Title
INSTRUMENTATION CALIBRATION

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ABSTRACT

Calibration is vital to the successful operation of any instrument. Conditions under which an instrument must operate, including the mode of operation, the number of measurements, the condition of the equipment and climatic effects all may in the course of time affect its performance. Thus recalibration must be performed from time to time. This must be done sufficiently often that loss incurred by faulty experimental measurement is not greater than the cost of recalibration.

The concept of calibration involves two types of errors - systematic and random; in addition two factors relate to the reliability of measurement, namely, accuracy and precision. If a normally operating instrument is used to make a number of measurements of an unknown sample, the readings will not be identical. The precision of the instrument refers to the reproducibility of the measurements; the closer the readings agree, the more precise the instrument. Accuracy, on the other hand, refers to the correctness of readings when measurements are made on an independent or reference standard. In general, calibration is the procedure taken to ensure instrument accuracy.

Calibration is usually carried out by comparing the value of a known standard with the readings of the instrument being calibrated in a series of measurments of that standard. Thus a laboratory facility must be equipped with appropriate working standards. These working standards are in turn compared with reference standards. National standards laboratories maintain the national standards to which regional or local laboratories may compare their reference standards. International agencies link the various national standardizing agencies by appropriate working committees that can arrange interlaboratory comparisons.

Reference standards of such quantities as voltage and frequency are commonplace; most research facilities should avail themselves of such devices. Standards for more specialized parameters such as the luminous flux of a light source can best be handled by submitting reference devices directly to a standardizing laboratory for calibration.

Procedures for the calibration of different types of laboratory equipment are described. Provisions for maintaining the integrity of reference and working standards traceable back to a national standard are discussed. Methods of validation and certification methods are included.

An appendix lists available publications and services of national standardizing agencies.

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I. INTRODUCTION

Back in antiquity as men began to construct places of worship, dwellings, and burial places they found a need to "scale" their constructions. Ancient Egyptians developed the Royal Cubit, the first known useful standard of length. Today we can see it on display as a piece of black granite 52.4 cm long and subdivided into increments of smaller length.[1] Length standards such as these were passed on to the Greeks and Romans. Some early measures of length were interesting; the English yard is thought to have had its beginning as the distance from the tip of the nose to the end of the outstretched thumb of an early king. The art of measurement has come a long way since some royal courtier helped define the yard. The manner in which science and technology progress is in no small measure matched by advances in the art of measurement. Indeed, Professor Frederick E. Terman of Stanford University has said, "The quickest way to assess the state of a nation's science and technology is to examine the measurements that are being made and the way in which the data accumulated by measurements are utilized."[2]

Early measurements were to a large extent based upon physical observations; however, during the past 40 years measurement technology has become more and more dependent upon electrical and electronic methods which make possible greater accuracy, reliability and speed. A number of sensors or transducers have been developed that produce accurate electrical output signals in response to a wide variety of physical parameters, such as pressure and temperature. Electrical signals can be processed, e.g., linearized, to provide output indications that read directly in the units of interest, such as milligrams/m^3. If the information is converted from analog to digital form, the data can be fed to a computer for immediate or delayed processing and display. Thus our discussion on standards and calibration will deal primarily with the electronic aspects of the subject.

II. UNITS OF MEASUREMENT

To refresh our memories let us briefly review the development of measurement units. The French proposed the metric system in 1670, but it took over 100 years before it was adopted in 1791. In 1875, the international treaty of the meter was signed by 17 nations establishing the International Bureau of Weights and Measures. The metric system, as we all know, is a decimal system of weights and measures based upon the meter and kilogram.

International measurements today rely on the Systeme International (SI) or International System of Units. The SI is based upon six units that are considered fundamental to a measurement system, namely, length, mass, time, electric current, temperature and luminous intensity. Table 1 shows these quantities along with two supplemental units, the radian and steradian.[2,3,4] Approximately 30 additional units have been derived from the above basic and supplemental units; they are defined as SI Derived Units. Some of them are also listed on Table I. A more complete list is given in Appendix A.

III. ERRORS IN MEASUREMENT

Before discussing specific problems of standardization and calibration it would be well to consider the factors relating to the reliability of instrument measurements. The reading of an instrument would be correct if it were exactly equal to the true value of the quantity being measured; however, instrument readings are seldom absolutely correct. The difference between the reading and the true value is the error of the reading. When an instrument is used repeatedly, it is generally found that the results will differ by small amounts. Such differences are evidences of errors from measurement to measurement.

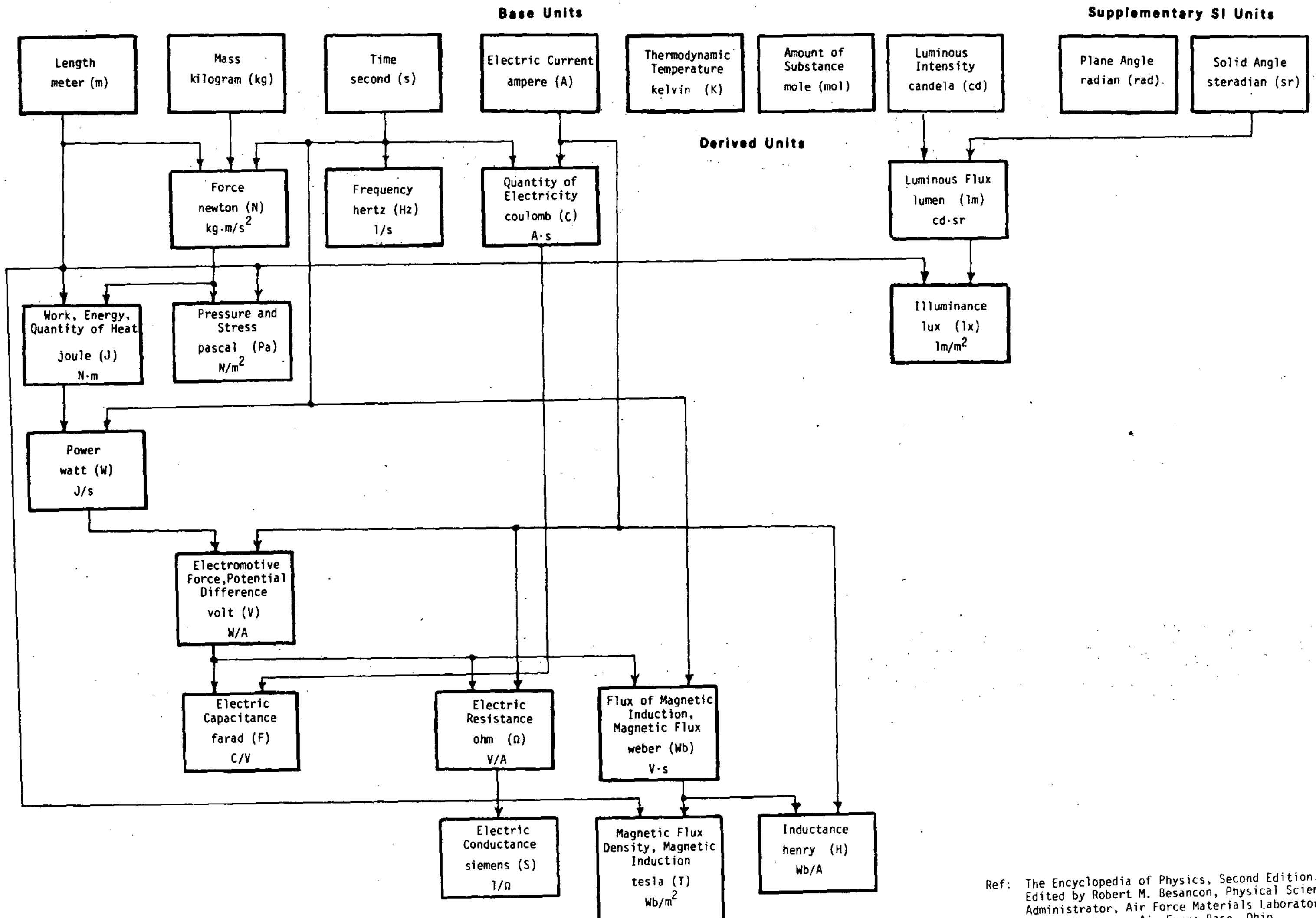
Some errors will vary from one reading to another, others remain relatively constant and still others will change slowly over a period of time. For purposes of discussion, let us distinguish between two types of errors: systematic and random.

Systematic errors are those that produce a drift, trend, cyclic or other predictable pattern throughout a series of repeated measurements. Systematic errors may even remain constant during a number of measurements (e.g., a meter whose needle has not been properly zero set). Incidentally, this latter type of error can often be found only by making comparisons with other methods.

Systematic errors are due to causes over which the operator has some degree of control. They may be caused by equipment and/or personnel. Human errors are reduced by using standard procedures; equipment errors may be minimized by proper calibration techniques.

TABLE 1

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)



Ref: The Encyclopedia of Physics, Second Edition, Edited by Robert M. Besancon, Physical Sciences Administrator, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio

XBL 768-10045

Random errors, on the other hand, vary in an irregular manner without a discernable or predictable pattern. Random errors are as likely to be positive as negative; their specific magnitude and direction cannot be predicted for each measurement. They occur because for every observation there are a number of experimental variables, each of which causes a small uncontrolled error. Random errors are described by laws of probability and statistics and are usually normally distributed.

