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1978 EDITION

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Calibration and Related Measurement Services of the National Bureau of Standards

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1978 EDITION

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Office of Measurement Services
National Bureau of Standards
Washington, D.C. 20234

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FOREWORD

NBS Special Publication 250 provides detailed descriptions of the currently available NBS calibration services, measurement assurance programs, and other measurement services. This revised edition reflects the services available as of the fourth quarter of 1977. Future editions of SP250 will be published periodically as NBS services change. SP250 was last issued in 1970, and considerable changes have occurred during the intervening years. Low-priority, little-used services have been dropped; a number of new services have been developed in response to needs of industry, other agencies, and state and local governments; and certain services have been upgraded to reflect improvements in the state of the art.

An Appendix to SP250 is published every 6 months (June and December) that lists current prices for the services described in this publication and the NBS points of contact (addresses and phone numbers) from whom additional information can be obtained. NBS will notify users of SP250 of changes in services or proposed changes in services by means of announcements in the Appendix. If you are not already on our mailing list for SP250 Appendices and wish to be, fill in and return the card at the back of this document.

Many users of this publication find it convenient to keep SP250 and the current price list (Appendix) in a three-ring binder. Since NBS is currently undergoing an extensive reorganization, it is important that you refer to the current issue of the Appendix in order to have up-to-date information with respect to NBS points of contact.

We call your attention to the availability of a variety of new Measurement Assurance Programs (MAP's) developed since the preceding edition of SP250. These are carefully designed quality control programs for critical measurements that allow the user to achieve a high level of confidence that the measurements being made in his/her laboratory are consistent with national standards and adequate for their intended use. As noted in the text, Measurement Assurance Programs are available for some traditional units (e.g., mass) and for some units associated with new technologies (e.g., laser power and energy).

The Office of Measurement Services welcomes suggestions on how this publication can be made more useful to those who rely on NBS measurement services. Suggestions are also welcome concerning needs for new calibration services, measurement assurance programs, or other measurement services.

BRIAN C. BELANGER, *Chief*
Office of Measurement Services

ABSTRACT

This publication provides detailed descriptions of the currently available NBS calibration services, measurement assurance programs, and other measurement services. In addition, each section describing specific services contains references to additional publications giving even more detail about the measurement techniques and procedures used. This revised edition reflects the services available as of the fourth quarter of 1977. NBS Special Publication 250 was last issued in 1970. The Appendix to SP250 is reviewed every 6 months (June and December). It lists current prices for the services described in this publication and the NBS points of contact (addresses and phone numbers) from whom additional information can be obtained.

Key words: calibration; measurement assurance; measurement services; standards; traceability.

EDGE INDEX

CONTENTS

Calibration and Related Measurement Services of the National Bureau of Standards

CHAPTER I

I. General Information

A. Purpose of This Publication—Introduction

A critical portion of the total mission of the National Bureau of Standards, a major technical arm of the Department of Commerce, is to provide the basis for a complete and consistent national system of physical measurements. The Bureau accomplishes this in a variety of ways, the calibration of instruments and devices being one of the most familiar. The purpose of this publication is to describe the calibration services that NBS provides to industry, other government agencies (federal, state, and local), and the general public, and to explain how to obtain these services. The legislative authority for this service is described in section K.

The calibration of standards and instruments is a widely used method of providing tie points to national standards. However, a number of other kinds of services relating to physical measurements are available, including:

(1) The broadcast of time and frequency signals
(2) Technical reports, monographs, and other publications
(3) Precision Measurement Seminars, talks, and other training aids
(4) Consultation and advisory services
(5) Use of NBS facilities in special cases*

These services are discussed in the main body of the text of this publication.

The Bureau also provides services in the following areas not covered in depth by this publication (see ch. XI for further details):

Standard Reference Materials
Standard Reference Data
Interlaboratory Testing Program (for engineering materials)
Product Standards (Specifications) Information
Engineering Tests
Laboratory Accreditation

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*Opportunity is afforded for collaborative work in the NBS facilities primarily through two programs. The Research Associate Program is a plan which enables scientists and engineers from industrial, professional, trade, and other organizations to work for specified periods (usually 1-2 years) on a full time basis under the sponsorship of their employers. Participants perform independent research having non-proprietary objectives within the scope of NBS interest. For further information, contact:

Industrial Liaison Officer
Room A402, Admin. Bldg.
National Bureau of Standards
Washington, D.C. 20234

A similar program, the Guest Worker Program, permits collaboration on an individual basis without the involvement of a sponsoring organization. In it an individual has the use of NBS facilities to pursue work benefiting NBS objectives. He must waive compensation and government liability for injury, death, or personal property damage.

Those who must make quality measurements consistent with national standards have available a wide variety of NBS measurement services from which to choose. NBS staff will provide assistance to users regarding the appropriateness of particular NBS services for individual measurement problems.

The Headquarters of the National Bureau of Standards is located in Gaithersburg, Maryland, approximately 25 miles northwest of Washington, D.C. In addition to the large office/laboratory complex in Gaithersburg, the Bureau maintains a major facility at Boulder, Colorado, which houses the offices and laboratories for electromagnetics, cryogenics, time and frequency, and quantum physics. Certain calibrations are performed in Gaithersburg while others are performed in Boulder. Accordingly, it is necessary to determine at which location the particular calibration desired is available, so that your instrument or device can be shipped to the proper location. In the Appendix to this publication it is clearly indicated whether a particular calibration is performed in Boulder or in Gaithersburg.

SP 250 is available at the following places:

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

Office of Measurement Services, National Bureau of Standards, Washington, D.C. 20234.

Field offices of the Office of Field Services, Department of Commerce.

Program Information Office, National Bureau of Standards, Boulder, Colorado 80303.

Federal Depository Libraries.

The Appendix listing current services and fees is issued twice yearly (June and December) and is available free from

Office of Measurement Services
National Bureau of Standards
Washington, D.C. 20234

Program Information Office
National Bureau of Standards
Boulder, Colorado 80303

B. How to Use This Publication

The chapters in this publication describing the calibration services are arranged according to technical discipline lines, which to some extent parallel the organizational structure of the Bureau. An index is provided to assist in locating particular calibrations.

The following four steps provide a checklist for obtaining a calibration service from NBS:

STEP 1: Determine whether or not an NBS calibration is the best solution to your measurement problem. If necessary, contact the appropriate person in NBS to discuss your particular needs. (Refer to the Appendix for NBS points of contact.) For some measurement problems, the use of a Standard Reference Material, Standard Reference Data or other Bureau services may be the best solution. Upon request NBS will provide detailed information on the services described in chapter XI.

Private metrology laboratories offering services to the general public can be found throughout the United States It is not uncommon to find laboratories which, in certain areas of specialty, are capable of making accurate measurements on a par with those made at NBS. Generally speaking, NBS' services are aimed at those special calibrations which are not readily available elsewhere and high accuracy calibrations required for direct reference to national standards. Accordingly, employing the services of a reputable private calibration laboratory may be a perfectly adequate and cost effective solution to many commonly encountered calibration problems. Two national organizations that can provide information regarding names and addresses of private calibration and test laboratories are:

National Conference of Standards Laboratories
c/o NCSL Secretariat
National Bureau of Standards
Boulder, Colorado 80303
(303) 499-1000 Ext. 3787
(Note: NCSL Directories are also available from the Office of Measurement Services, NBS-Gaithersburg.)

American Council of Independent Laboratories, Inc.
1725 K Street NW.
Washington, D.C. 20006
(202) 659-3766

STEP 2: Locate the description of the service in this publication. Having determined that an NBS calibration is warranted, the next step is to use the index in this book to find the description of the particular service of interest. If your technical questions are not answered by the appropriate section of this book, you may call the telephone number listed for that service for further information or write to the NBS technical point of contact indicated.

Many calibrations are listed in the fee schedule (Appendix) as being performed "At Cost." At-cost calibrations are those for which the required amount of NBS labor, materials, etc., is so variable from instrument to instrument as to make it impossible to state a fixed price. If you wish to have further information on the factors which influence the actual cost of such calibrations, it is recommended that you telephone the technical point of contact listed. Often a cost estimate or a range of cost can be provided over the telephone if the NBS staff member is given a description of the particular instrument and the desired calibration.

STEP 3: Request the calibration from NBS. Read carefully the material in section C. The purchase order should be sent to either Boulder or Gaithersburg depending on the location at which the calibration is to be performed. Many users of NBS calibrations find it convenient to schedule in advance the date of calibration by phone or letter so that the instrument or device need not be shipped to NBS until the time of its scheduled calibration approaches.

STEP 4: Prepare the instrument/device for shipping to NBS and ship. Follow the instructions in section D. *Note that the fee for calibration does not include shipping to or from NBS.*

The sections which follow provide additional information on NBS calibrations.

C. Request Procedure

A formal purchase order for the calibration or test should be sent before or at the time the instrument or standard is shipped. This should provide clear identification of the apparatus being submitted and give separate instructions for return shipment, mailing of report, and billing. If you wish to minimize the time during which your equipment is out of service, you can usually arrange to delay shipment until the test is scheduled to start. Requests from Federal agencies, or from State agencies, for calibrations or tests on material to be used on private or Federal contract work, should be accompanied either by purchase order or by letter or document authorizing the cost of the work to be billed to the agency. The Bureau's acceptance of purchase orders does not imply acceptance of any provisions set forth in the order contrary to the policy, practice, or regulations of the National Bureau of Standards or the U.S. Government. The purchase order should clearly state special or necessary conditions of test where appropriate (i.e., operating frequency, temperature, etc.).

Requests for measurement services should be directed to the address given in the appropriate section of the Appendix (Fees for Services).

D. Shipping, Insurance, and Risk of Loss

Shipment of apparatus to NBS for calibration or other tests should be made only after the customer has accepted the estimate of cost and the tentative scheduling. Repairs and adjustments on apparatus submitted should be attended to by the owner since NBS will not undertake them except by special arrangement. Apparatus not in good condition will not be calibrated. If defects are found after calibration has begun, the effort may be terminated, a report issued summarizing such information as has been found, and a fee charged in accordance with the amount of work done.

The customer should pack apparatus sent to NBS so as to minimize the likelihood of damage in shipment and handling. In every case, the sender should consider the nature of the apparatus, pack it accordingly, and clearly label shipments containing fragile instruments or materials such as glass. Care should be taken in selecting the best mode of transportation.

To minimize damage during shipment resulting from inadequate packing, the use of strong reusable containers is recommended. As an aid in preventing loss of such containers, the customer's name should be legibly and permanently marked on the outside. In order to prolong the container's use, the notation REUSABLE CONTAINER, DO NOT DESTROY should be marked on the outside.

Shipping and insurance coverage instructions should be clearly and legibly shown on the purchase order for the calibration or test. *The customer must pay shipping charges to and from NBS; shipments from NBS will be made collect.* The method of return transportation should be stated and it is recommended that return shipments be insured, since NBS will not assume liability for their loss or damage. For long-distance shipping it is found that air freight provides an advantage in reduction of time in transit. If return shipment by parcel post is requested or is a suitable mode of transportation, shipments will be prepaid by NBS but without covering insurance. When no shipping or insurance instructions are furnished, return shipment will be made by common carrier collect and uninsured.

The risk of loss or damage in handling or testing of any item by NBS must be assumed by the customer, except when it is determined by the Bureau that such loss or damage was occasioned solely by the negligence of Bureau personnel. In such cases, the owner may apply for reimbursement.

Shipments from foreign countries which are to be transported to NBS for test, must be prearranged with a customs broker either in the country of origin or in the United States for entry of the instrument, with or without bond as may be necessary, and prepaid transportation to and from the ports of entry and exit. Entry in bond is required for all foreign made instruments shipped to NBS for calibration, whereas instruments made in the United States may be entered without bond. If arrangements are made with a broker in the country of origin the broker should, in turn, have a customs broker in or near the port of entry arrange for entry of the instrument and its transportation to the National Bureau of Standards. Direct arrangements can be made with customs brokers located in the Washington, D.C./Baltimore, Maryland area. These brokers will arrange for entry of instruments, prepaid transportation from the port of entry to the Bureau, and transportation to the port of exit after measurements have been completed. This recommendation does not preclude the use of customs brokers at ports such as Baltimore, Maryland or New York, New York if such an arrangement is preferred by the owner of the instrument. An alternative method of shipment which eliminates the need for the services of a customs broker is by air freight to the National Bureau of Standards. When shipments are made by this method the Bureau will pick up the instrument at the airport, arrange for entry in bond when necessary, and after test obtain release from bond if required and deliver the instrument to the airport for return shipment. The instrument will be returned collect with transportation charges payable at destination. Transportation by air is much more expensive than by ship but the difference is largely offset by customs broker's charges. An added advantage of air transportation is the very great decrease in the time the instruments are away from the owner's facility. The Bureau's charges for calibrations or tests will be billed separately from those of a customs broker. Prepayment of all NBS charges is required, with respect to instruments being shipped to NBS from outside the United States.

