bureau of Standards
Boulder, Colorado 80302

Telephone: (303) 447-1000, extension 3453

3. The NBS SPEC. PUBL. 236—NBS Frequency and Time Broadcast Services is revised annually. Copies are available from the USGPO.

4. A mailing list for current scientific and technical publications of the Atomic Frequency and Time Standards Section is maintained. On the basis of need, make written request to:

Chief, Atomic Frequency and Time Standards Section, 273.04
Time and Frequency Division
National Bureau of Standards
Boulder, Colorado 80302

Telephone: (303) 447-1000, extension 3755


Note: This is a comprehensive treatment of methods and techniques for predicting long-term performance of HF telecommunication systems. Measures of the system performance are derived in terms of circuit reliability and service probability. A complete listing of the electronic computer program is given which includes descriptions of input and output data.

Many people helped in the compilation of this bibliography. Don Halford and Roger Beehler gave much encouragement to this work. Grateful appreciation is expressed to the NBS Library personnel, the Electromagnetic Metrology Center, and the Boulder Program Information Office. We thank Mrs. Louise Gaskill and Mrs. Carol Wright for patience and skill in typing this manuscript. Thanks are also due Mrs. Glynetta Perrymore, Mrs. Darlene Noble, and Mrs. Sandra Gainsforth for assistance in checking and documenting references.
**Title and Subtitle:**  
Time and Frequency:  
A Bibliography of NBS Literature  
Published July 1955 - December 1970

**Author(s):**  
B. E. Blair

**Performing Organization Name and Address:**  
National Bureau of Standards  
Department of Commerce  
Washington, DC 20234

**Abstract:**  
This publication gives bibliographic references to NBS time and frequency papers (principally those of the Time and Frequency Division or its predecessor sections) published over the past 15 years. Its purpose is to document past progress, aid access to available literature, and give an indication of the present direction, scope, and status of NBS time and frequency research. The listing includes some non-NBS references which show the widespread usage of the NBS time and frequency services.

**Key Words:**  
- Atomic clocks;  
- Atomic standards;  
- Clock dissemination;  
- Crystal oscillators;  
- Definition of second;  
- Flicker noise;  
- Frequency;  
- Frequency stability;  
- Lasers;  
- Length standards;  
- Measurement standards;  
- Spectral density;  
- Standard frequency broadcasts;  
- Statistics of time/frequency measurements;  
- Time;  
- Time/frequency dissemination time scales;  
- Timing (HF, LF, satellite, TV, VLF);  
- Velocity of light;  
- Wavelength standards: WWV: WWVB: WWVH: WWVL.

**Availability Statement:**  
- Unlimited.  
- For official distribution, do not release to NTIS.
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* Difference in price is due to extra cost of foreign mailing.

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