If a normally operating analyzing instrument is used to make a number of measurements, the resultant readings will not be identical to one another. The closer they are together the more precise the instrument. On a more quantative basis, let us assume that we make n measurements on the unknown. The average or arithmetic mean of the readings is

$\bar{R} = \frac{1}{n} \Sigma R_i$ where R_i is the series of readings from 1 to n.

The standard deviation of the reading is $S = \sqrt{\frac{\Sigma (R_i - \bar{R})^2}{n}}$

If the instrument is well behaved and its error is made up of a number of small internal inaccuracies, then a graph of a large number of readings R_i plotted against the number of times a value occurs will be a Gaussian in shape. It can be shown that there is a 50% chance that any given reading lies within 0.6915 times the standard deviation. In fact, the most probable error is 0.6915 X (standard deviation). If, in testing an instrument, a reading is found to fall much beyond the probable error, then it is probably because the operator misread the device. However, such a value of R_i should alert the user to the possibility that there is an intermittent connection or similar defect in the device. It might be pointed out that in the case of a well functioning instrument (where systematic errors have been minimized and a Gaussian error response cure is obtained), the average value of the readings approaches the true value as the square root of the number of readings.

IV. PRECISION AND ACCURACY

Calibration of an instrument may be defined as the determination of its deviation from a standard in order to ascertain the proper correction that should be made to obtain the required accuracy. Once the deviation has been determined it may be applied as a correction factor to the readings being taken, or as the basis for readjusting the instrument to minimize the deviation. For instruments which generate a signal (e.g., a square wave generator) calibration is making the value of the output function correspond to the dial setting on the instrument. Conversely, for analyzing instrumentation, it is adjusting the instrument so that the value of the output reading corresponds to the value of the standard sample being measured. Both types of instruments require the use of standards of known value which serve as a basis for comparison in the measurement.

The terms <u>precision</u> and <u>accuracy</u> are characteristics of the measuring process. The precision of an instrument refers to the reproducibility of the measurements by that device. The closer the readings agree with each other, the more precise the instrument, and incidentally, the smaller the standard deviation of a series of readings. Accuracy of an instrument, on the other hand, refers to the correctness of a reading with reference to the true value (usually found by measuring an independent or reference standard). Stated another way, precision refers to the extent to which a given set of measurements agrees with the mean of these measurements. Accuracy refers to the departure of a set of measurement results from the value which is accepted as true or correct for the quantity measured. Fig. 1 illustrates examples of accuracy and precision in target shooting.

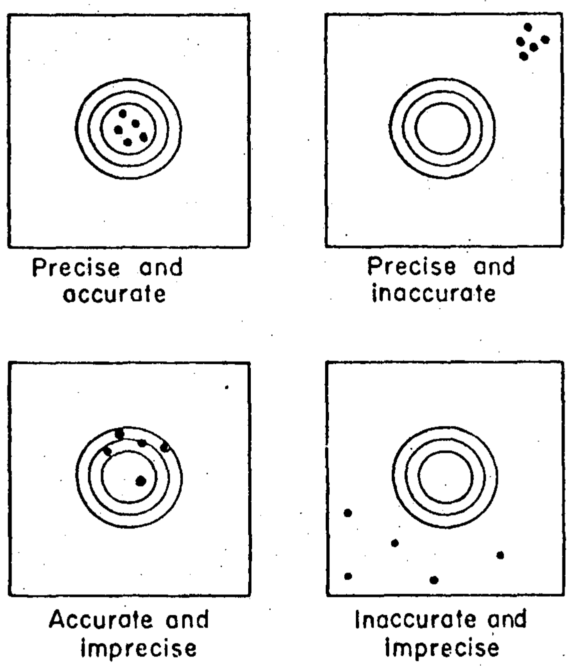


Fig. 1 Illustrations of precision and accuracy in target shooting.

(Ref. 5)

If an instrument whose characteristic being measured is known very exactly, the accuracy of the instrument determines how close an individual R_i is to C_i, the known standard. If these differences are small the instrument can be said to be accurate.

Calibration is the procedure used to help ensure instrument accuracy. If the instrument is of low or poor precision, the calibration cannot improve its precision, but it can make $\overline{R}$ the average of the readings correspond to the desired standard, C_i. The calibration may take one of two forms. There may be an adjustment that can be made on the instrument permitting R_i or $\overline{R}$ to be brought closer to C_i as measurements are made on one or more C_i's (standard samples). Alternatively the calibration may be in the form of a curve giving the functional relationship between R_i and C_i.

V. STANDARDS AGENCIES

Almost every nation has its own standards organization set up to provide reference standards for its citizens. Appendix B lists a number of national standards agencies. An example of a national standardizing laboratory is the U. S. National Bureau of Standards with laboratories located in Gaithersburg, Maryland and Boulder, Colorado. The Bureau was established in 1901, and among other responsibilities, develops and maintains the National Standards of Measurements as well as furnishing essential services that lead to accurate and uniform measurements throughout the country. Appendix C describes the various publications available from the USNBS. See also References 6, 7, 8 and 9 for specific test services, standard reference materials and time and frequency information that are available. Appendix D lists publications available from the British National Physical Laboratory.

International commerce demands that the reference standards of one nation adhere closely to those of another. Appendix B also lists several international agencies that have been established to correlate the standardization efforts of its member nations. For example, the Bureau International de l'Heure (BIH) was established in 1913 as a coordinating body for time keeping services. Several annual and monthly publications relate time and time scale comparisons. Two of the major functions of the BIH is the establishment of Coordinated Universal Time (UTC) and International Atomic Time (TAI). The former is based upon the rotation of the earth upon its axis and the latter on transitions in the cesium atom.[10]

VI. INTERNATIONAL, NATIONAL, REFERENCE AND WORKING STANDARDS

It would be unrealistic to expect that each time a portable voltmeter or frequency counter required calibration it would be returned to an international standardizing laboratory for that purpose. To solve the need for the great number of working standards required by the science and industry of each country, a hierarchy or echelon of standards has been set up that is traceable to a common source. Obviously, there can be only one International 1-kilogram mass. National standardizing laboratories have replicas of the International Kilogram called "prototypes". For example, the United States has Prototype Kilogram No. 20. Similarly other national standards are correlated on an international basis.

Fig. 2 illustrates a national eschelon of standards for measurements in general.[11] National standards have for practical purposes been formed for many of the derived SI units listed in Table 1; for example, a bank of saturated Weston standard cells is used in the U. S. as a national voltage standard.

Within a given echelon there are quite often two levels of standards; see Fig. 2.

Reference standards serve as highly stable units that can be referred to once or twice a year to calibrate the working standards. (Reference standards may be the same as the national standards; compare Fig. 2 and 3.)

Working standards are used on a day-by-day schedule to calibrate standards sent in from second echelon laboratories.

Standards shipped from various research laboratories around the country to the national standardizing laboratory are known as interlaboratory standards. These interlaboratory comparisons are made at intervals ranging from 6 months to several years depending upon the nature of the standard.

The structure within a research laboratory (labelled Echelon II in Fig. 3) resembles the organization of a national laboratory. At our Laboratory, for example, the voltage reference standard consists of two banks each consisting of six Eppley saturated standard cells. Each cell has been certified to be within 1 part per million (ppm) by NBS. The cells are maintained in an air bath within $\pm$ .01°C which is in turn in an air conditioned room maintained at 23°C $\pm$ 1°C.