E. Priorities and Time of Completion

Scheduled work assignments for calibrations and other tests generally will be made in the order in which confirmed requests are received. However, Government work may be given priority. For the regular services, the workload is usually such that the turnaround interval, between the date a customer's apparatus is received and the date it is prepared for return shipment, will be not more than 45 days. Some types of instruments may require a considerably longer time, particularly if their abnormal behavior requires reruns to check reliability. Others can be calibrated and returned within 10 days. The customer who can spare his instrument for only a short time usually can arrange by letter or phone call for shipping it to the Bureau just as his assigned starting date approaches. Generally, the acknowledgement of the purchase order gives the expected completion date.

F. Use of NBS Reports

Reports on calibrations or other services rendered to a customer are regarded as proprietary and solely the property of the customer and will not be given to other parties without permission of the customer. The results shall not be used to indicate or imply that they are applicable to other similar items. In addition, such results must not be used to indicate or imply that NBS approves, recommends, or endorses the manufacturer, the supplier, or the user of such devices or specimens, or that NBS in any way "guarantees" the later performance of items after calibration or test.

NBS does not approve, recommend, or endorse any proprietary product or proprietary material. No reference shall be made to the Bureau or to reports or results furnished by NBS in any advertising or sales promotion which would indicate or imply that NBS approves, recommends, or endorses any proprietary product or proprietary material.

G. Units

The policy of the National Bureau of Standards is to encourage and lead in national use of the metric system, also called the SI or International System of Units. The International System of Units (SI) was defined and given official status by the 11th General Conference of Weights and Measures, 1960. A complete listing of SI units is presented in detail in NBS Special Publication 330. SI is now the dominant system used throughout the world and its use in the United States is growing. In fact, U.S. legislation to encourage metric education recognizes that it will become the dominant system in the United States (Public Law 93-380, August 1974). Public Law 94-168, "The Metric Conversion Act of 1975" serves as a national focus on the use of SI and will enhance its implementation.

The National Bureau of Standards develops and maintains the national standards of measurement including the U.S. National SI standards (both the base units, supplementary units, and numerous units derived from these). The NBS practice is to express data in SI units unless this makes communication excessively complicated. For example, commercial gage designations, commonly used items identified by nominal dimensions, or other commercial nomenclatures or devices (such as drill sizes, or commercial standards for weights and measures) expressed in customary units are an exception from this practice. However even in such instances, when practical and meaningful, SI and customary units may be given in parallel. Users of NBS calibration services may specify the units to be used in the calibration, especially for commercial devices and standards using customary units or units having some legal definition. For additional information on NBS practices and on SI see:

NBS LC1056, NBS Guidelines For Use of the Metric System

ISO—International Standard 1000, SI Units and Recommendations for Use of Their Multiples, American National Standards Institute (ANSI), 1430 Broadway, New York, New York 10018

E380-76—Standard for Metric Practice, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103 (Also available from ANSI to Z 210.1 or IEEE as 268).

Reference E380-76 is particularly valuable where precise conversion from customary or other units to SI must be made. NBS Special Publication 304A, Measurement Systems, provides a brief history of measurement systems along with a chart (in color) on the basis of the modernized metric system.

For information on metric units, direct inquiries to the National Bureau of Standards, Washington, D.C. 20234, (301) 921-2401

H. Measurement Assurance Programs

In recent years, NBS has offered to the public a new measurement service—the so-called Measurement Assurance Program ("MAP"). This section briefly explains the concept.

All measurements are made for a purpose—our health, safety, the goods we produce or use and all our technology depend on measurements. It is important that the errors of measurement be small enough so that actions taken are only negligibly affected by these errors. The overall objective involves the end result of the performance of measurement systems—the quality of measurements made by systems which include instruments, operators, environments in which they function, procedures, and special characteristics of the objects being measured. One must always carefully distinguish *system* performance from *element* performance—that is, the performance of an instrument, operator, or any other single element of the system. Adequate instrument performance in some abstract sense may be a necessary condition for adequate system performance but obviously it cannot be a sufficient condition. It is the performance of instruments under actual practical conditions of use which must be considered in approaching the problem of adequacy of the measurement effort.

It is essential to recognize that when the quality of measurements is at issue, standardization must take into account all factors influencing the uncertainty of measurements. In general, conformity to good instrument design or good calibration, while important, is not sufficient to guarantee "good" measurement.

The uncertainty of measurements will, in general, depend on the instruments, the environment in which they are used, the procedures used, the training of the operator, the treatment of measurement data, and other factors. It must be remembered that uncertainty is a property of measurements—it is not a property of instruments.

Measurement assurance (like quality control in industrial production) is the means by which one guarantees that whatever errors occur in the measurement process are kept sufficiently small to be adequate to the need. There are several elements in a measurement assurance program:

- It has its beginning in a requirement on the limit of measurement error which can be tolerated (e.g., radioactivity to ±1%)
- There must be a reference base to which the allowable error is referred (e.g., NBS Volt, NBS Kilogram)
- There must be documented technical proof of measurement uncertainty
- There must be some continuing redundancy in the system so that one is able to "sample" the quality of the measurements being made (e.g., by remeasuring a test item, or by the use of well characterized artifacts).

This redundancy should be truly indicative of system performance. If a test item is used for routine checking, it should have the characteristics of the regular workload and should be run at intervals sufficiently large to permit a full range of the factors which cause random variation.

The importance of continuing verification that the measurements are "in control" is obvious in regulatory situations where action may be taken on only a few measurements. In any legal contest one would have to show that the system had predictability—i.e., that the announced error limits were applicable at the time of measurement.

NBS has developed such programs for those whose measurement process involves the calibration of other standards. Examples include mass, voltage, voltage ratio, watthour meters, capacitance, resistance, and laser power). These depend on the development and maintenance of an "in control" measurement process by the user. NBS provides the means by which the offset of this process relative to the national reference unit can be determined. Usually this involves on-site measurements of an NBS transfer standard or suitable artifact so that all elements of the users process are involved (not just the standard as is the case when the instrument is shipped to NBS for calibration).

All who measure need to know that the errors of their measurement relative to the accepted reference are less than the allowable limit—the procedures by which this is achieved constitute a measurement assurance program whether it be the result of extensive redundancy or from performance data from produced items or similar measures of operational success.

Currently available NBS Measurement Assurance Programs are described in the main body of the text of this publication.

I. Traceability

Traceability is a term which a number of contracting and regulatory agencies have invoked to specify the standards used in the calibration of instruments.

Perhaps the first and most far-reaching traceability requirement has been that of the Dept. of Defense MIL-C-45662A, "Calibration Systems Requirements," which states (sec. 3.2.5.1):

> "Measuring and test equipment shall be calibrated by the contractor or a commercial facility utilizing reference standards (or interim standards) whose calibration is certified as being traceable to the National Bureau of Standards, has been derived from accepted values of natural physical constants, or has been derived by the ratio type of self-calibration techniques."

This specification does not define the term "traceable" (nor do those of any other government agency). However, section 3.2.3 states that:

"Measuring and test equipment and measurement standards shall be calibrated at periodic intervals.";

and section 3.2.5.1 states that:

"The Standards used in obtaining the results have been compared at planned intervals with the National Standard either directly or through a controlled system."

Without further definition, the meaning of this term is necessarily somewhat indefinite as applied to relationships between calibrations by NBS and measurement activities of manufacturers and suppliers. "Traceability" is not given any special meaning by the National Bureau of Standards, and information as to possible special meanings of the term in procurement activities cannot, of course, legally be supplied by NBS. In other words, NBS can provide you with technical advice on how to make quality measurements consistent with national standards but NBS cannot legally state what you must do to comply with a contract calling for "traceability to NBS" to which NBS is not a party. Where questions arise, it is suggested that they be directed to the cognizant inspection or contracting agency.

It is obvious that instrument calibration is not a sufficient condition for good measurement. In fact, with highly automated systems often one cannot meaningfully do the calibration outside the system. A widely held view of traceability is that it relates to properties of standards and not properties of measurement. If it is control of the latter which is desired, then traceability should be implemented by performance requirements on the measurements themselves. There will be some minimum amount of work needed to verify the adequacy of the measurement process—i.e., some measurement assurance program will be needed.

J. Policy on Collecting Fees for Services

The basic congressional directive concerning charges to the public for services is stated in 31 U.S.C. 483a, reading in part:

"It is the sense of the Congress that any work, service publication, report, document, benefit, privilege, authority, use franchise, license, permit, certificate, registration, or similar thing of value or utility performed, furnished, provided, granted, prepared, or issued by any Federal agency...to or for any person (including groups, associations, organizations, partnerships, corporations, or businesses)...shall be self-sustaining to the full extent possible..."

Services for which charges are to be made are those which provide special benefits to individuals and small segments of the public above and beyond those which accrue to the general public. Special benefits obviously accrue in the case of calibration services.

A number of guidelines have been set up in Department of Commerce Administrative Order 203-5, dated August 20, 1973, as amended including the following:

° Department of Commerce policy is to recover full cost of performing a special service, not the value to the recipient.

° However, charges or fees should not be established if they would seriously impair the objectives of programs or are against public policy.

° Department policy is to refuse to furnish special services to individuals, groups, or companies when the service would be considered in competition with commercial enterprise.

Cost elements for inclusion in charges to the public should include but not be limited to:

1. Direct costs, such as labor, accrued leave factor, personnel benefits, supplies, etc.

2. Direct and indirect supervisory costs
3. Overheads, including supporting services, depreciation on equipment, maintenance, etc.

Calculations of fees for NBS calibrations are based on the above guidelines.

K. Legislative Authority

The text of chapter I of this publication follows closely the language of Part 200, Title 15, of the Code of Federal Regulations. That issuance in the Federal Registers of December 29, 1967, July 26, 1968, December 30, 1972, and July 2, 1973, pursuant to the authority contained in 15 U.S.C. 275a and 277, incorporates by reference the full text of NBS Special Publication 250 (SP 250), "Calibration and Related Measurement Services of the National Bureau of Standards."

The recognition of the need for a consistent measurement system led to the formation of the National Bureau of Standards and in particular to the responsibility (15 U.S.C. 272) for "The custody, maintenance, and development of the national standards of measurement, and the provision of means and methods for making measurements consistent with those standards, including the comparison of standards used in scientific investigations, engineering, manufacturing, commerce, and educational institutions with the standards adopted or recognized by the Government."

Section 2 of the NBS Organic Act (15 U.S.C. 272) specifically authorizes activities related to calibration and measurement to be undertaken when the need arises in the operation of Government agencies, scientific institutions and industrial enterprises such as the testing, calibration, and certification of standards and standard measuring apparatus; the study and improvement of instruments and methods of measurements; the compilation and publication of general scientific and technical data resulting from the performance of the functions specified in the Organic Act or from other sources when such data are of importance to scientific or manufacturing interests or to the general public, and are not available elsewhere.

CHAPTER II

II. Mass and Dimensional Metrology

The National Bureau of Standards maintains the national standards for mass in the form of the prototype kilograms (K4 and K20) and has established a number of realizations of the length unit relative to the international definition of length in terms of the wavelength of radiation from a Krypton source. This section describes the services available to those needing tie points to the measurement system maintained by the Bureau.

A. Mass, Volume, and Density

The Bureau provides services to support the segments of the national measurement system which rely directly or indirectly on mass measurements. These services include the calibration of reference standards of mass, of glass and metal volumetric reference standards, and of reference standard hydrometers, also the density determinations of solids and liquids, and are offered only if suitable service is not available otherwise. In order to provide prompt and useful service, the acceptance of the items for calibration or test is based on discussions with each user to determine details necessary to meet measurement and delivery requirements, and on inspection of the item at the Bureau with reference to its suitability for the usage intended. The section in the Appendix entitled "Mass, Volume, and Density" lists the most common services. The services are not limited to these specific items and inquiries are invited concerning other measurement problems in the above areas.

Services are available to enable a user to establish a measurement assurance program for certain measurement processes. This may involve developing procedures for establishing and maintaining a state of statistical control for the measurements, the determination of the offset of the process from the national system, and assisting in the determination of the uncertainty of measurements made by the user's process. The philosophy behind this service is given in:

[1] **Measurement philosophy of the pilot program for mass calibration,** P. E. Pontius, *Nat. Bur. Stand. (U.S.), Tech. Note 288,* 41 pages (May 1966).
[2] **Notes on the fundamentals of measurement and measurement as a production process,** P. E. Pontius, *NBSIR 74-545,* 65 pages (Sept. 1974). Order from NTIS as COM 74-11656, $5.25.

Arrangements for Calibration or Test

Arrangements for calibration (or test) must be completed before shipping apparatus to the Bureau. While all of the services related to mass, volume, and density are on an actual cost basis, subject to a $25 minimum charge, a mutual agreement on the work to be performed generally results in substantial savings for the user. Detailed packing and shipping instructions are available on request. Items not accepted for calibration or test will be returned, the cost of inspection or the minimum charge will be applicable.

The results of a calibration or test will be reported either in a National Bureau of Standards Report of Test (which in many cases is prepared by a computer program), a continuation report, or a letter report. In each of these, the values reported are accompanied by an appropriate estimate of uncertainty (allowance for random and systematic errors) as determined by an analysis of the specific measurement process. A continuation report is used for those items submitted for recalibration on which preliminary tests indicate that no significant changes have occurred since the last calibration. Usually a letter report is used to report a test for compliance with a specification which states limits for the departure of the actual value from nominal.

Charges for these services are listed "At Cost." Upon receipt of a request for services, an estimated cost will be given along with a firm date for completion. An effort will be made to discuss the measurement requirement with the customer so as to give proper service at minimum cost and delay.

1. Reference Standards of Mass

The Bureau's calibration of reference standards of mass provides extensions of the mass unit embodied in the NBS standards of mass. A normal calibration consists of establishing a mass value and the appropriate uncertainty for that value for each weight which has been designated to be a reference standard. It is desirable, but not necessary, that a weight meet the adjustment tolerances established for Classes A, B, M, or S-1 prior to submission. Normally weights are available from manufacturers, many of whom can furnish directly documentation suitable for meeting quality assurance contracts and requirements.

Individual weights or sets of weights in the range of 30 kg to 1 mg or 50 lb to 1 μlb in decimal subdivisions, which are designated as reference standards, must be of design, material, and surface finish comparable to but not necessarily limited to present Classes A, B, M, S, or S-1. Design, material, and surface finish of large mass standards (over 50 to 50,000 lb) must be compatible with the intended usage. For these large mass standards an adjustment with reference to a nominal or desired value can be included as a part of the calibration procedure.

The values of true mass (and an apparent mass correction) included in the report will be determined by using computed volumes based on the manufacturer's statement of density of the material, on the density computed from measured volumes, or, in the absence of this information, on estimated density values. The apparent mass corrections are computed for 20° C with reference to Normal Brass (density 8.4 g/cm^3 at 0 °C, volume coefficient of expansion 0.000054/° C) in an ideal air density of 1.2 mg/cm^3. Apparent mass corrections to any other basis can be furnished if requested.

For periodic recalibrations of reference mass standards, the user need measure only differences between weights or groups of weights within a set and compare them with computed differences. As long as the agreement is within allowable limits, the values can be considered constant within the precision of the comparison process. Mass standards which are submitted to the Bureau for recalibration frequently are tested in this manner. If these tests indicate that no significant changes have occurred, a continuation report so stating and referring to the previous NBS Report of Calibration will be issued.

References

[1] **Mass and mass values,** P. E. Pontius, *Nat. Bur. Stand. (U.S.), Monogr. 133,* 39 pages (Jan. 1974).

[2] **Realistic uncertainties and the mass measurement process,** P. E. Pontius and J. M. Cameron, *Nat. Bur. Stand. (U.S.), Monogr. 103,* 18 pages (Aug. 1967).

[3] **Designs for the calibration of standards of mass,** J. M. Cameron, M. C. Croarkin, and R. C. Raybold, *Nat. Bur. Stand. (U.S.), Tech. Note 952,* 64 pages (June 1977).

2. Reference Standards of Volumetric Apparatus

The procedure used almost universally for testing glass volumetric apparatus is to weigh the amount of distilled water contained or delivered with reference to the graduations marked on the instrument, the volume being computed from the density of the water (for tables see NBS Circular 19, available on request). The quality of the markings and the care exercised in reading or setting the liquid level are major factors in test calibration and usage. Normally the Bureau will accept instruments for calibration which have volumes in the range 1 ml to 1 gal and which conform essentially to requirements contained in NBS Circular 602, "Testing of Glass Volumetric Apparatus," Federal Procurement Specifications NNN-B-00789 (Buret, straight, precision), NNN-F-00289a (Pipet, volumetric), NNN-P-00350a (Pipet, measuring), or NNN-F-00289a (Flask, volumetric), if such instruments are to be used as reference or transfer standards.

The following comments relate to commonly used volumetric apparatus:

° Groups of blood pipets which are used as factor standards for quality control will be accepted for test. Values will be furnished in a letter report.

° Suggested test procedures for the verification of the compliance of precision grade glassware with specifications and tolerances are available on request.

° The usual calibration procedure for metal volumetric apparatus consists of determining the value "to contain" or "to deliver" by either gravimetric means or by the use of transfer standards. Normally the Bureau will accept instruments for calibration which have values in the range 1 gill to 1000 gal, which comply essentially with the specifications contained in NBS Monograph 62, "Testing of Volumetric Standards," and which are free from dents, bumps, or scratches.

° While it is preferred that the zero index or the gage scale be adjusted and scaled prior to calibration, these operations can be incorporated into the calibration procedure if requested. Slicker plate type standards should be adjusted by the manufacturer.

References

[1] **Procedures for the calibration of volumetric test measures,** J. F. Houser, *NBSIR 73-287,* 24 pages (Aug. 1973). Order from NTIS as COM 73-11928, $4.00.

[2] **Calibration of small volumetric laboratory glassware,** J. Lembeck, *NBSIR 74-461,* 34 pages (Oct. 1974). Order from NTIS as PB246623, $4.50.

[3] **The equivalence of gravimetric and volumetric test measure calibration,** R. M. Schoonover, *NBSIR 74-454,* 16 pages (Feb. 1974). Order from NTIS as COM 74-10988, $4.00.

3. Density Determinations of Liquids and Solids

The usual procedure for determining the density of solids is hydrostatic weighing. At the Bureau liquid densities usually are determined by gravimetric methods. Other methods are available depending on the requirements. The Bureau will accept requests for density determinations if the need is critical, as in the support of scientific studies or standard sample programs. Limitations on the mass, physical dimensions, or volume of the sample are available on request.

Specific gravity hydrometers covering the range 0.62 to 3 and proof spirit hydrometers in the range 0 to 200 proof, which are designed reference standard hydrometers (used to test other hydrometers), normally are accepted for calibration. A limited number of other types of reference standard hydrometers will be accepted for multipoint calibration subject to a discussion of detailed requests. Instruments accepted must comply essentially with the requirements of NBS Circular 555, "Testing of Hydrometers."

References

[1] **A density scale based on solid objects,** H. A. Bowman, R. M. Schoonover, and C. L. Carroll, *J. Res. Nat. Bur. Stand. (U.S.),* **78A** (Phys. and Chem.), No. 1, 13-40 (Jan.-Feb. 1974).

[2] **Reevaluation of the densities of the four NBS silicon crystal standards,** H. A. Bowman, R. M. Schoonover, and C. L. Carroll, *NBSIR 75-768,* 36 pages (Aug. 1975). Order from NTIS as PB247943, $4.50.
[3] **The utilization of solid objects as reference standards in density measurements,** H. A. Bowman, R. M. Schoonover, and C. L. Carroll, *Metrologia* **10,** 117-121 (1974).
[4] **Liquid level instrumentation in volume calibration,** R. M. Schoonover, H. H. Ku, J. Whetstone, and J. F. Houser, *NBSIR 75-900,* 37 pages (Oct. 1975). Order from NTIS as PB250859, $4.50.

B. Length

Length measurement services offered by NBS are intended to serve several purposes: (1) to disseminate the length unit to the industrial and scientific community, (2) to offer guidance in establishing measurement assurance programs in length, (3) to provide assistance where there are special problems in measurement techniques, or where extreme accuracy requirements exist, and (4) to resolve disagreements between parties involving length measurements.

Arrangements for Calibration or Test

Charges for services in length are listed "At Cost" in the Appendix. Upon receipt of a request for services an estimated cost will be given along with a firm date for completion. An effort will be made to discuss the measurement requirement with the customer so as to give proper service at minimum cost and delay.

1. Gage Blocks

All gage blocks submitted for test should be in substantially new block condition and each block should be marked with an identification number.

In shipping gage blocks extreme care should be taken both against corrosion and damage by contact with other gage blocks. All defining steel surfaces should be greased and the blocks padded with waxed paper or volatile rust inhibitor treated paper. A greased steel surface coming in contact with newspaper, wrapping paper (unwaxed), or excelsior is very likely to corrode. Sets of gage blocks should have packing inside the case and the case should be bound shut as the clasps open or break frequently during shipment.

References

[1] **Measurement assurance program—A case study: Length measurements. Part 1. Long gage blocks (5 in to 20 in),** P. E. Pontius, *Nat. Bur. Stand. (U.S.), Monogr. 149,* 75 pages (Nov. 1975).
[2] **Gage block flatness and parallelism measurement,** J. S. Beers and C. D. Tucker, *NBSIR 73-239,* 12 pages (Aug. 1973). Order from NTIS as P273962, $4.00.
[3] **Intercomparison procedures for gage blocks using electromechanical comparators,** J. S. Beers and C. D. Tucker, *NBSIR 76-979,* 23 pages (Jan. 1976). Order from NTIS as PB248992, $4.00.
[4] **A gage block measurement process using single wavelength interferometry,** J. S. Beers, *Nat. Bur. Stand. (U.S.), Monogr. 152,* 34 pages (Dec. 1975).
[5] **Preparations for gage block comparison measurements,** C. D. Tucker, *NBSIR 74-523,* 14 pages (July 1974). Order from NTIS as COM 75-11126, $4.00.

2. Linear Thermal Expansion of Length Standards

A coefficient of linear thermal expansion will be determined for length standards such as gage blocks and line scales only where the manufacturer's stated value is inadequate or unknown. Coefficients will be determined in a temperature range near 20 °C (68 °F).

3. Gage Block Comparator Stylus Tip Radius

If gage blocks of different materials are being compared it is important to know the stylus tip radius so a penetration correction can be determined. Tips received for measurement will be examined for flaws and imperfect geometry. Only tips which are spherical in the contact area and are free from cracks and chips will be measured because imperfections prevent predictable performance.

Reference

[1] **Contact deformation in gage block comparisons,** J. S. Beers and J. E. Taylor, *Nat. Bur. Stand. (U.S.), Tech. Note 962* (In press).

4. Line Standards of Length

Graduated scales up to 6 m (20 ft) in length and having suitable graduations and cross-sectional shapes will be measured interferometrically. The length values will be reported at 20 °C (68 °F).

5. Surveying and Oil Gaging Tapes

The calibration of surveying tapes and oil gaging tapes will be made with the tape under tension and supported on a horizontal flat surface in a laboratory controlled near 20 °C (68 °F). Unless otherwise requested the total length and each 50 ft or 15 m subinterval will be measured and reported at 20 °C (68 °F). For oil gaging tapes the height from the tip of the plumb bob will also be reported at 60 °F.

Each interval calibrated on a surveying tape will have a table of computed lengths for two (single catenary), three, four, and five equidistant points of support. The computed values will be based on the measured lengths and the average values for weight per unit length and AE (cross-section area of tape times modulus of elasticity) determined during the test and given in the report.

The following thermal expansion coefficients will be assumed unless another value is provided by the customer or the tape manufacturer:

Steel:	0.0000116/°C (0.00000645/°F)
Stainless:	0.0000106/°C (0.00000589/°F)
Invar:	0.0000004/°C (0.00000022/°F)

Horizontal tension will be applied to the tapes by weights hanging from a pulley device. A pound weight produces a poundal force, and a kilogram weight produces a Newton force at the tape end. For various materials and lengths of tapes the following weights will be used in the calibration:

	Equal or less than		Longer than	
Material	30m	100 ft	30m	100 ft
steel	5 kg	10 lb	10 kg	20 lb
stainless	5 kg	10 lb	10 kg	20 lb
Invar	15 kg	20 lb	15 kg	20 lb

An NBS serial number will be engraved on each calibrated tape for identification.