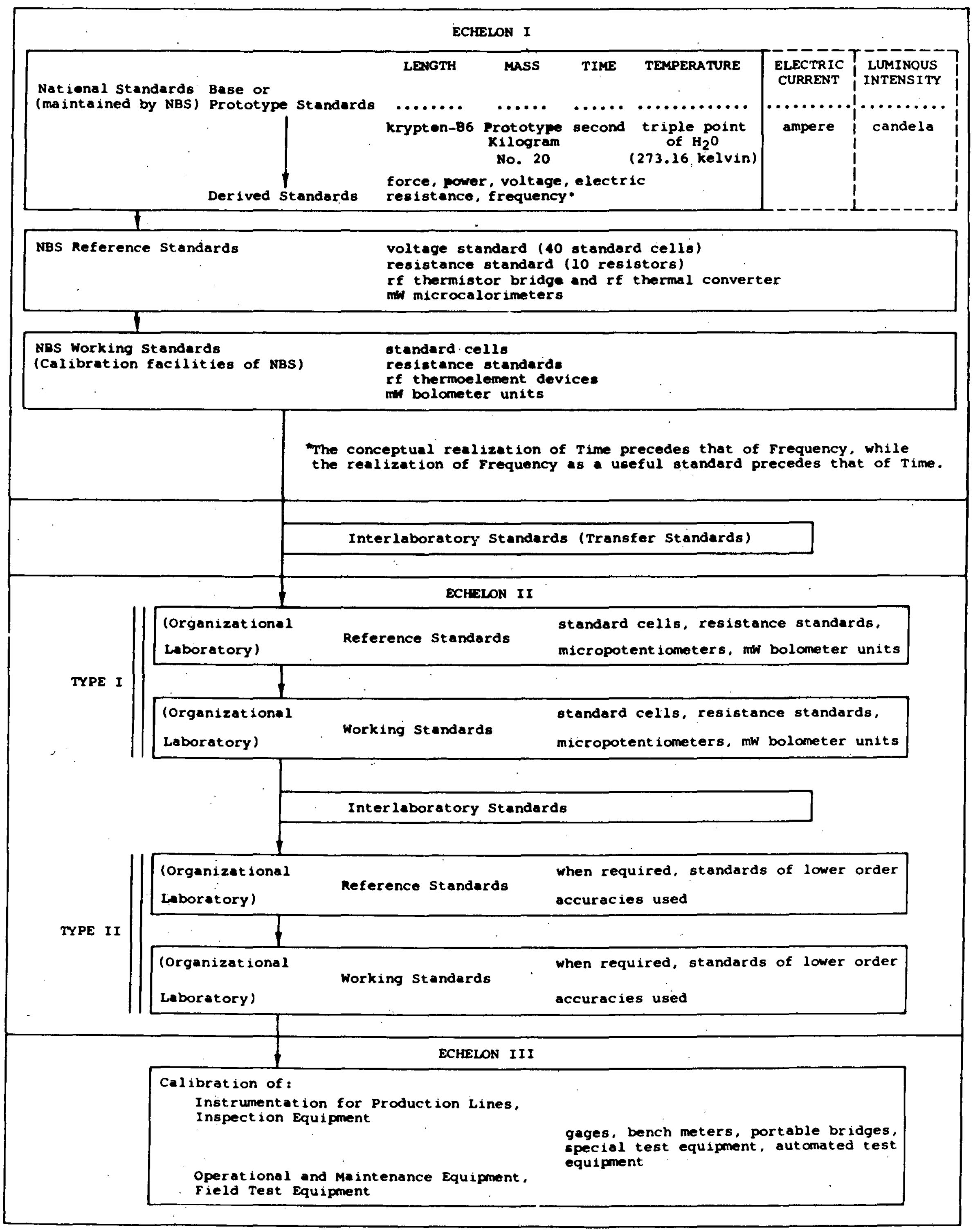


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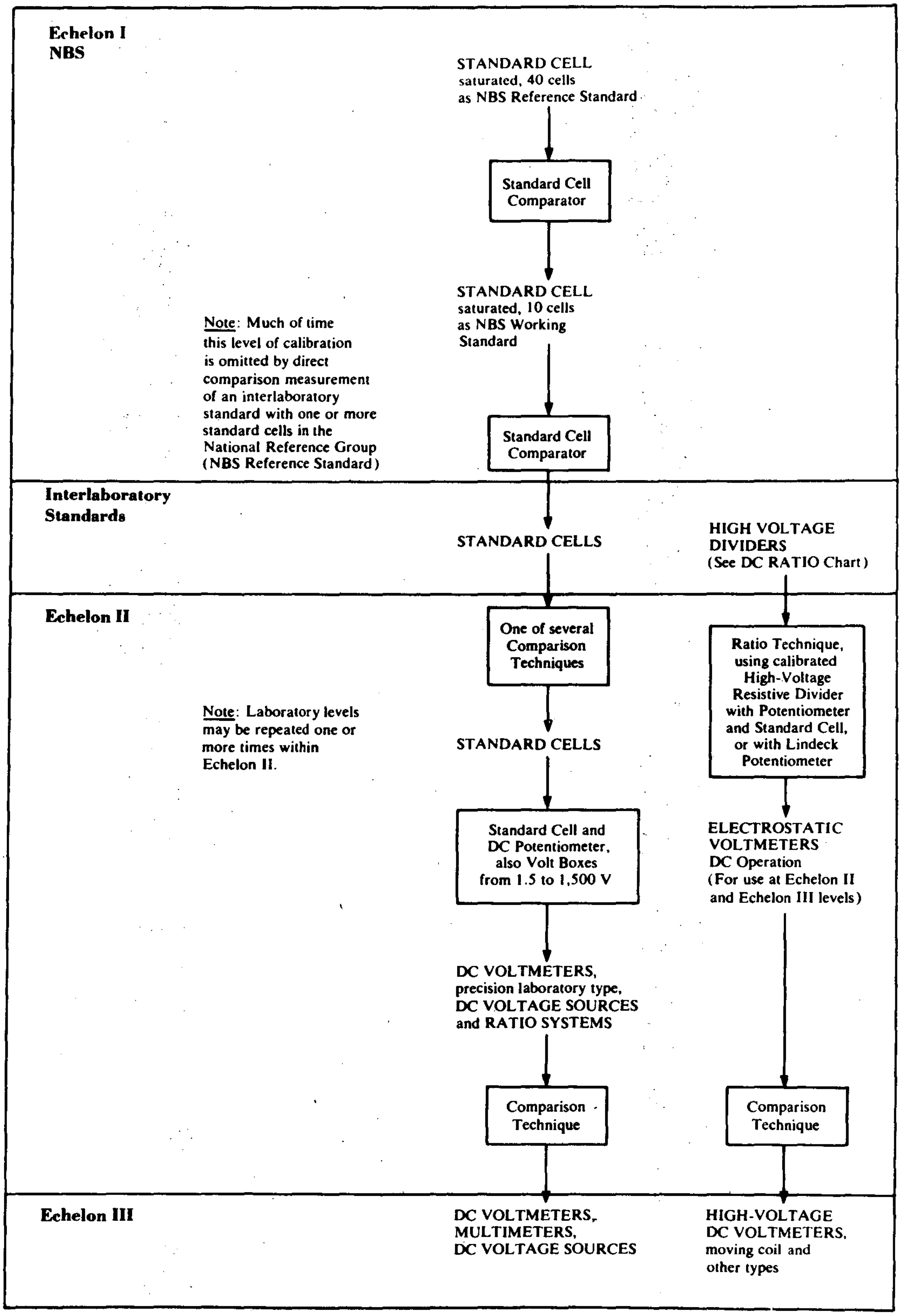
Fig. 2 An echelon of standards for a general measurement system.

(Ref. 11)



XBL 768-10145

Fig. 3 An echelon of DC voltage measurement standards.

(Ref. 16)

Working standards are derived from our Laboratory reference standard by means of a Gildline potentiometer which has a resolution of 0.5 ppm. This unit provides us with voltages between 1 μV and 2V. See Fig. 4. For higher voltages we employ a Leeds and Northrup voltbox calibrated by NBS with a resolution of better than 10 ppm.

Finally, Echelon III in Fig. 3 is illustrated by bench type digital voltmeters and portable volt-ohm-milliammeters that are employed throughout the Laboratory. These instruments are brought to our meter calibration shop perhaps once a year for recalibration and any necessary maintenance. See Fig. 5 and 6.

Although the calibration of voltmeters has been used as an illustration, a similar procedure is available for calibrating precision resistors, shunts, and portable ohmmeters. This calibration procedure is illustrated by the chart in Fig. 7. Several precision resistors are shown in the foreground of Fig. 8.

Brightness temperature may be calibrated by means of an optical pyrometer certified by the NBS. The uncertainty in calibration is $\pm 3^{\circ}$ at 1063°C. See Fig. 9.

VII. TIME AND FREQUENCY STANDARDS

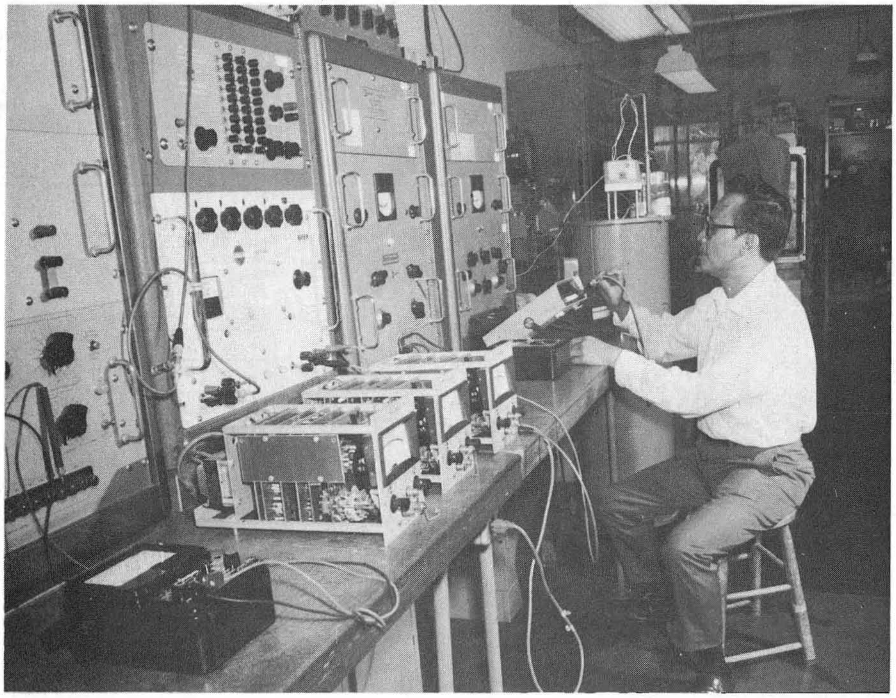
For many centuries astronomical observations were the primary means by which the passage of time was recorded. Indeed, early Egyptians were famous for their observations of the heavens. In recent decades the quartz resonator became an accepted standard frequency source, or in other words, a time standard. With appropriate electronic frequency dividers the resonating frequency of a quartz plate can be reduced to seconds, minutes and hours.