6. Surveying Leveling Rods

Surveying leveling rods having invar graduated strips will be calibrated in a laboratory controlled near 20 °C (68 °F). The 1, 2, and 3 meter intervals will be measured from a zero point on the footpiece established by the intersection of the centerline of the invar strip with the plane of the bottom of the footpiece. A thermal expansion coefficient of 0.0000015/°C will be assumed for the invar strip unless another value is provided by the customer or the manufacturer. The lengths of the intervals will be reported at 20 °C unless otherwise requested.

7. Sieves

The precision seal of the National Bureau of Standards on any sieve indicates that the sieve has been tested at the Bureau and found to conform to specification. Except by special arrangements, the testing of sieves at the Bureau is limited to No. 3 1/5 to No. 400, inclusive.

The following Standard Reference Materials are available for use in sieve calibrations.

Glass spheres for particle size

SRM*	Type	Size (μm)	Sieve Nos.	Wt/unit (g)
1003	Calibrated Glass Spheres	5-30	--	40-45
1004	Calibrated Glass Beads	34-120	400-140	63
1017a	Calibrated Glass Beads	100-310	140-50	84
1018a	Calibrated Glass Beads	225-780	60-25	74
1019	Glass Spheres	890-2590	18-8	100

*See section on Standard Reference Materials (ch. XI) for ordering procedure.

8. Haemacytometers

Each haemacytometer chamber and each cover glass which conforms to the specification is marked with a National Bureau of Standards precision seal. In general, work will be discontinued when a substantial number of items in a lot fail to comply with specifications and the fee will be computed on the basis of the number of items tested plus a special handling charge.

9. Precision Circles

Graduated circles or encoder discs having suitable graduations and being not less than 50 mm (2 in) in diameter will be tested for maximum angular error in the mean of opposite angles.

C. Dimensional Metrology

For controlling dimensions in the manufacture of all products, various types of dimensional gages are used. Gages which are used for precise size control of critical dimensions are measured in our laboratories as a service to the public. The wide variety of such gages measured includes end standards for length, cylindrical plug and ring gages and balls for diameter, and screw thread gages and master gears for those more complex dimensional requirements. Angle gage blocks, polygons, angular indexing tables, and other such items are calibrated for controlling angular dimensions. In addition, various instruments, measuring tools, and accessories are calibrated such as optical flats for measuring flatness, surface roughness specimens for calibrating measuring instruments, cylinders used for the measurement of threads and gears, micrometer and vernier calipers for measuring size, and many other specialized components. Consultation services with respect to dimensional and angular measuring problems are available also.

The length and diameter standards and gages, with the exception of thread and gear measuring wires, are in general intended to be used as comparison masters. In addition to the items listed, high quality components requiring gage tolerance inspection of length or diameter may be calibrated as special measurements. In addition to the items listed in the Appendix, other items such as gage block accessories, gill net gages, and Knoop indenters are calibrated upon special request. Sizes other than those listed in the fee schedules also are calibrated on special request.

A 3-axis measuring machine built to state-of-the-art specifications is housed in a stabilized environment, and can be operated either manually or under full control from a programmed computer. It has a working volume of 48 $\times$ 24 $\times$ 12 in with a 16-in clearance under the bridge, and can detect a difference in length of 0.0250 nm (10 μin). Bulk disc storage of computer programs is provided, and a line printer capable of graphic presentation is available. Reference to the SI meter is provided by a stabilized laser interferometer.

The machine can provide digital data on probe position in three dimensions, or two-dimensional graphic projection of complex three-dimensional shapes.

Reference

[1] **Unified three-dimensional program—Two useful noncontacting probes,** J. A. Simpson, *NBS Report 10597* (May 1971).

Shipping Instructions

In the shipment of gages, extreme precautions should be taken against both corrosion and damage by contact with other gages during transit. All defining steel surfaces should be greased and protected with rust inhibiting paper or a suitable strippable plastic coating. A greased steel surface coming in contact with newspaper, untreated wrapping paper, or excelsior is very likely to corrode. Small gages suitably wrapped may be fastened in place in a strong container so that no movement is possible. Plug and ring gages ordinarily should not be shipped mated. In the case of large-size threaded plugs and rings, however, mating is permissible as a means of protecting the plug threads. In such cases a grease must be used that will prevent corrosion between the mating gages.

1. End Standards of Length

The listed end standards, having spherical, flat, or pointed ends normally are used as instrument or machine tool setting standards. End standards up to 20 ft in length can be calibrated. As a special test, end measuring bars with flat ends of gage block quality can be calibrated with higher accuracy than listed below. Lengths are reported with a 2.5 lb measuring force unless otherwise requested.

2. Step Gage Standards of Length

Step gages having flat parallel faces along a common center line are calibrated as special measurements. The test is made horizontally in lengths up to 40 in. Step blocks having flat parallel adjacent faces also are calibrated as special measurements.

3. External Diameter Standards and Gages: Plug Gages

In addition to the scheduled plug and wire gages, external diameters of other products may be accepted for measurement.

Reference

[1] **Measurement of cylindrical standards,** R. C. Veale, *NBSIR 73-136,* 25 pages (Mar. 1973). Order from NTIS as PB273995, $4.00.

4. Measuring Wires for Threads and Gears

Thread measuring wires for 60° and 29° threads are tested for compliance with the latest specifications in commercial use given in NBS Handbook H-28 and American National Standards Institute, Inc. Standard B1.2. These wires, which are supplied in 3-wire sets, are calibrated and the pitch diameter correction factor is computed for the average diameter of the 3 wires in the set. Special thread measuring wires for unusual sizes and for threads finer than 80 tpi are measured in a manner consistent with current commercial practice as a special test. The published fee is for a single set of 3 wires. Gear measuring wires in the 1·92″/P, 1·728″/P, 1·44″/P, and 1·68″/P series supplied in sets of 2 wires are tested for compliance with the latest specifications in commercial use and the mean diameter reported. Reference master wires for threads and gears are supplied as single wires which are intended as transfer standards of diameter for the calibration of working sets of thread measuring and gear measuring wires. Wires are measured using standard measuring practice.

Reference

[1] **On the measurement of thread measuring wires,** B. N. Norden, *NBS Report 10987* (Jan. 1973).

5. Spherical Diameter Standards: Balls

Balls used in precision bearings and master balls used as transfer diameter standards are calibrated according to current commerical practice. The ball diameters reported are the undeformed sizes as calculated with the Hertz relations to maintain a consistency in reported sizes.

6. Internal Diameter Standards: Ring Gages

In addition to ring gages, holes in precision products can be calibrated as special measurements.

7. Plain Conical Plug and Ring Gages

Plain conical plug and ring gages are tested for angle and diameter at a specified position.

8. Threaded Plug and Ring Gages

Threaded plug and ring gages are tested in accordance with current commercial practice as outlined in NBS Handbook H-28 and American National Standards, Inc. Standard B1.2. Threaded plug gages can be tested for pitch diameter, major diameter, flank angle, lead, and taper. Threaded ring gages must be submitted with the setting plug gage for test and are set for fit and tested for minor diameter, flank angle, lead, and taper, and standoff if applicable.

American Petroleum Institute (API) reference master thread gages are tested as required by the API specifications. The gages submitted should be marked with the API monogram and the API registration number if required. If not so marked, the information should be submitted with the gages and they will be marked. Gages which meet the specifications will be marked as specified in the API standards. All thread gages must be submitted in sets of plug and ring. The name of the gage owner should be given for inclusion in the report. Copies of all reports are sent to the American Petroleum Institute. API standards may be obtained from the American Petroleum Institute, Corrigan Tower Building, Dallas, Texas 75201. Fee is for single set of plug and ring.

9. Master Gears

Master gears and high precision working gears can be inspected for tooth spacing, involute profile, and lead. Tests may be made on setting masters for gear testing equipment such as involute masters and lead masters. All such equipment should be supplied with a reference diameter for the definition of the center.

10. Length and Diameter Measuring Instruments

Instruments accepted for calibration include micrometer calipers, vernier calipers, plain snap gages, micrometer screws, dial micrometers, vernier calipers, and other similar devices.

11. Length Measuring Elements

Length measuring elements such as micrometer screws, dial micrometers, and other length-transducing systems are included in this schedule.

12. Instrument Components Requiring Dimensional Control

Some instruments such as penetration needles, polariscope tubes, and Knoop indenters contain elements which require dimensional control of lengths and angles.

Penetration needles and cones are tested for compliance with ASTM specifications and supplied with individual labels so stating. All needles must have individual identification numbers; needles received without identification will be marked for a fee.

D. Flatness, Roundness, and Angular Measurements

This section deals with the calibration of reference surfaces of flatness and straightness such as optical flats, surface plates, and straight edges.

1. Optical Reference Planes: Flats

Optical reference planes are tested interferometrically, horizontally supported with test surface supported on three equally spaced pads located at 0.7 of the radius from the center. The measurement is performed along two marked diameters at 90° to each other on each surface when each diameter is parallel to two of the support pads.

References

[1] **A survey of the stability of optical flats,** C. P. Reeve and R. C. Veale, *NBSIR 73-232,* 27 pages (June 1973). Order from NTIS as PB273947, $4.50.
[2] **The calibration of an optical flat by interferometric comparison to a master optical flat,** C. P. Reeve, *NBSIR 75-975,* 40 pages (Dec. 1975). Order from NTIS as PB253113, $4.50.

2. Surface Plates and Straight Edges

The straightness of specified lines on surface plates and the straightness of straight edges are calibrated by optical and mechanical techniques.

3. Roundness

In addition to the measurement of the deviation from roundness of round parts, instrument calibration standards for roundness measurement equipment can be calibrated.

4. Roundness Measurement

The deviation from roundness at eight or more specific positions around nominally round standards is determined. The size of the calibration step or deviation from roundness on calibration standards is determined. The departure from roundness of components and gages is measured and the results are reported in graphical form.

5. Angular Standards

Fixed angular standards having flat defining surfaces are calibrated by autocollimation and interferometric techniques. Angle gage blocks are calibrated using autocollimation techniques.

The calibration of polygons is done with autocollimation techniques. It consists of the determination of flatness of each face, variation of the angle between each face and the base (where possible the polygon will be adjusted for minimum variation), and the angle between faces.

The solid angle calipers and step mirrors are calibrated by autocollimation or interferometric techniques as to the angle between faces. Wedges are calibrated by autocollimating or interferometric techniques at a specified wavelength for deviation angle.

Mechanical angular references such as cylindrical squares and machinist's squares usually are calibrated by mechanical techniques.

Reference

[1] **A survey of the temporal stability of angle blocks,** R. C. Veale and C. P. Reeve, *NBSIR 74-601,* 22 pages (Nov. 1974). Order from NTIS as PB273948, $4.00.

6. Angular Measuring and Setting Instruments

Instruments and tools used for the precise measurement of angle, such as precision angular rotary and indexing tables, autocollimating telescopes, or angle generating equipment, are calibrated at specific angular settings.

Reference

[1] **The calibration of indexing tables by subdivision,** C. P. Reeve, NBSIR 75-750, 38 pages (July 1975). Order from NTIS as PB249934, $4.50.

E. Surface Texture

Precision surface roughness specimens and test measurements on other surface finishes can be made in accordance with American National Standards Institute, Inc. Standard B-46.1 (1962). Since 1 July 1973, these measurements are made with an interferometrically calibrated minicomputer/stylus instrument system rather than by comparisons against master specimens. (See September 1973, "NBS Dimensions," p. 221 and ref. [7], part 1.)

1. Instrument Calibration Specimens

Instrument calibration specimens for surface roughness measuring equipment having regular geometrical surface profiles are calibrated with the use of the interferometrically calibrated minicomputer/stylus instrument system (see ref. [7], part 1).

2. Surface Roughness Measurements

Roughness measurement of roughness comparison specimens or of other surfaces are measured in accordance with American National Standards Institute, Inc. Standard B46.1, using our instrumentation.

3. Step Height Measurements

Thin film step heights are measured with the use of the minicomputer/stylus instrument system and interferometrically calibrated reference step heights (see ref. [7], part 1).

References

[1] **Surface microtopography,** R. D. Young, *Phys. Today* **24,** No. 11, 42–49 (Nov. 1971).

[2] **Precision reference specimens of surface roughness: Some characteristics of the Cali-Block,** R. D. Young and F. E. Scire, *J. Res. Nat. Bur. Stand. (U.S.),* **76C** (Eng. and Instr.), Nos. 1 and 2, 21-23 (Jan.-June 1972).

[3] **The topografiner: An instrument for measuring surface microtopography,** R. Young, J. Ward, and F. Scire, *Rev. Sci. Instrum.* **43,** No. 7, 999-1011 (July 1972).

[4] **A system for computerized surface roughness measurement,** D. A. Swyt, *NBSIR 73-106,* 41 pages (Feb. 1973). Order from NTIS as PB273940, $4.50.

[5] **Eight techniques for the optical measurement of surface roughness,** R. D. Young, *NBSIR 73-219,* 38 pages (May 1973). Order from the author at National Bureau of Standards, Washington, D.C. 20234.

[6] **Surface finish, friction and wear; the need for more than one parameter,** D. A. Swyt, *NBSIR 73-196,* 28 pages (May 1973). Order from NTIS as PB273941, $4.50.

[7] **Evaluation, revision and application of the NBS stylus/computer system for the measurement of surface roughness,** E. C. Teague, *Nat. Bur. Stand. (U.S.), Tech. Note 902,* 151 pages (Apr. 1976).

[8] **Evaluation, revision and application of the NBS stylus/computer system for surface roughness measurement: Minicomputer software,** E. C. Teague, *NBSIR 75-924,* 79 pages (Apr. 1975). Order from NTIS as PB248686, $6.00.

[9] **Surface finish measurements: An overview,** E. C. Teague, *Soc. Manuf. Eng. Tech. Pap.* **IQ75-137,** 1-21 (1975).

[10] **The measurement and characterization of surface finish,** R. D. Young and E. C. Teague, Chapter 2 in *Properties of Electrodeposits, Their Measurement and Significance,* R. Sard, H. Leidheiser, and F. Ogburn, Eds., pp. 22-49 (Electrochemical Society, Princeton, NJ, 1975).

[11] **Instrumentation for the chemical analysis of manufactured surfaces,** R. D. Young, *Ann. CIRP* **24,** No. 2, 549-554 (Aug. 1975).

F. Office of Weights and Measures

The role of the Office of Weights and Measures (OWM) is to provide leadership and those technical resources that will assure accuracy of the quantity representatiions in all commercial transactions for all buyers and sellers in the United States, and to promote a uniform national weights and measures system.

In fulfilling its mission, OWM engages in a wide range of activities, including providing the secretariat and other technical input for the National Conference on Weights and Measures. Foremost is the assistance offered to the States in the following areas:

(1) The development of model weights and measures laws and technical regulations for the States and local jurisdictions.

(2) The development and dissemination of design and performance specifications for various standards of mass, length, and capacity for use as State and local reference, laboratory, and field standards.

(3) The design of testing equipment and the development of testing procedures for weighing and measuring devices.

(4) The examination of prototype commercial weighing and measuring devices and equipment submitted by manufacturers for conformance with National Bureau of Standards requirements.

(5) The calibration of State standards. State weights and measures laboratories perform calibrations and tolerance tests of mass, volume, and length secondary standards for industry and service agencies.

(6) The conduct of technical training in weights and measures enforcement and laboratory metrology. OWM serves as a central resource for metric information and coordination, and prepares and disseminates information on standards, testing equipment technical procedures, technical investigations, and standard practices.

(7) The conduct of a railway calibration project which provides services in the test of master railroad scales, and the calibration of test weight cars and other mass standards (at Clearing, Illinois).

1. Prototype Examination of Commercial Weighing and Measuring Devices, Reference and Field Standards

OWM operates a Prototype Examination Program which provides for an evaluation of (1) prototype weighing and measuring devices to determine compliance with the requirements of NBS Handbook 44, "Specifications, Tolerances, and Other Technical Requirements for Commercial Weighing and Measuring Devices," (2) standards to determine compliance with the requirements of NBS Handbooks 105-1, 105-2, 105-3, "Specifications and Tolerances for Reference Standard and Field Standard Weights and Measures." This program may be used by manufacturers and weights and measures officials in determining the acceptability of devices for commercial use or the suitability of reference and field standards.

Equipment will be examined at any stage of development on request. The examination may be made in the laboratories of the National Bureau of Standards, at the factory, or in the field.

When a device is found to be in compliance with Handbook 44, or standards in compliance with H-105-1, H-105-2, or H-105-3, a report of test will be issued to the submitter. When equipment is found not to be in compliance, the submitter will be notified by letter and the discrepancies fully explained. The equipment may then be modified and resubmitted. If it is the submitter's decision not to make any modifications, a report of test will be issued detailing the areas where discrepancies exist. Copies of all reports of test will be sent to each state weights and measures office.

To obtain a prototype examination:

Address a letter giving a reasonably complete description of the equipment, its operating characteristics and instructions, and its intended application, model number, capacity, size, and shipping weight, to the Office of Weights and Measures, National Bureau of Standards, Washington, D.C. 20234, requesting an examination.

CHAPTER III

III. Mechanics and Acoustics

That broad area of the physical sciences generally prescribed by the action of forces on bodies, materials and matter is quantified through measurements based on mass, length, and time. Length and mass are the capstones of this measurement system usually characterized by the discipline of mechanics. In addition to the base units of mass and length, a wide range of derived quantities and multiples or submultiples of all these units are employed by science and technology to implement the affairs of industry, commerce, and government. Among the mechanics-related derived quantities maintained and disseminated by NBS are force, volume flowrates, air and water velocity, acoustic quantities, and vibration. Well-characterized instruments are compared with these standards through calibrations and measurement assurance programs to provide measurement traceability and to ascertain the quality of measurements in the field. Supporting research and development programs are conducted to extend the range and quality of these types of measurement and to increase the efficiency of the measurement system.

A. Force

A force measuring system consists of two elements, an elastic device and a means to sense the distortion, or deflection, of that device under the action of applied forces. The calibration procedure consists of applying known forces, either tension or compression, to the elastic device and recording the sensed deformation. An analysis of the data provides correspondence between the system indication and the magnitude of the applied force. In some cases, force can be applied to two or more systems in series or series parallel arrangements using a hydraulic press. In this case, the correspondence for one system is established relative to the known correspondence for one or more previously calibrated systems.

For the range of 10 lbf to 10^6 lbf, the NBS force generators are "dead weight" machines with fixed load increments. For loads in excess of 10^6 lbf, a large universal testing machine is used as a press. Compression calibrations from 10^6 lbf to 12×10^6 lbf are relative to calibrated load cell systems. Tension calibrations from 10^6 lbf to 6×10^6 lbf are relative to the indicating system of the testing machine.

Subject to the conditions that the instruments submitted are sufficiently stable as to warrant the calibration effort, and that an adequate calibration service is not available elsewhere, NBS will perform the following tests:

(1) Characterize a transducer-indicator system in any accepted force units for the correspondence between indication and applied force, uncertainty estimates, and estimates of other parameters as identified which may be of importance relative to the manner in which the instrument is to be used. Direct current powered transducers can be characterized in a similar manner in which case the correspondence is expressed in a dimensionless ratio (mV/V).

(2) Perform calibration tests as specified by accepted voluntary standards or by companies or individuals. Test data will be processed in the manner specified or requested. Reports, however, may include a disclaimer with regard to the validity of the uncertainty estimate.

(3) On a time available basis, NBS will conduct tests to support developmental work on force measurement devices and systems in excess of 1000 lbf. Devices must be

proof tested and test procedures must be reviewed prior to submission of the device. Resulting test data will be returned in a letter report, normally without further analysis. Where intermediate parties are involved, the reports will be issued to the ultimate user. NBS will, when appropriate, discuss the calibration details with the user and reserves the right to modify the testing procedures accordingly. All work is done on an "At Cost" basis.

Reference

[1] **A study of the National Force Measurement System,** D. E. Marlowe, *NBSIR 75-929,* 40 pages (June 1975). Order from NTIS as PB261498, $4.50.

B. Acoustic Measurements

NBS performs calibrations of special microphones and ultrasonic reference blocks as described below.

1. Microphones

Pressure calibrations are performed only on type-L microphones satisfying the requirements of American National Standards Institute publication S1.12.1967 (R1972), Specifications for Laboratory Standard Microphones. In addition, microphones must be suitable for use with the calibrating couplers shown in figures 6 and 10 of publication S1.10-1966 (R1971), Calibration of Microphones. Copies of these standards can be purchased from the Institute at 1430 Broadway, New York, New York 10018.

Pressure calibrations are reported in terms of open-circuit voltage per unit sound pressure applied uniformly to the diaphragm. The open-circuit voltage at the electrical terminals of a microphone may be influenced by stray capacitances evident at these terminals. These capacitances are defined by the geometrical configuration of the ground shield shown in figures 6 and 13 of S1.10 (R1971). If the ground shield dimensions are not adhered to in making use of the response levels reported by the Bureau, errors may result. Methods for the measurement of open-circuit voltage are described in Clause 2.1 and in figures 1 and 7 of S1.10 (R1971).

The free-field response levels of Western Electric Company Type 640AA condenser microphones, or equivalent, can be computed with good accuracy from the pressure response levels reported by the Bureau, using table A1 of S1.10 (R1971), provided the microphone is mounted on a preamplifier of size and shape illustrated in figure 12 of S1.10 (R1971). However, the use of manufacturers' response levels in conjunction with table A1 might result in errors unless the manufacturer has measured pressure response levels in accordance with S1.10 (R1971).

Since American National Standards Institute publications S1.10-1966 (R1971) and S1.12-1967 (R1972) were issued, certain types of "half-inch" diameter precision microphones have attained widespread use. Therefore, NBS has developed procedures for determining the pressure and free-field response of "half-inch" microphones. Since no current standards are directly applicable, details of the ground-shield configuration, coupler and other procedures will be incorporated in the test report.

Associated preamplifiers or power supplies should not be forwarded to the Bureau. The response levels reported are based on measurements of open-circuit voltage and are essentially independent of the electronic equipment used in the test.

2. ASTM E-127 Type Ultrasonic Reference Blocks

The ultrasonic response of 7075 aluminum alloy reference blocks is determined relative to an NBS interim reference standard by immersion, pulse echo, longitudinal wave testing as described in NBS Technical Note 924, "Procedures for the Calibration of

ASTM E127-Type Ultrasonic Reference Blocks," by D. J. Chwirut, G. F. Sushinsky, and D. G. Eitzen. Response following the ASTM Recommended Practice E-127-75 can also be determined.

C. Vibration Services—Pickups

These comments apply only to the calibration of acceleration and vibration pickups. Each piezoelectric acceleration pickup which is used with a cathode-follower or amplifier shall be accompanied by the cathode-follower or amplifier, and all necessary connecting cables.

When instruments submitted are found to be unsuitable for test or unreliable, a charge will be made to cover the cost of the work done.

References

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[5] **Piezoelectric accelerometer low-frequency response by signal insertion methods,** R. S. Koyanagi and J. Pollard, *NBSIR 74-597,* 33 pages (May 1975). Order from NTIS as COM 75-11069, $4.50.

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D. Structural Engineering—High Capacity Testing Machine

The research and testing facilities for structural engineering include a 53-MN (12 million-lbf) capacity universal testing machine believed to be the largest in the world. A significant addition to the nation's facilities for research and testing in the field of large structures, this unique machine is available to do work for the entire technological community upon consideration of requests on a case-by-case basis. This hydraulically operated machine is a vertical, four-screw type with the main fixed platen flush with the floor. It is capable of applying 53 MN (12×10^6 lbf) in compression to test specimens up to 17 m (58 ft) in height and 27 MN (6×10^6 lbf) in tension to specimens up to 16 m (53 ft) in length. To extend the versatility of the machine, the reinforced concrete foundation incorporates a floor tie-down system which can accommodate test specimens for transverse loading up to 27 m (90 ft) in length. Calibration of all load ranges indicates that they exhibit error generally no greater than 0.5 percent of the applied load. A more detailed description of this facility is presented in NBS Special Publication 355.

E. Fluid Flow

Standards for flow measurement of fluids are maintained using water, air and a stable hydrocarbon as test mediums. These facilities are used for extending the types of measurement services, for research on how to characterize flow measurement systems and to evaluate and test transfer flow standards.