However, scarcely more than a decade ago time keeping took another quantum leap forward with the institution of cesium beam frequency standards.[8,9,10,12,13,14] The cesium beam standard employs an invariant atomic frequency to stabilize a high quality quartz oscillator. The long term stability of such a standard is generally better than 3 parts in 10^{12} for the life of the cesium beam tube which has an expectancy of more than 1 year.[10] Obviously the cesium beam tube must be readily reproducible.

A rubidium vapor frequency standard makes an excellent short term standard but must be calibrated against another reference such as a cesium standard.

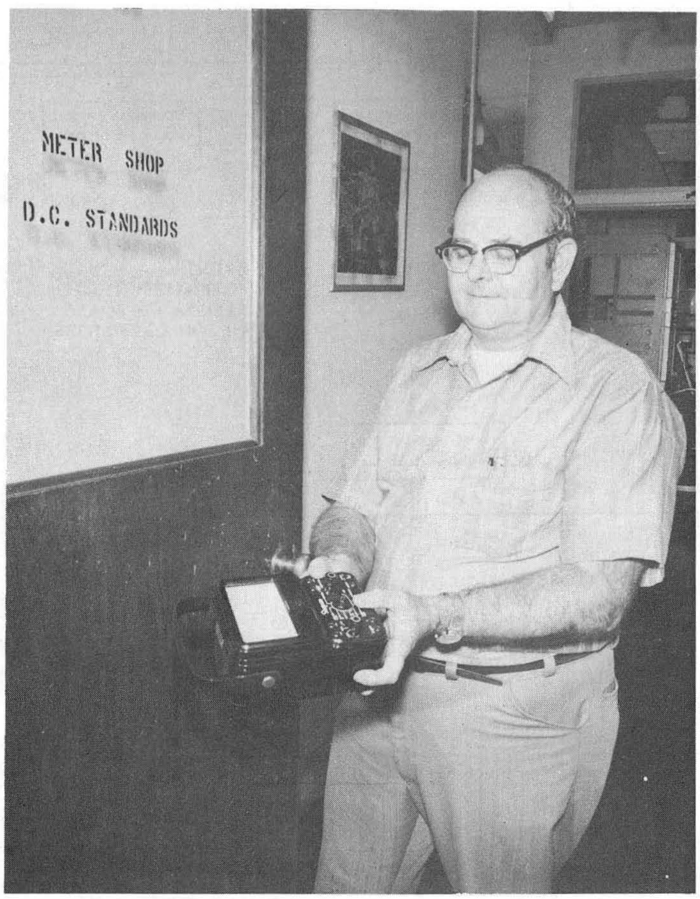
CBB 767-6763

Fig. 4 Voltage standards staff inspecting potentiometer which transfers reference standard voltages to working standard voltages.



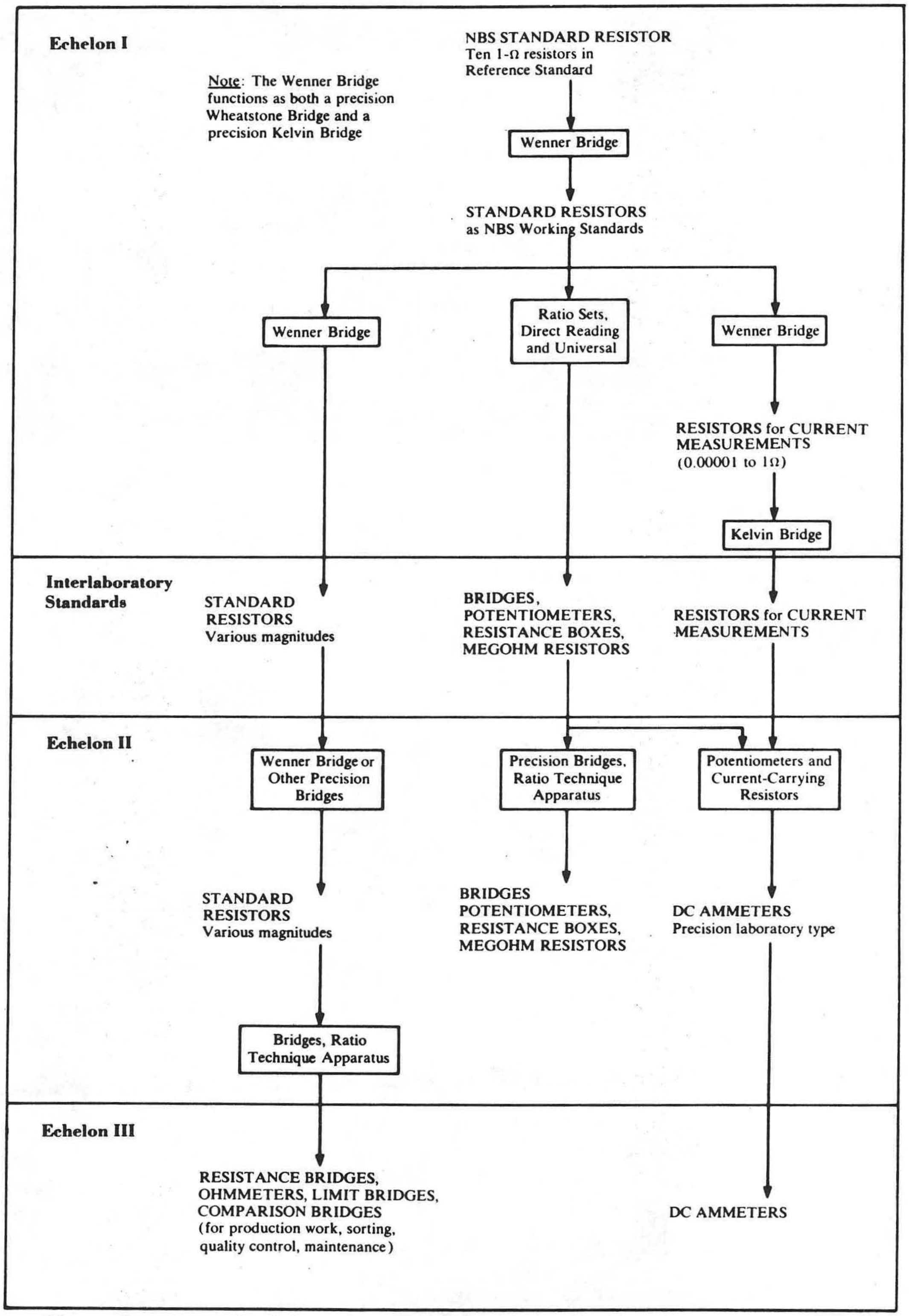
CBB 767-6779

Fig. 5 Calibration of digital voltmeters



CBB 767-6759

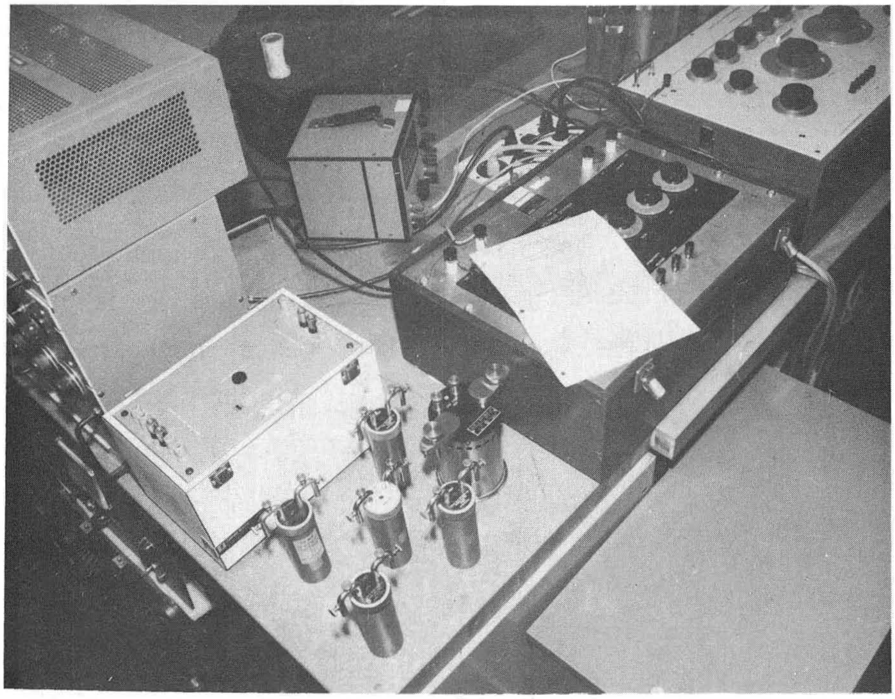
Fig. 6 Portable volt-ohm-milliammeter returned for calibration.