1. Fluid Quantity and Flowrate Meters

Flow meter systems, i.e., meter, pertinent adjacent tubing, and readout equipment having precision commensurate with the quality of the calibration are accepted for calibration over a wide range of flows in air, water, and hydrocarbon fluids. Meter systems should not be sent to the Bureau until all arrangements for the calibration have been completed. When submitted meter systems are found to be unreliable or unsuitable, a calibration may be discontinued and a charge will be made to cover the cost of the work done.

Meter systems submitted should have connections for A/N flare fittings up to 2-in (5 cm) nominal diameters, or with connections for National Pipe Thread fittings up to 3-in (7.6 cm) nominal diameter and larger meters must terminate with ASA 150-lb steel flanges, or grooved-end steel pipe compatible with Victaulic couplings (for water meters), or with adapters thereto; for air, flanges must terminate with ASA 300-lb steel flanges. Connections other than these should not be submitted unless special arrangements have been made in advance.

Fees are based on the actual cost of calibration.

Fees are based on calibrations of meters submitted with connections for A/N flange fittings up to 3-in nominal diameters, or with connections for National Pipe Thread fittings up to 3-in nominal diameter. For pipe sizes 4-in nominal diameter and larger, meters must terminate with ASA 150-lb steel flanges, or grooved-end steel pipe compatible with Victaulic couplings (for water meters), or with adapters thereto. Meters with connections other than these should not be submitted unless special arrangements have been made in advance.

References

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[2] **Introduction to liquid flow metering and calibration of liquid flowmeters,** L. O. Olsen, *Nat. Bur. Stand. (U.S.), Tech. Note 831,* 60 pages (June 1974).

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[4] **Practical considerations for gas flow measurement,** M. R. Shafer, Jr. and D. W. Baker, *Proc. 3d Annual Precision Measurement Association Metrology Conf., National Bureau of Standards, Gaithersburg, MD, June 17-18, 1970,* **1,** 187-227 (Precision Measurements Association, Burbank, CA, 1970).

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[6] **Evaluation of a low flow generator and calibrator as a flow measurement standard,** G. Baumgarten, *NBS Technical Report 10921* (1972).

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[10] **Building and evaluation of a second polluted air delivery system,** G. P. Baumgarten, *NBSIR 74-612,* 11 pages (Nov. 1974). Order from NTIS as COM 75-10414, $4.00.

[11] **Expansion factors for two variable area flow meters,** F. W. Ruegg, *J. Eng. Ind. Trans. ASME Papers No. 73-WA/FM-2,* **96,** No. 4, 1347-1353 (Nov. 1974).

[12] **The National Measurement System for fluid flow,** W. C. Haight, P. S. Klebanoff, F. W. Ruegg, and G. Kulin, *NBSIR 75-930,* 66 pages (Aug. 1976). Order from NTIS as PB258250, $5.25.

F. Hydraulics

Hydraulic flow measurement facilities are operated to evaluate measurement systems and to provide information on relating laboratory practices to field requirements, particularly for supply water and waste water systems.

1. Water Current Meters

Current meters will be calibrated in a water tunnel with rod mounting. When meters submitted are found to be unsuitable for tests or unreliable, a charge will be made to cover the cost of the work done.

References

[1] **A guide to methods and standards for the measurement of water flow,** G. Kulin and P. R. Compton, *Nat. Bur. Stand. (U.S.), Spec. Publ. 421,* 97 pages (May 1975).

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G. Aerodynamics

Well-characterized wind tunnels are maintained and operated to serve as reference standards for air speed measuring systems over a wide range of velocities and operating conditions. Recently a laser velocimeter has been combined with a high quality air flow duct to provide a very low speed standard. Fundamental research on turbulence and fluid dynamical problems of national interest serve to extend measurement competence.

NBS also offers a calibration service for the dynamic response of mechanical-rotary anemometers by which the "distance constant" for such instruments can be accurately specified over a range of mean speeds from 30 to 15 m/s. This service is made possible by a uniquely designed unsteady flow wind tunnel which was recently put into operation. This is a closed-return low-turbulence facility that has a 4.5 ft square test section, 16 ft in length, in which oscillatory flows can be generated. The flow in the test section can be oscillated sinusoidally over a continuous frequency range from 0.1 to 25 Hz. The amplitude of the velocity fluctuation can be varied, for example, from near zero to 100 percent of mean speed at 0.1 Hz for mean speeds up to 15 m/s. The rate at which the amplitude attenuates with increasing frequency is determined by the inherent time constant of the tunnel which is approximately 0.2 s. It can be operated as a conventional low-turbulence wind tunnel, with a maximum available steady speed of 90 ft/s.

References

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[4] **Mechanism by which a two-dimensional roughness element induces boundary-layer transition,** P. S. Klebanoff and K. D. Tidstrom, *Phys. Fluids* **15,** No. 7, 1173-1188 (July 1972).

[5] **Probability distributions and correlations in a turbulent boundary layer,** F. N. Frenkiel and P. S. Klebanoff, *Phys. Fluids* **16,** No. 6, 725-737 (June 1973).

[6] **On the lognormality of the small-scale structure of turbulence,** F. N. Frenkiel and P: S. Klebanoff, *Boundary-Layer Meteorol.* **8,** No. 2, 173-200 (Mar. 1975).

[7] **The dynamic response of helicoid anemometers,** J. M. McMichael and P. S. Klebanoff, *NBSIR 75-772,* 54 pages (Nov. 1975). Order from NTIS as PB246861, $5.25.

CHAPTER IV

IV. Electrical and Magnetic Measurements—dc and Low Frequency

The National Bureau of Standards has the responsibility for the establishment and maintenance of the legal electrical units and in addition for making them available for use by industry, science, and government at all levels. The Electrical Quantities Program provides for the dissemination of the electrical units and related electrical and magnetic quantities in the frequency range from 0 (dc) to 1 MHz. Dissemination takes place in three ways: via routine calibration of electrical, electronic, and magnetic standards and measurement apparatus of the highest accuracy; by in-situ calibrations performed on equipment which for technical reasons cannot be moved to or calibrated at NBS; and through Measurement Assurance Programs. Educational, consultative, and metrology engineering services are also available. The following sections contain more detailed descriptions of each type of service.

The group of services offered has evolved over the years in response to needs emanating from the measurement, technical, and scientific communities. Suggestions of new, needed or useful, services are welcomed by NBS.

Note: Calibration and other metrology-related services to support measurements of electromagnetic quantities in the frequencies above 1 MHz are discussed in the next chapter.

Services

Educational: The Bureau sponsors a biennial Low Frequency Electrical Measurement Seminar generally held in the spring at the Gaithersburg site of NBS. The 4-day event covers the methods used by the Bureau to establish and maintain the basic electrical units and to perform many of the dissemination services covered in this publication. Emphasis is on techniques useful to standards and calibration laboratories and that are applicable to general quality assurance situations. Topics peripheral to electrical metrology such as solid-state devices, statistical data analysis techniques, and laboratory automation are also generally covered. The course is generally geared to those working at a professional level and involved with using basic electrical standards for quality control purposes.

Consultations: Arrangements may be made for consultations with appropriate NBS staff members either at NBS or in a client laboratory to solve critical measurement problems. This is done on a cost-reimbursable basis. Because of the depth and variety of NBS staff expertise, many such problems may be simply solved with a telephone call. Requests for limited assistance, such as can be handled with a telephone conversation or a letter, are encouraged as they contribute to NBS awareness of problems facing the metrology community.

Research and Development: R&D activities on new methods of measuring electrical quantities and the development, design, and construction of measurement apparatus are natural outgrowths of the Bureau's unique responsibility. The special competence of scientists in the Electrical Quantities Program is reinforced by the ready accessability of experts in the many other technical areas of NBS. Expertise from diverse fields, such as cryogenics, solid state electronics, semiconductor physics, automatic data processing and metallurgy may be quickly brought to bear on a problem. Special measurement problems of concern to industrial or technical organizations, whether they arise in the course of pure research or result from application of new technology—may be addressed by NBS scientists and engineers on a contractual basis.

Publications: NBS publishes the results of its researches extensively to aid others who may wish to use its developments or services. An up-to-date list of publications (NBS LP 38) on electrical units, instruments and measurements is available upon request. NBS has recently joined GIDEP, the Government-Industry Data Exchange Program. All NBS publications will be included in the GIDEP data bank for ready reference.

Calibrations: Routine calibrations of standards and precision electrical measurement apparatus submitted to NBS are performed on a cost reimbursable basis using permanent facilities at the Bureau. These services are intended to support primary standards laboratories rather than to assign values to apparatus used by secondary laboratories. Accordingly, NBS will calibrate only standards and apparatus of the highest quality except under unusual circumstances such as to fulfill legal requirements or to resolve certain technical disputes. Those requiring support for secondary activities are encouraged to seek help from the numerous commercial calibration sources available. NBS can be of some assistance in locating a convenient source.

NBS will, within the constraint of its resources, address critical measurement problems not explicity covered in the fee schedule. Involvement in these problems may be negotiated in certain measurement areas as indicated in the Appendix (Fee Schedule) to this document by the heading "Special Measurement Services by Prearrangement."

Note: The Electrical Quantities Program does not provide tests for electrical devices or supplies not directly related to the field of measurement except occasionally for other agencies of the Federal government. Tests of power transformers, motors, generators, relays, wiring, appliances, etc., should not be requested. Tests are not generally performed on low accuracy electrical devices or components not intended for use as reference standards.

Limited manpower precludes NBS from undertaking repair activities. Therefore all apparatus submitted for calibration should be free of defects and in proper working order. Electrical contacting surfaces should be in proper condition both mechanically and electrically. Minor repairs and necessary cleaning may be performed, workload permitting, at the discretion of NBS personnel and on an at-cost basis. Electrical standards and instruments, with the exception of unshippable saturated standards cells, may generally be shipped. However, due to their delicate nature and to the limited NBS repair capability, it is advisable to pack them extremely carefully. Special reusable shipping containers customized for this purpose are a worthwhile consideration.

A report is issued upon the calibration of each item. This report contains the measured values of each of the appropriate attributes of the device and their uncertainties relative to the legal units. The measured values and the reported uncertainties describe the results of the calibration process only. No allowance is made for the long-term drift of the item, for its performance under conditions differing from those of the test, or for the effects of transporting the item to and from the Bureau. Additional uncertainties associated with these effects must be quantified by the user from additional measurements. NBS personnel can assist in setting up the appropriate experiments.

NBS neither insists upon nor recommends intervals between NBS calibrations for electrical standards except as explicitly stated in the following sections. These intervals depend upon the performance of the individual standard and the accuracy requirements of its application. These must both be determined by the user. A number of users make lists of intervals they have determined to be necessary for specific items available to anyone interested. NBS can serve as a focal point for contacting those organizations.

Laboratory turnaround time for fixed-fee calibrations can be as long as 4 weeks, depending upon workload, except in the case of standard cells, which require longer periods to stabilize. An estimate of turnaround time will be given for at-cost items.

Technical details particular to each type of calibration are to be found in the following appropriate sections of this chapter.

In situ Calibration: NBS performs calibrations in instances of critical need in which the transportation of the apparatus to be calibrated to the Bureau is not possible or when the magnitude of the stimuli required lies outside its in-house capability. For example, NBS has developed a special portable, current-comparator bridge of high accuracy. This bridge, together with low and intermediate voltage compressed gas dielectric capacitors, can readily be taken to field sites or high voltage laboratories. This system is then used by NBS personnel to calibrate potential transformers, high voltage capacitors, shunt reactors, and other high voltage equipment for the power industry. This approach not only permits equipment to be calibrated in its normal environment and location under normal conditions of use but serves as well as a training experience for the calibration customer's personnel.

NBS has also developed a mobile system for the precise calibration of CCVT's, coupling-capacitor voltage transformers, used by the electric power industry for metering. This precision system can be transported via van to the power station site of CCVT's. The calibration unit is then assembled and placed in parallel with the transformer to be calibrated. The outputs of the two devices are compared to obtain the precise ratio of the device under test.

Well-established Measurement Assurance Programs (MAP's) are available in the areas of resistance, capacitance, voltage, voltage ratio, and electrical energy. Specifics of each of these are discussed in the appropriate following technical section.

Consideration will be given to establishing new Measurement Assurance Programs in areas other than those described below where critical needs can be documented. For those instances where the required program is not generally applicable to a broad user group, NBS may provide the requesting organization with guidance so that they may develop the necessary techniques themselves.

A. Resistance Measurements

Services covered in this section include the following types: Resistance Measurement Assurance Programs, resistance standards with nominal values in the range between 10^{-4} and 10^{6} Ω, high valued standards falling in the range between 10^{6} and 10^{14} Ω, and standard resistors for the measurement of high currents. Resistors not intended for use as primary standards, such as common decade resistance boxes, are not normally dealt with.

In addition to the routinely offered resistance measurement services described here and in the Appendix to this document, NBS will provide such other special services as to aid in the solution of particular measurement problems deemed to be significant. For example, the Bureau has provided a special valued resistor which when used at a production line, assisted a company in ensuring the quality of high precision manufactured electronic components. Requests for assistance of this type will be given thorough consideration. If undertaken as a development project, programs of this nature will generally lead to joint publications in the open literature describing the new measurement techniques or approach. Such services are provided on the basis of operational costs being defrayed by the user.

1. Resistance MAP Services

In the Resistance Measurement Assurance Program, the quality of the client's laboratory standards, maintenance program, and ability to disseminate the unit of resistance is assessed and new values determined for his standards, if necessary. This is done by viewing the measurement process as a system and sampling the measurement quality at a point in that system using NBS transportable standards with well understood properties. As the objective is to determine the laboratory's primary capability, NBS standard resistors at levels selected by the client are measured as unknowns in the client's standards laboratory or elsewhere as appropriate. In addition to using their normal procedure to obtain assignments for the values of the transport group, the laboratory uses NBS suggested procedures which permit determination of the process precision as well as offsets in equipment, etc. Data taken using the client's normal measurement process are combined with those taken before and after the transport process at NBS using least squares techniques to determine the precision and random error of the measurement process as well as the offset of the calibrated values from those expected.

It should be understood that participation in this program is generally not advisable unless one is required to support resistance measurements at or near the state-of-the-art in accuracy and is willing to adopt a system for the continuous surveillance of standards during the intervals between NBS MAP transfers. A successful transfer requires a considerable amount of data collection and a willingness to become involved in the data analysis process. Data supplied in the course of routine NBS calibrations suffice for normal measurement requirements of standards laboratories if proper methods are used by the laboratory to quantify the additional uncertainties caused by transportation and their own measurement process. NBS stands ready to assist client laboratories in this regard.

Apparatus and procedures exist for routine performance of this service at the following levels of resistance, listed in order of increasing uncertainty: one, 10^2, 10^3, 10^4, 10^7, 10^8, 10^9, and 10^{10} Ω. Although the actual uncertainty of these transfers depend upon the capability of the laboratory, they can be said to range from sub-tenths of a ppm in the case of the 1-Ω level to the 20-30 ppm range for the highest valued resistors. Measurement assurance programs to address the maintenance problem at other levels of resistance may also be arranged by consultation.

2. *Resistance Standards* (10^{-4}-10^6 Ω)

Resistance standards with nominal values in the range between 10^{-4} and 10^6 Ω are calibrated by comparison with NBS working standards of the same nominal value. This service is for primary standards of resistance only. Because of this and to maximize their value as standards, resistors submitted for calibration should have the following attributes:

1. A drift rate of less than 20 ppm per year
2. A temperature coefficient of less than 30 ppm per °C at the temperature of use
3. A low thermoelectric coefficient against copper, especially for low-valued resistors

In essence, the standard should be capable of performance at the 0.2 ppm level over a short period (1-3 days).

The standard resistors are generally calibrated in stirred oil at 25 °C. Normally a power level of 0.01 W is maintained in the resistor during the calibration as at that level neither the load coefficient of the standard nor the flow characteristics of the oil bath have appreciable effect upon the outcome of the calibration. At the levels of accuracy involved, four terminal measurements are required for resistors whose nominal value is 100 Ω or less. Any resistor submitted should be designed accordingly. Precision standard resistors of this type are commonly designed with amalgamated current terminals. These should be clean and in generally good condition upon submission to NBS for test.

High quality resistors suitable for use as standards, but not intended for oil immersion, may be accepted for calibration in air (22-44 °C) if their variation of resistance with temperature does not exceed 2.5 ppm per K and if the design provides for accurate determination of the temperature of the resistor under conditions of test. Such standards may have any nominal value. The uncertainty of calibration depends largely upon the performance characteristics of the resistor itself. Acceptability for NBS calibration of these standards remains at the discretion of the Bureau.

A number of services may be performed by prearrangement as indicated in the Appendix to this document. They are:

a. The determination of temperature coefficients
b. The determination of pressure coefficients for Thomas-type resistors and others affected by variations in ambient pressure
c. The calibration of resistance standards at power levels exceeding 0.01 W
d. The determination of the load (power) coefficients of standard resistors for nominal values of one ohm and higher

3. Resistance Standards (10^7-10^{14} Ω)

High-valued resistance standards in the range between 10^7 and 10^{14} Ω are calibrated at room temperature (22-24 °C) and at a relative humidity of less than 50 percent. This is done by one to one comparison with NBS standards at levels of 10^{10} Ω and lower and via capacitive discharge techniques for those resistors whose nominal value exceeds 10^{10} Ω. Uncertainties depend upon the stability and performance of the specific resistor involved. They can be as low as 10-20 ppm for 10^7 Ω resistors to as high as 1.0 percent for 10^{14} Ω.

Because of the high resistances of these standards, their measured values can be affected by leakage currents, which in turn are related to relative humidity and surface cleanliness. Accordingly, they should be so constructed and treated that the effect of humidity is minimized. As with other standards, these resistors should be made of suitable materials and processed in such a manner that resistance values do not change appreciably with time relative to the uncertainty required by their use. The resistance of such standards is frequently highly voltage dependent. Hence, the magnitude of the appropriate test voltage should be specified for each resistor submitted. Each resistor should also have an identifying number engraved on or permanently attached to it.

The Bureau does not have facilities for the determination of temperature or humidity coefficients of resistors whose nominal values exceed 10^6 Ω. Allowance for normal variations due to these effects is made in the uncertainty statement of the test.

4. Resistance Standards (High Current)

Standard resistors for use in precise measurement of high direct currents (shunts) are also calibrated by NBS. Normally only those resistors of 0.04 percent accuracy or better are calibrated. Although the uncertainty of measurement as in other areas depends largely upon the performance of the standard involved, it may be generally said that oil-immersed shunts having a rated current capacity of 50 A or less can be calibrated with uncertainties of the order of 50 ppm as can those designed for use in air at currents of 25 A or less. As current ratings increase, calibration uncertainties increase.

To be effective, standard resistors for current measurements must be of four-terminal design, i.e., one for which the resistance is defined as the ratio of the open-circuit potential difference between the potential terminals to the current flowing through the current terminals. The resistance value will be definite and reproducible only if the current flow pattern at the potential terminals is independent of the way in which current is introduced at the current terminals, and if the voltage observed at the potential terminals is independent of the location of leads on the potential terminals. In some instances where this has not been done, the type and location of connections to the current terminals can be specified adequately to fix the flow pattern at the potential terminals.

Resistors for very high currents (above about 1000 A) require considerable power so that their temperature rise between low and rated current, and the resulting change in resistance, will depend not only on their design, including means provided for dissipating heat, but also on the connecting bus bars and their junctions to the resistor. Bus bars of generous cross-section may carry away a significant part of the heat generated in the resistor. In addition, contact resistance at the points of connection to the bus bars, unless carefully minimized, may contribute appreciably to the heating. (Contact resistance of bolted connections depends on area of contact, cleaniness of surfaces, and pressure.) Resistance determinations made in the laboratory at rated current, therefore, may be of little value because the working temperature conditions cannot be duplicated. The best experimental procedure to use in such cases is to place the standard in a temperature-controlled enclosure and measure its resistance with a comparatively low test current when it is heated uniformly to a temperature approximately that at which it will operate in service. From data at two or more elevated temperatures, combined with that at room temperature, a curve can be plotted from which the resistance at the operating temperature can be read, provided this temperature is determined by the user with the resistor under the actual operating conditions.

Changes in resistance may also result from strains in the resistance element produced by mechanical forces incidental to clamping the resistor connections, as well as from inherent internal expansion constraints on resistor parts, or forces from the magnetic field produced by the current.

B. Precision Apparatus

Ratio, transfer, and scaling devices of high accuracy are covered in this category. Included are Hamon and other transfer devices, Mueller and other high-accuracy Wheatstone bridges, Kelvin (double-arm), and direct reading ratio sets, high-accuracy potentiometers and voltage ratio standards, and inductive voltage dividers. Specific details for each type of calibration not following or contained in the Appendix to this document may be obtained from the office designated in the Appendix.

The complexity and diversity of modern precision apparatus is such that it is difficult to list concisely the cost of calibration of every item acceptable for test. Purchasing agents should identify apparatus by maker and model or catalog number in their purchase orders and should be prepared to supply this information when making inquiries by telephone. In some instances when the apparatus is of an unfamiliar type the Bureau may not be able to quote a calibration fee until the apparatus has been received for inspection.

In general, precision apparatus should be packed carefully to avoid damage during shipment. Instrument lids of light metal or wood associated with heavy items of equipment should be protected from damage by the weight of the instrument itself such as might occur if the shipping container were inverted during transportation.

Calibrations of precision apparatus are carried out at room temperature (22-24 °C) with the exception of Hamon transfer units designed for oil immersion at 25 °C. Some potentiometers and bridges employ self-contained ovens in which temperature-critical components are mounted. These devices exhibit a certain amount of after effect due to the abrupt change in the temperature of resistors. Accordingly, they are allowed to "soak" for a period not shorter than 1 week at their normal operating temperature before calibration. This same precaution should be observed in use.

1. Double Ratio Sets

Double ratio sets (used for wide-range Kelvin double bridge measurements) are calibrated as precision Wheatstone bridges. The method of operation pertinent to these ratio sets is such that the user does not ordinarily need calibration values for the inner ratio arms. The same consideration applies to the inner ratio arms of double direct reading ratio sets.

2. Resistive Dividers and Potentiometers

Precision resistive dividers, either the Kelvin-Varley or Universal Ratio Set types, are calibrated by comparison of their ratios with those of a precision divider comprised of a carefully-constructed network of resistance standards or with those of a more precise divider with adequately known corrections, generally at low voltages. Calibration data furnished are of sufficient extent to permit corrections to be made for loading changes within Kelvin Varley-type dividers. A short test by ninths of the ratios of Kelvin-Varley dividers is performed as an inexpensive means of determining device drift characteristics.

Precision potentiometers (normal uncertainties of 50 ppm or less) are calibrated as resistive ratio devices. Normally precision dividers, such as those mentioned above, are used for this purpose. Uncertainties of calibration reflect instrument performance and calibration error rather than manufacturer's specifications and do not include allowances for reference source errors or fluctuations.

3. Inductive Voltage Dividers

Inductive voltage dividers (decade transformer dividers) are accepted for calibration only at frequencies near optimum design frequencies. The largest contribution of instability in inductive voltage dividers often arises in the decade switches. Variable contact resistance in these switches sometimes affects the stability of voltage-ratio measurements to a significant extent but is most evident by its effect on the phase angle. When a decade inductive voltage divider exhibits large changes in phase angle for repeated measurements after the switches have been disturbed, the divider should no longer be considered satisfactory for use as a reference standard of voltage ratio. Inductive voltage dividers which use pushbutton switching or which incorporate a resistive divider as a fine adjustment usually are not accepted for calibration.

Corrections to the separate decades of an inductive divider, in general, cannot be simply combined; however, the correction to a step setting of one of the higher decades usually is independent of the setting of the lower decades. The effects of stray impedances must be corrected by connecting the case to the divider at one point, and unless otherwise specified, the case will be connected to one of the common terminals.

Decade inductive voltage dividers are calibrated at the Bureau by a comparison method, using as a working standard a well-constructed inductive divider which has been calibrated previously by capacitance-ratio or other suitable methods. The comparison method is simple and convenient and can be used in other laboratories for the rapid calibration of other voltage dividers. Also, it can be extended readily to permit calibration of the lower decades of a divider in the user's laboratory. (See *NBS Technical News Bulletin* **49**, 1, Jan. 1966.) Accordingly, it is recommended that, in general, only one divider from a laboratory be submitted to the Bureau for calibration and that other reference dividers be calibrated by a comparison method using it as a standard.