*These numbers refer to the list of references.

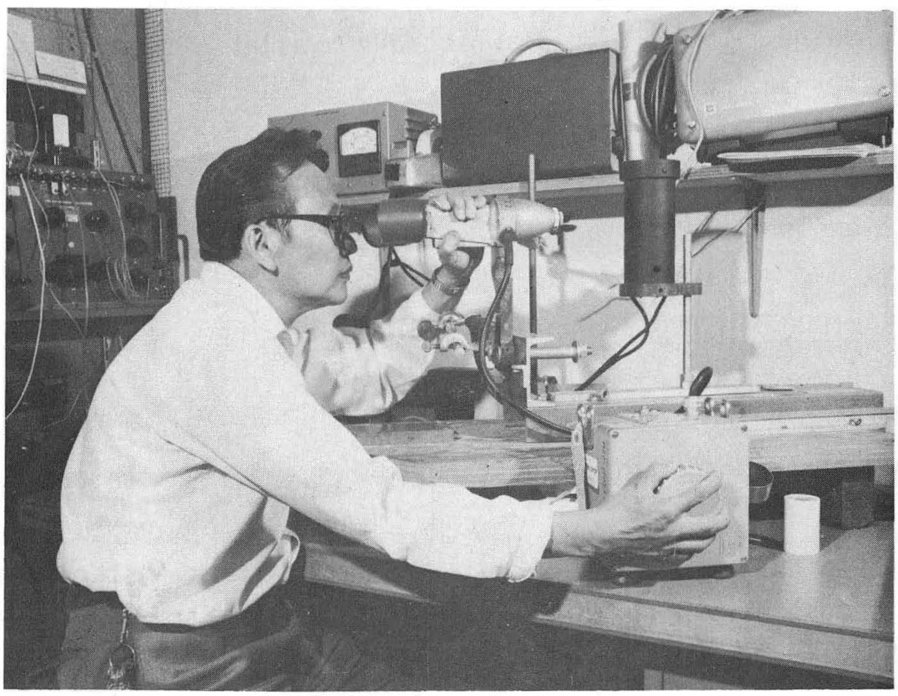
XBL 768-10143

Fig. 7 An echelon of DC and low frequency resistance measurement standards. (Ref. 17)



CBB 767-6751

Fig. 8 Precision resistors in calibration laboratory.



CBB 767-6773

Fig. 9 Technical staff member calibrating brightness temperature source.

It is interesting to note that the precision of these new "clocks" is considerably greater than the rotation of the earth as a time standard.

Fig. 10 illustrates the national time and frequency standards available from a national facility such as the NBS. The transmission of time information from a national standard to various other research organizations is a fascinating study and the subject of many papers. One of the most interesting was an airplane flight in 1967 in which Hewlett-Packard engineers transported two portable self-contained cesium beam frequency standards around the world. Fifty-three locations in 18 countries were successfully time correlated to within approximately 10^{-7} seconds.[10,15]

Where the highest accuracy is not required, time information can be transmitted from standard frequency radio stations preferably via a frequency that avoids ionospheric reflections.

Our Laboratory frequency standard (see Fig. 11) is a special low frequency receiver tuned to Station WWVB at Fort Collins, Colorado. The receiver output is used to stabilize a 5 MHz quartz crystal frequency standard. A locally designed frequency divider generates 1, 10, 100, 10^3, 10^4, and 10^5 Hz sine waves and 10^4 and 10^5 Hz square wave signals which are available to other parts of the building.

Fig. 12 is an illustration of a frequency synthesizer which is being serviced. After completion of the servicing it will be recalibrated with the standard frequency signals described above.

VIII. CALIBRATION PROCEDURES AND FACILITIES

In the previous section procedures were discussed for transferring information from reference or working standards via interlaboratory transfers to a local laboratory. In the case of time and frequency, the information can be transmitted via low frequency radio signals. In most other instances the local laboratory reference must be shipped or carried to the national standard facility for calibration. Services for calibrating laboratory standards are available from many sources. For example, the National Bureau of Standards offers to calibrate many hundreds of physical standards ranging from basic units such as mass, volume and density to the more specialized services such as vacuum ultraviolet spectral radiance standards.[6]

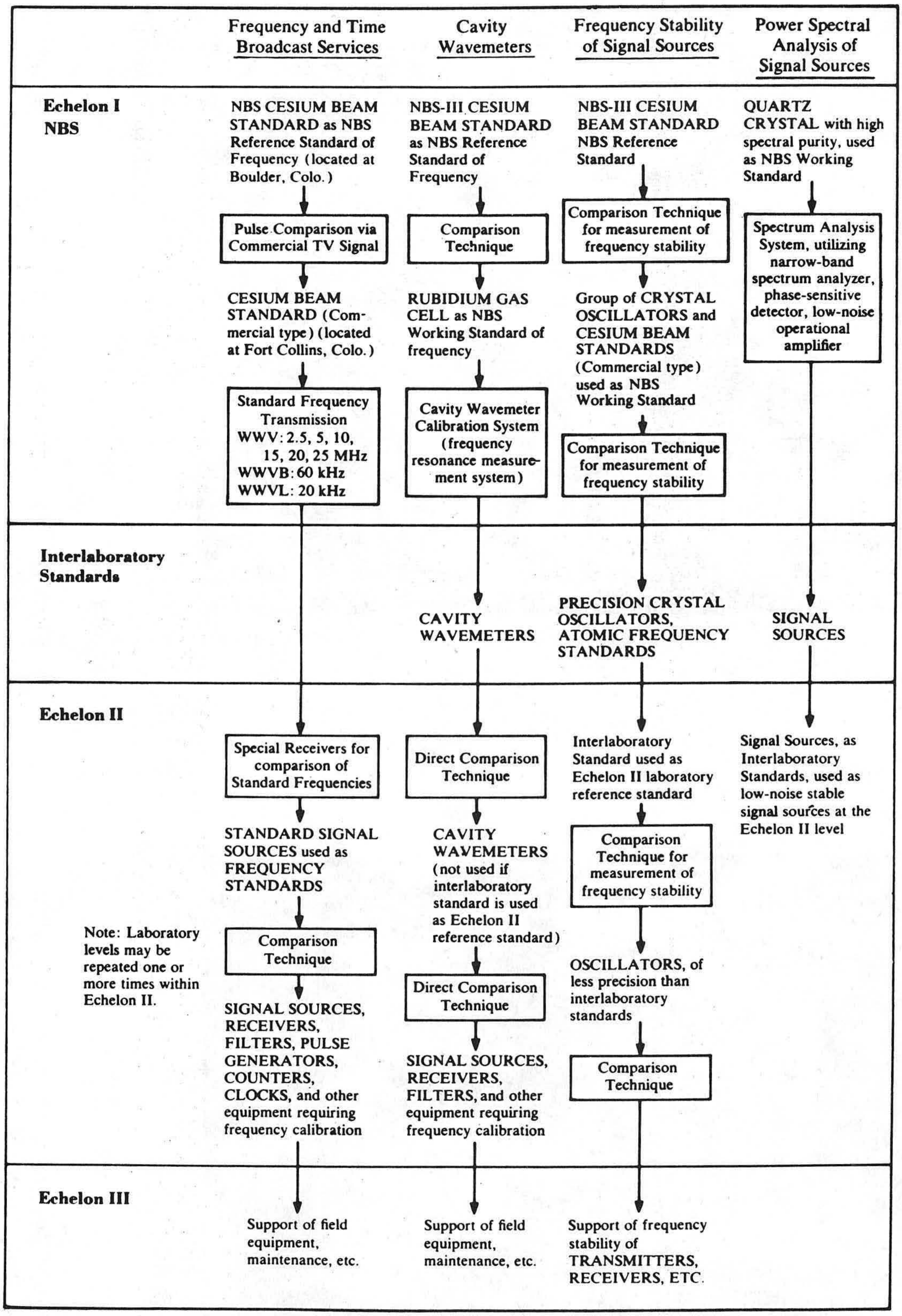


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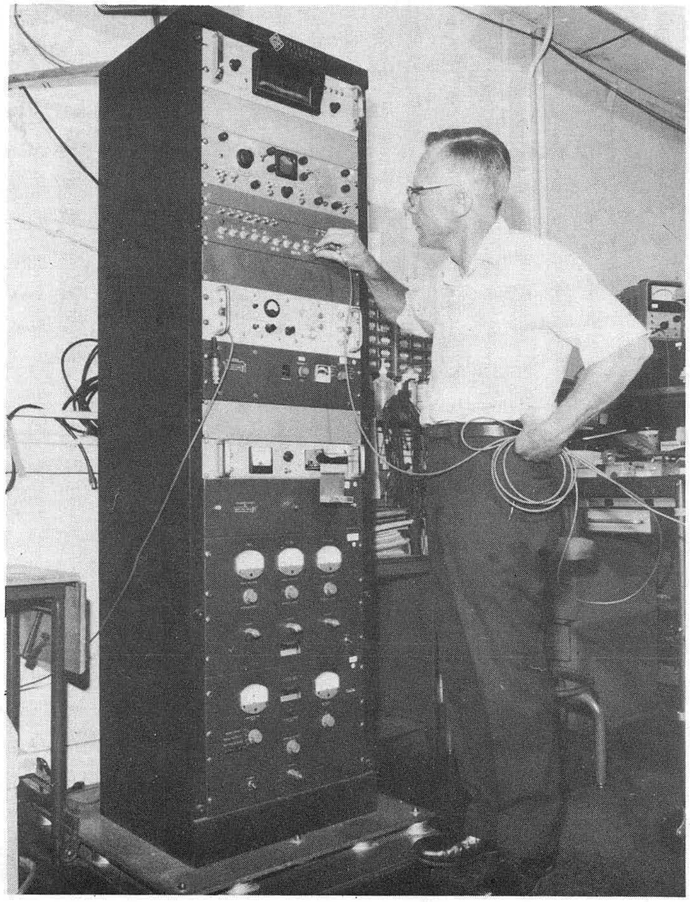
Fig. 10 Chart of basic frequency standards and traceability of frequency. (Ref. 18)



CBB 767-6807

Fig. 11 Staff member connecting an output signal from LBL frequency standard.

CBB 767-6791

Fig. 12 Maintenance and calibration of General Radio frequency synthesizer.

Originally the NBS issued Certificates of Calibration indicating that a particular standard had been physically taken to the Bureau and a calibration conducted there. The certification also usually stated that the device could be expected to remain within a certain value for 1 year. Since 1963 NBS has been issuing Reports of Calibration which give essentially the same information as the Certificate but make no claim of the expected calibration life. See Fig. 13.

Manufacturers of precision standards often issue certificates of their own traceable back to NBS. Fig. 14 is a copy of a Certificate issued by the Eppley Laboratory, Inc., for a standard cell.

Our own Laboratory performs numerous checks and calibrations; these are of a much less formal nature. The calibration information is usually placed in a log book and the fact that it has been serviced noted on a tag attached to the instrument. See Fig. 15.

Now let us discuss the working space required for standards and calibration services. At our facility the standards laboratory for voltage, current, resistance and temperature calibration have for historical reasons been located on one floor of a building. See Fig. 16. This area of approximately 114 m^2 is also used for the maintenance and repair of meters, chart recorders, shunts and similar DC or low frequency devices. The calibration of high voltage dividers is made in one room of this shop. Another area in the same building has been set aside for the calibration and maintenance of oscilloscopes, signal generators, digital voltmeters, power supplies, mobile radios and intercommunications sets. The Laboratory time standard is located here. This area shown in Fig. 17 is about 272 m^2.

The servicing of nuclear instrumentation employed directly in the investigation of various physical research experiments is ordinarily undertaken in yet other laboratories adjacent to these research areas.

IX. SUMMARY

This report is a brief study of a remarkably diverse and complex field. Many research workers spend an entire lifetime exploring the problems of quantifying one of the physical principles or constants under discussion. Reference to reports in the Reference section is recommended for further study.

FORM NBS-318
(7-1-63)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

NATIONAL BUREAU OF STANDARDS

REPORT OF CALIBRATION

STANDARD RESISTOR

Submitted by

University of California
Berkeley, California

Maker	Maker's serial number
Leeds and Northrup Company	726253

Resistance, Ohms
0.9999954

Temperature, °C	Resistance uncertainty, %
25.0	0.0001

For the Director

Chester Peterson, Chief
Resistance and Reactance Section
Electricity Division

Test No. 1.1/179086
Date: December 30, 1963
Reference: 9448306

(Over)

USCOMM-DC 18526-P63

Fig. 13 Report of calibration.

EPLAB

THE EPPLEY LABORATORY, INC.
SCIENTIFIC INSTRUMENTS
NEWPORT, R.I.
U.S.A.

CERTIFICATE

FOR

EPPLEY STANDARD CELL

CAT. NO. 100

SERIAL NO. 855794

The electromotive force of the above cell is

1.01926 Volts at 22°C.

This value, correct to 0.00001 volts, is the mean of a series of measurements concluded May 11, 1976, and is accurate to within 0.005% for a period of one year from the date of this certificate, as long as the cell is maintained at a temperature between 15°C and 30°C. The above value is in terms of Eppley reference standards and is traceable to the National Bureau of Standards, Washington, D. C., through test no. 212275 dated 5/6/75

This is a cadmium cell of the unsaturated type. Such cells have a temperature coefficient that is negligible within the ordinary range of room temperatures. Abrupt changes in temperature may, however, produce temporary variations greater than one hundreth of 1 per cent in the electromotive force.

Precautions in using standard cells: (1) If 0.005% accuracy is required the cell should be used within the termperature range specified above, or between 4°C and 40°C if 0.01% accuracy is satisfactory. (2) Abrupt changes in temperature should be avoided. (3) All parts of the cell should be at the same temperature. (4) Current in excess of 0.0001 ampere should never pass through the cell. (5) The electromotive force of the cell should be redetermined upon the expiration of this certificate.

The standard cell for which this is a certificate of value is sold subject to the mutual agreement that it is warranted by us free from defects of material and of construction, which warranty we will make good by replacing or repairing at our laboratory any defective material or construction which becomes apparent within one year after the equipment is received, without charge for this service; but that we assume no liability for consequential damages of any kind, and that the purchaser by the acceptance of this equipment will assume all liability for the consequences of its use or misuse by the purchaser, his employees, or others.

Newport, R. I.

May 11, 1976

(This certificate expires one year from above date)

THE EPPLEY LABORATORY, INC.
By George B. Jennings

Fig. 14 Certificate of a standard cell.

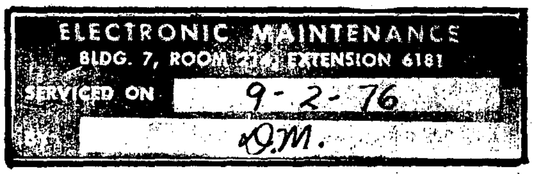


Fig. 15

LBL Maintenance Service Tag

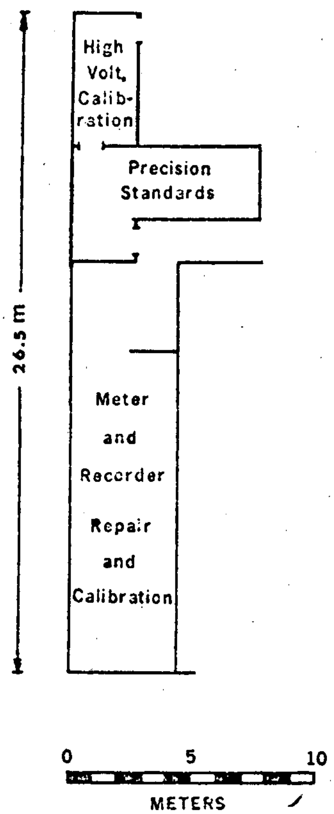


Fig. 16.

STANDARDS AND METER SHOP

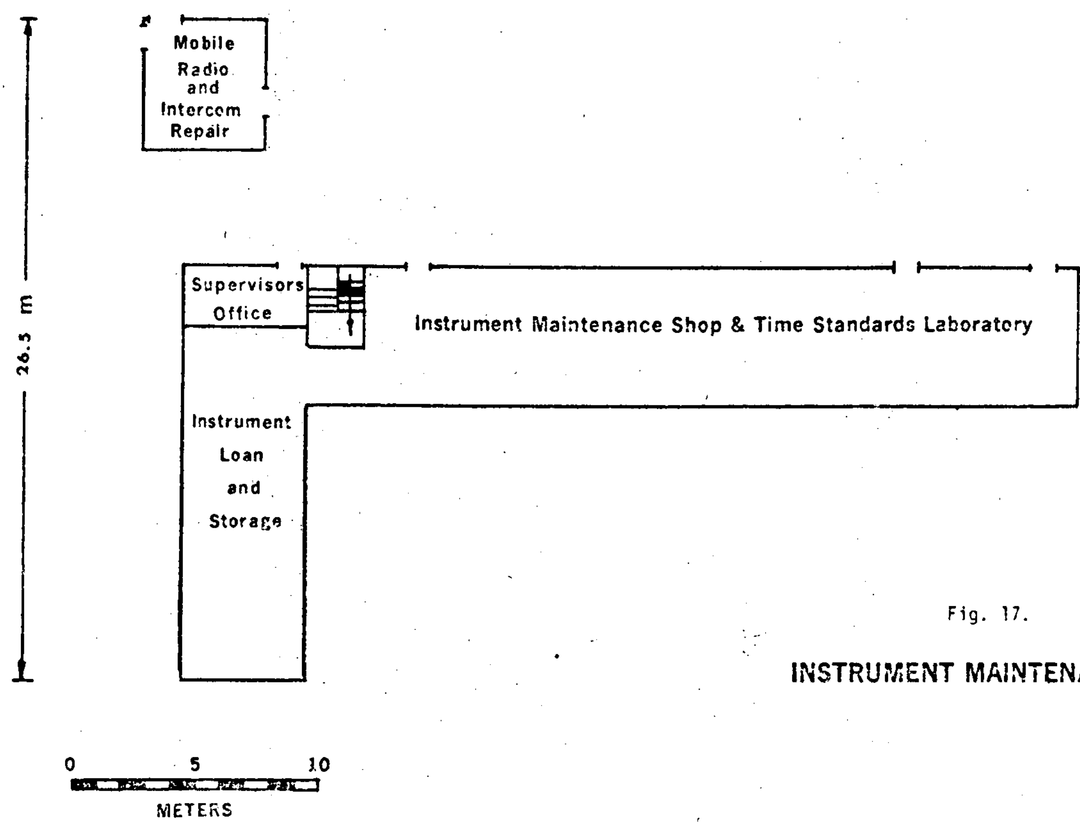


Fig. 17.

INSTRUMENT MAINTENANCE SHOP

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Lillian A. Wirth for its preparation.

APPENDIX A

International System of Units for Physical Measurement

Quantity	Unit	Symbol	Derivation
Base units			
Length	Meter	m	
Mass	Kilogram	kg	
Time	Second	s	
Electric current	Ampere	A	
Thermodynamic temperature	Degree Kelvin	K	
Light intensity	Candela	cd	
Supplementary units			
Plane angle	Radian	rad	
Solid angle	Steradian	sr	
Derived units			
Area	Square meter	m^2	
Volume	Cubic meter	m^3	
Frequency	Hertz	Hz	(s^{-1})
Density	Kilogram per cubic meter	kg/m^3	
Velocity	Meter per second	m/s	
Angular velocity	Radian per second	rad/s	
Acceleration	Meter per second squared	m/s^2	
Angular acceleration	Radian per second squared	rad/s^2	
Force	Newton	N	$(kg \cdot m/s^2)$
Pressure	Newton per square meter	N/m^2	
Kinematic viscosity	Square meter per second	m^2/s	
Dynamic viscosity	Newton-second per square meter	$N \cdot s/m^2$	
Work, energy, quantity of heat	Joule	J	$(N \cdot m)$
Power	Watt	W	(J/s)
Electric charge	Coulomb	C	$(A \cdot s)$
Voltage, potential difference, electromotive force	Volt	V	(W/A)
Electric field strength	Volt per meter	V/m	
Electric resistance	Ohm	Ω	(V/A)
Electric capacitance	Farad	F	$(A \cdot s/V)$
Magnetic flux	Weber	Wb	$(V \cdot s)$
Inductance	Henry	H	$(V \cdot s/A)$
Magnetic flux density	Tesla	T	(Wb/m^2)
Magnetic field strength	Ampere per meter	A/m	
Magnetomotive force	Ampere	A	
Flux of light	Lumen	lm	$(cd \cdot sr)$
Luminance	Candela per square meter	cd/m^2	
Illumination	Lux	lx	(lm/m^2)
Wave number	1 per meter	m	
Entropy	Joule per kelvin	J/K	
Specific heat	Joule per kilogram-kelvin	J/kgK	
Thermal conductivity	Watt per meter-kelvin	W/mK	
Radiant intensity	Watt per steradian	W/sr	
Activity of a radioactive source	1 per second	s^{-1}	

XBL 768-10142

(Ref. 19)

APPENDIX B (Ref. 10 and 20)

Representative International Standards Organizations

Arab Organization for Standardization and Metrology (ASMO), 11 Marashly St., Zanalek, P. O. Box 690, Cairo, Egypt

Bureau International de l'Heure (BIH), 61, Avenue de l'Observatoire, 75014, Paris, France

International Bureau of Weights and Measures, 92 Severes, France

International Commission on Radiation Units and Measurements, 4201 Conn. Ave., N.W., Washington, DC 20008

International Electrotechnical Commission (IEC), 1, Rue de Varembe, 1211 Geneve 20, Switzerland

International Standards Organization (ISO)

Representative National Standards Organizations

Commission National de l'Heure (F), Paris, France

Deutsches Hydrographisches Institut (DHI), Hamburg, West Germany

Direction Generale des PTT (PTCH), Berne, Switzerland

Egyptian Organization for Standardization (EOS), Cairo, Egypt

Instituto Elettrotecnico Nazionale (IEN), Torino, Italy

Laboratoire d'etat de l'etalon de temps et de frequence (URSS), USSR

National Institute for Standards (NIS), Cairo, Egypt

National Physical Laboratory (NPL), Teddington, Middlesex, England

National Physical Research Laboratory (NPRL), Pretoria, South Africa

National Research Council of Canada (NRC), Ottawa, Canada

Physikalisch-Technische Bundesanstalt Braunschweig (PTB), West Germany

Research Institute of National Defence (FOA), Stockholm, Sweden

Royal Greenwich Observatory (RGO) Herstmonceux, England

Telecommunication Laboratories (TCL), Taiwan, Republic of China

U.S. National Bureau of Standards (USNBS), Washington, DC 20234

U.S. Naval Observatory (USNO), Washington, DC

Ustav Radiotechniky a Electroniky (URE), Prague, Czechoslovakia

Zentralinstitut Physik der Erde (ZIPE), Potsdam, East Germany

APPENDIX C

U. S. NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] was established by an act of Congress March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Institute for Computer Sciences and Technology, and the Office for Information Programs.

The Bureau's four periodicals are addressed to specific NBS audiences:

THE NBS JOURNAL OF RESEARCH reports National Bureau of Standards research and development in physics, mathematics, and chemistry. It is published in two sections, available separately: PHYSICS AND CHEMISTRY (SECTION A) carries papers of interest primarily to scientists working in these fields. This section covers a broad range of physical and chemical research, with major emphasis on standards of physical measurement, fundamental constants, and properties of matter. Issued six times a year. MATHEMATICAL SCIENCES (SECTION B) carries studies and compilations designed mainly for the mathematician and theoretical physicist. Topics in mathematical statistics, theory of experiment design, numerical analysis, theoretical physics and chemistry, logical design and programming of computers and computer systems. Short numerical tables. Issued quarterly.

DIMENSIONS/NBS (formerly Technical News Bulletin). Published monthly to inform scientists, engineers, businessmen, industry, teachers, students, and consumers of the latest advances in science and technology, with primary emphasis on the work at NBS. The magazine highlights and reviews such issues as energy research, fire protection, building technology, metric conversion, pollution abatement, health and safety, and consumer product performance. In addition, it reports the results of Bureau programs in measurement standards and techniques, properties of matter and materials, engineering standards and services, instrumentation, and automatic data processing.

THE JOURNAL OF PHYSICAL AND CHEMICAL REFERENCE DATA (JPCRD). Published quarterly by the American Chemical Society and the American Institute of Physics for the National Bureau of Standards. The objective of the Journal is to provide critically evaluated physical and chemical property data, fully documented as to the original sources and the criteria used for evaluation. Critical reviews of measurement techniques, whose aim is to assess the accuracy of available data in a given technical area, are also included. The principal source for the Journal is the National Standard Reference Data System (NSRDS). The Journal is not intended as a publication outlet for original experimental measurements such as are normally reported in the primary research literature, nor for review articles of a descriptive or primarily theoretical nature. See also National Standard Reference Data Series below.

NBS nonperiodical publications:

MONOGRAPHS - major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

HANDBOOKS - recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

SPECIAL PUBLICATIONS - include proceedings of conferences sponsored by NBS, NBS annual reports, and other publications appropriate to this grouping (such as wall charts, pocket cards, and bibliographies).

APPLIED MATHEMATICS SERIES - mathematical tables, manuals, and studies of special interest to physicists, engineers, chemists, biologists, mathematicians, computer programmers, and others engaged in scientific and technical work.

NATIONAL STANDARD REFERENCE DATA SERIES - provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a worldwide program coordinated by NBS.

BUILDING SCIENCE SERIES - disseminates technical information developed at the Bureau on building materials, components, systems, and whole structures. The series presents research results, test methods, and performance criteria related to the structural and environmental functions and durability and safety characteristics of building elements and systems.

TECHNICAL NOTES - studies or reports which are complete in themselves but restrictive in their treatment of a subject. Analogous to monographs but not so comprehensive in scope or definitive in treatment of the subject area. Often serve as a vehicle for final reports of work performed at NBS under the sponsorship of other government agencies.

VOLUNTARY PRODUCT STANDARDS - developed under procedures published by the Department of Commerce in Part 10, Title 15, of the Code of Federal Regulations. The purpose of the standards is to establish nationally recognized requirements for products, and to provide all concerned interests with a basis for common understanding of the characteristics of the products. The National Bureau of Standards administers the Voluntary Product Standards program as a supplement to the activities of the private sector standardizing organizations.

FEDERAL INFORMATION PROCESSING STANDARDS PUBLICATIONS (FIPS PUBS) - publications in this series collectively constitute the Federal Information Processing Standards Register. The purpose of the Register is to serve as the official source of information in the Federal Government regarding standards issued by NBS. FIPS PUBS will include approved Federal information processing standards information of general interest, and a complete index of relevant standards publications.

CONSUMER INFORMATION SERIES - practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

NBS INTERAGENCY REPORTS - comprise a special series of interim or final reports on work performed by NBS for outside sponsors (both government and non-government). In general, initial distribution is handled by the sponsor; public distribution is by the National Technical Information Service (Springfield, VA 22151) in paper copy or microfiche form.

NBS bibliographic subscription services:

NBS BIBLIOGRAPHIC SUBSCRIPTION SERVICES - issued by the Cryogenic Data Center and the Electromagnetics Division of the National Bureau of Standards, Boulder, Colorado. They provide interested audiences with information on latest developments in certain specialized fields. These issuances, together with subscription information are listed below.

CRYOGENIC DATA CENTER CURRENT AWARENESS SERVICE - (Publications and Reports of Interest in Cryogenics). A literature survey issued weekly.

ELECTROMAGNETIC METROLOGY CURRENT AWARENESS SERVICE - (Listing of Selected Articles on Measurement Techniques and Standards of Electromagnetic Quantities from D-C to Millimeter-Wave Frequencies). Issued monthly.

LIQUIFIED NATURAL GAS - A literature survey issued quarterly.

SEMICONDUCTING DEVICES AND MATERIALS - A literature issued quarterly.

[1]Headquarters and Laboratories at Gaithersburg, Maryland and Boulder, Colorado. Mailing address: Washington, DC 20234.

This material adapted from: National Bureau of Standards Publications Program, Bulletin LP 80, (April 1976).

APPENDIX D

The National Physical Laboratory, Teddington, Middlesex TW11 OLW, England, will provide the following upon request:

BASES OF MEASUREMENT - definition and realization at the NPL.

FUNDAMENTAL PHYSICAL CONSTANTS AND ENERGY CONVERSION FACTORS - available as a wall chart or pocket folder.

MEASUREMENT SERVICES - a series of booklets describing measurement and calibration services and facilities available from the NPL.

Colorimetry, Spectrophotometry, Photometry and Radiometry

Electrical Science - Direct Current and Alternating Current

Length, Diameter and Angle

Mass, Force, Hardness, Viscometry and Density

Optical Metrology

Pressure and Vacuum

Radiation Science

Temperature

NPL SERVICES-MATERIALS - facilities and services, consultancy services, standard materials.

NPL SERVICES-MEASUREMENT - National standards, facilities and services, consultancy services.

NPL SHIP DIVISION EXPERIMENT FACILITIES - aspects of the Division's activities are summarized and the main experiment facilities are described.

NPL TODAY - a list of items on the 1975 programme of work and the names of staff concerned with each.

A number of additional publications are listed in a brochure, "NPL Publications", and are available from Her Majesty's Stationery Office, P. O. Box 569, SE1 9NH, London, England.

This material adapted from: NPL Publications, National Physical Laboratory, Department of Industry, 1975.

APPENDIX E

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT BRAUNSCHWEIG AND BERLIN[1]

The PHYSIKALISCH-TECHNISCHE BUNDESANSTALT (PTB) IN BRAUNSCHWEIG AND BERLIN is a national institute for science and technology and the highest technical authority for metrology in the Federal Republic of Germany. It was founded in Berlin in the year 1887 as the Physikalisch-Technische Reichsanstalt (PTR) "to foster by experimental work the exact sciences and precision technique".

Publications of the Physikalisch-Technische Bundesanstalt

The results of the work of the Physikalisch-Technische Bundesanstalt are published in journals in Germany and abroad.

The headings of the publications edited in the course of one year are listed in the Annual Report of the Bundesanstalt with reference to the individual divisions.

An annual list, alphabetical and with reference to the individual divisions, is included in the PTB-Berichte (Reports from PTB) of the series PTB-L "Literaturzusammenstellungen und Veroffentlichungsverzeichnisse" (Lists of literature and publications).

Moreover, PTB publishes the following papers:

PTB-COMMUNICATIONS-RESEARCH AND TESTING (PTB-Mitteilungen-Forschen und Prufen) Scientific and official publication of PTB. The numbers comprise original contributions, short reports and references to literature of scientific publications in other technical journals, reports on legislation and legal judgements in metrology and verification, official announcements of the Bundesanstalt. The PTB-Mitteilungen are published every two months by the publishing house Friedrich Vieweg & Sohn BmbH, 3300 Braunschweig, Burgplatz 1.

ANNUAL REPORT OF PTB (Jahresbericht) From its contents: Report of the Presidential Board - research and development - tests, approvals, licenses - cooperation and consultation - scientific and technical services for the Bundesanstalt - organizational and personnel matters - reports on the results of scientific work.

PTB-REPORTS (PTB-Berichte) They comprise scientific papers and compilations printed as manuscripts which - due to their very special subject or their length - are not suited for a publication in technical journals. They are published in several series according to the fields of work.

Series of the PTB-Berichte:

PTB-Ak	Acoustics Division
PTB-APh	Atomic Physics Division
PTB-ATWD	Division of General Technical and Scientific Services
PTB-E	Electricity Division

PTB-EW	Electronic Development
PTB-FMRB	Research and Measuring Reactor, Braunschweig
PTB-JB	Berlin Institute of PTB
PTB-L	Lists of Literature and Publications
PTB-Me	Mechanics Division
PTB-ND	Neutron Dosimetry
PTB-Opt	Optics Division
PTB-Ra	Radioactivity Measurements
PTB-W	Heat Division

TESTING INSTRUCTIONS (PTB-Prufregeln) The PTB-Prufregeln shall serve as a basis and guidance for the testing and measuring instruments and working equipment. They are published in separate editions for each test object and comprise the detailed description of the testing procedures, for the necessary standard instruments and of other testing appliances. The scope of the PTB-Prufregeln does not only include the measuring instruments acceptable for verification and approval, but also other kinds of measuring instruments and objects which are tested by PTB. The Prufregeln are destined for the authorities of legal metrology, state approved test centres, supervisory bodies and test laboratories of industry and economy. A prospectus with the tables of contents refers to the published numbers.

VERIFICATION ORDER (Eichordnung) The verification order (EO) of 15th January 1975 contains all the technical legal specifications for the verification of measuring instruments to be used in commercial and official trading, traffic control and in the field of medical science, which have to be tested by official verification authorities, pursuant to the law on verification. The legal administrative regulations for approval and verification of measuring instruments, the stamp which is to be introduced and the general fundamental technical requirements are included in the general specifications (AV) of the EO. The technical requirements for construction and measurement for each measuring instrument subject to official verifications - divided into groups according to specific types of instruments - are set down in 21 EO drafts. The EO as a whole has been classified according to subject in 11 single volumes, which are published in DIN A4 form. Deutscher Eichverlag Gmbh, 3300 Braunschweig, Burgplatz 1, Postfach 3367.

VERIFICATION INSTRUCTIONS (Eichanweisung) General administrative regulations for the verification of measuring instruments of June 12, 1973. Bundesanzeiger Verlagsgesellschaft mbH, Koln.

TECHNICAL DIRECTIVES (Technische Richtlinien) Information and recommendations for the state approved test centres for electricity meters (for pyrometers, in preparation).

UNITS IN METROLOGY (Einheiten im MeBwesen) Law on units to be used in metrology, version of July 6, 1973, with explanatory annotations concerning the amendment of the law. Deutscher Eichverlag BmbH, 3300 Braunschweig, Burgplatz 1, Postfach 3367.

INFORMATION BROCHURES (Informationsbroschuren) These brochures give a short survey of the organization and activities of the Bundesanstalt as well as of the fields of work of the various divisions.

The following titles are obtainable or to be published in the near future:

Physikalisch-Technische Bundesanstalt - An Outline (in German and English)

Mechanics Division
Electricity Division
Heat Division
Optics Division
Acoustics Division
Atomic Physics Division
Research and Measuring Reactor, Braunschweig, FMRB
Division of General Technical and Scientific Services
Berlin Institute

} in German

PRESS RELEASES (Presse-Informationen) These papers contain topical information on special projects or events.

[1]Addresses:

Physikalisch-Technische Bundesanstalt
33 Braunschweig, Bundesallee 100, West Germany

Berlin Institute of the Physikalisch-Technische Bundesanstalt
1 Berlin 10 (Charlottenburg), Abbestr. 2-12, West Germany

This material adapted from: Physikalisch-Technische Bundesanstalt - An Outline, PTB '75.

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3. Robert M. Bensancon, The Encyclopedia of Physics, 2nd Ed., Van Nostrand Reinhold (1974).

4. H. J. Gray and Alan Isaacs, A New Dictionary of Physics, Longman (1975).

5. Environmental Instrumentation Group, "Instrumentation for Environmental Monitoring", Lawrence Berkeley Laboratory Report LBL-1, Vol. 2, Water, Calibration, Technical Information Dept., Lawrence Berkeley Laboratory, Berkeley, CA (1976).

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10. Hewlett-Packard, "Fundamentals of Time and Frequency Standards", Application Note 52-1, Hewlett-Packard, Inc. (March 1974).

11. Ref. 2, p. 2-11.

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17. Ref. 2, p. 3-7.

18. Ref. 2, p. 3-61

19. McGraw-Hill Encyclopedia of Science and Technology. Vol. 10, McGraw-Hill (1971).

20. H. Steffen Peiser, National Bureau of Standards, Private Communication.

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