4. Volt Ratio Standards

Resistive volt ratio standards (volt boxes) are used to extend the range of the voltage measured by a potentiometer. The ratio for any range is obtained by dividing the voltage across the input terminals by the open-circuit voltage across the section to be connected to the potentiometer. Normally, NBS calibrates only dividers for which the maker's stated ratio accuracy is 50 ppm or better. Dividers normally are calibrated by direct comparison with the NBS ratio standard. Values of ratio normally are reported with an uncertainty in the range from 25-50 ppm. However, the values of ratio of some special types having combined humidity, temperature, internal heating, and high voltage effects of less than 10 ppm can be reported with uncertainties much lower, depending upon the performance of the volt box. Silsbee-type dividers of design similar to that described in NBS RP 1419 are calibrated by the Dunfee method (NBS Paper 67C1-114). Values of ratio normally are reported with an uncertainty of 10 ppm, but higher accuracies could be attained if the apparatus were to warrant it.

The following should be considered in the calibration and use of such dividers:

(1) The insulating structure of a divider is equivalent to a network of high resistances in parallel with one or more of its wire-wound precision resistance elements. Thus, changes in insulation resistance as a result of variations in surface or volume moisture may affect the ratios. Such ratio changes normally are less on low than on high ratios. This effect can be reduced or eliminated by constructions which provide built-in guard electrodes, maintained at appropriate potentials. Another effect of humidity is to

produce changes in the values of the precision wire-wound resistors. The magnitude of this effect varies with coil construction and with wire size and coating. Because humidity effects may reach equilibrium only after days (or even weeks), it is recommended that laboratory humidity be held continuously at or below 50 percent.

(2) Changes in ambient temperature should have little effect on the ratio if all the resistance elements have small and nearly equal temperature coefficients.

(3) Internal heating, which includes both the self-heating of the high-resistance coils and the transfer of heat to other coils (proximity heating), may significantly change the ratio of a divider.

(4) The magnitude of this change and the time required for a state of "ratio equilibrium" to be established varies with divider construction and with operating and ambient conditions. For example, many dividers constructed of manganin resistors exhibit heating curves (ratio versus time) that go through a maximum within 10 min after the divider is energized then decrease to an equilibrium value. The time required to reach equilibrium usually is 2 h or less. For the highest ranges of a divider having a relatively large operating current the difference between the maximum value and the equilibrium value can be as large as 200 ppm. The Silsbee-type and special dividers that are constructed of resistance elements having small and nearly equal temperature coefficients and designed to have low power dissipation per element usually have ratio changes less than 10 ppm due to internal heating.

(5) Corona and other high voltage effects usually are negligible for voltages up to 1500 V.

Dividers are calibrated on each range at rated voltage. However, the first calibration test should also include a complete test at reduced voltage (20% rated voltage or less) to provide significant information on heating effects. The general procedure at NBS for calibrating a divider by the direct comparison method is to measure the ratio at rated voltage on the highest range as a function of time and then proceed to the lower ranges in descending order. Approximately 5 to 15 min are required for ratio equilibrium to be established on these lower ranges.

5. Volt Ratio MAP Services

Specially designed NBS transportable volt ratio standards provide the means for a Measurement Assurance Program in dc voltage ratio. This program can be used in two ways. It can be used to evaluate the ability to maintain a high precision volt box or ratio standard as a basis for the calibration of similar devices. A variation in approach, however, permits the evaluation of the ability of the laboratory to produce accurate dc voltages up to 1000 V for the calibration of precision sources and voltmeters. This program is unique among MAP's for electrical parameters in that portable NBS measurement instrumentation is also used to aid in the identification and solution of problems limiting laboratory performance at high levels of accuracy.

Data handling is very much like that in other MAP's. Before and after data are coupled with the client's calibration results to determine the offsets of his ratio assignments from those of NBS and the uncertainty of those offsets. Redundancy of measurement is achieved through the use of interchangeable connectors which permit slight but well-characterized alterations of the ratios of the transport standard. Their use is effectively identical to using a number of volt-ratio standards. Uncertainties less than 1 part in 10^5 can readily be achieved using this program.

C. Impedance Measurements

1. Impedance MAP Services

The Measurement Assurance Program in capacitance is routinely carried out at the 1000 pF level. An NBS designed transportable capacitance standard forms the basis for this service. It consists of four specially-selected commercial gas dielectric 1000 pF capacitors housed in a temperature-controlled oven capable of sustained operation via a battery pack. Data handling in general is similar to other MAP's. Redundant measurement designs provide data for estimation of process precision and of the magnitude of some systematic effects such as ground loops. Before and after data are combined with client data in a linear regression analysis used to determine the difference between the client's unit of capacitance and the legal unit. Upon completion of a number of transfers, this difference may be characterized as a function of time and that characterization used in conjunction with the results of a continuing internal surveillance program to ensure the quality of capacitance measurements at the client facility. The uncertainty of the process depends very much on the client's laboratory capability and could be as low as one in 10^7.

Similar programs at other levels of capacitance will be initiated as needs and resources dictate. NBS personnel can assist in the design of measurement assurance programs using client equipment and normal routine calibration data if circumstances permit.

2. Standard Capacitors

The following apply to the calibration of standard capacitors at NBS:

(a) Calibrations are ordinarily performed at an ambient temperature of 23±1 °C except for high stability gas dielectric capacitors. These are placed in a highly insulated chamber for 48 h to achieve temperature stability during calibration. Calibration temperature is reported to within ±0.1 °C. Relative humidity is maintained at 50 percent or less in all cases.

(b) Precision three terminal air capacitors, such as ESI Model SC1000 and GENRAD Model 1404 have been found to be variously affected by mechanical shock. Accordingly, two types of calibrations are offered. The higher accuracy calibration requires a qualification test to determine the effects on capacitance of various impacts and changes in orientation. Results of this test are coupled with the random error of the precision calibration which follows to provide a definitive accuracy for the process. For the lower accuracy test, a similar calibration, albeit with reduced resolution, is performed. The assigned uncertainty is fixed and has been deduced from an analysis of data taken from tests on a large population of standard capacitors.

(c) The frequencies available for these calibrations depends upon the type of capacitor and its connectors. In general, capacitors with coaxial connectors can be calibrated at 100, 400, and 1000 Hz. Capacitors with binding posts, banana plugs, etc., can be calibrated at 66⅔, 100, 400, 1000 and 10,000 Hz.

(d) The capacitance value given is the equivalent parallel capacitance. In general a determination of the equivalent parallel conductance with high accuracy is not feasible; however, for solid dielectric capacitors an approximate value is given without charge.

(e) The uncertainty stated in the report of calibration is determined in part by the accuracy of the Bureau's measurements and in part by the characteristics of the capacitor itself, and is sufficiently broad to allow for variations in the stray capacitance at the connectors, variations in temperature of a few degrees Celsius, considerable variation in relative humidity and atmospheric pressure, and frequency deviations of a few percent from the stated test conditions. Over the above frequency range, and in the capacitance range from 0.001 to 100 μF, the uncertainty usually lies in the range 0.002 to 0.5 percent.

(f) When capacitors requiring terminal plugs (banana plugs) for parallel connection are sent to the Bureau, the plugs which will be used with the capacitor after calibration should be sent also. If such a capacitor arrives without plugs, the Bureau must attach plugs temporarily in order to calibrate the capacitor. The plugs used by the Bureau are GENRAD Type 274-P. If after calibration with these plugs, the capacitor is used with plugs of even slightly different length and base, the value of capacitance can differ significantly from the value reported. Unless otherwise requested, the measured value reported by NBS is the capacitance added when the standard is plugged directly into the binding posts of the Bureau's bridge. For two-terminal GENRAD capacitors Type 1401, Type 509, and Type 1409 (used as two-terminal capacitors) it has been found that plugs which are different from the Type 274-P can cause a capacitance increase ranging from 0.04 to 0.14 pF. For three-terminal use of GENRAD Type 1409 capacitors it has been found that different plugs can cause a capacitance increase ranging from 0.01 to 0.04 pF. No significant change in conductance has been found in either the two-terminal or three-terminal value. The importance of terminal connection methods becomes extremely critical when capacitance values of 0.01 μF or less are being measured. Improved accuracy in two-terminal measurement can be realized if standards are provided with precision coaxial connectors.

(g) In the case of direct capacitance standards, it is assumed that the connectors are coaxial. While the connectors available for this purpose are adequate, it should be noted that changes or instabilities in the impedance of the shield or guard connection of a three-terminal capacitor can change the capacitance significantly.

(h) The following capacitors are no longer accepted for calibration by the Bureau:

Two-terminal air capacitors with exposed terminals, nominal value of capacitance 1000 pF or less. (For example, GENRAD Type 1401 capacitors with either old or new style terminals.) Two-terminal air capacitors with the "low" terminal (ground terminal) extended and surrounding the "high" terminal are acceptable. Refer questions regarding acceptable types to the information source given in the Appendix.

(i) In applying the fee schedule in the appendix to decade capacitance boxes and variable air capacitors, the first entry applies to a determination of the zero capacitance and conductance of the box (all dials set at zero). The second entry applies to the determination of the capacitance and conductance added to the circuit when any one dial is advanced from zero to a specified setting, and at the frequency used in determining zero capacitance. For measurements at additonal frequencies the schedule is applied in the same manner, i.e., the higher fee is used for the first point (zero calibration) at the new frequency and the lower fee applied to additional points at that frequency.

(j) Unless otherwise specified in the client's purchase order, capacitors with solid dielectric will be calibrated as two-terminal capacitors (measurement of "grounded" capacitance, case connected to low terminal).

(k) If a capacitor arrives in a condition such that minor repairs are required, the owner will be notified and requested to supply a letter granting permission for NBS to perform the repairs.

3. Standard Inductors

Standard inductors for use in ac bridges are tested at 100, 400, 1000, or 10,000 Hz at a room temperature of 23 °C and a relative humidity of 50 percent or less. Measurements at 10,000 Hz are limited to standard inductors of 0.1 H or less. Most inductors used at 60 Hz can be tested at 100 Hz since the variation of inductance with frequency in this range is usually negligible. Purchase orders should state which frequency or frequencies are to be used for calibration purposes. If no test frequency is specified in the order, measurements will be made at 1000 Hz. A metal encased standard is calibrated with the case connected to the "low" terminal of the inductor unless other conditions are specified. Variable inductors used as circuit elements in laboratory setups are low accuracy devices which do not come within the purview of this schedule and should not be submitted for calibration. Q values are not supplied for inductors calibrated in this section. Inductors intended for use as Q standards at radio frequencies are covered in the next chapter.

Accuracy: The effective series inductance value is given to as many significant figures as are justified at the time of measurement. The uncertainty figure given in the report of calibration will vary from 0.02 to 0.2 percent depending on the nominal value of the inductor and the frequency of the test current employed.

Usually inductors can be shipped safely by express but they should be packed carefully to avoid damage to the coil fastenings and terminals.

D. Voltage Measurements

1. Voltage MAP Services

The Volt Transfer Program, VTP (the MAP for standard cells), is designed to reduce the uncertainty of the assignment of the unit of voltage at the participating laboratory, and to provide the laboratory with quantitative information about its own measuring process.

In the VTP, rather than have standard cells sent to NBS for calibration as is usually done, the Bureau will provide transport standards of voltage, appropriate measuring techniques, and overall supervision of the experiment. As far as is practical, the service will be tailored to meet the needs of each participating laboratory.

The experiment is carried out in three phases: First, NBS analyzes the participant's procedures and measurement setup. From the analysis, NBS proposes certain internal experiments, determines various operating parameters, and establishes that the local measurement process is in control. Where measurement problems are encountered, NBS will assist in solving these problems even to the extent of sending personnel to the laboratory, if necessary.

Second, NBS provides the laboratory with a suitable transport standard (saturated cell group) and the procedures for intercomparing it with its reference group of standard cells. Usually, the transport standard will be shipped via air freight under carefully controlled conditions.

Finally, upon return of the transport standard, NBS analyzes the results and suggests any change in the laboratory's unit of voltage that might be in order.

The level of participation by each laboratory will depend on its own internal requirements. It may vary from four such experiments per year to one every 2 years. This type of approach eliminates several sources of uncertainty that are inherent in the regular procedure in which customers send or bring their cells to NBS. This is because the Volt Transfer Program calibrates the whole process and not just a portion of it. At the present time, NBS is quoting as the standard deviation of a single experiment 0.14 ppm or a three standard deviation uncertainty for the complete calibration of 0.42 ppm. It should be again emphasized, however, that this service is not meant to replace the regular calibration procedure. Rather, it is designed for those laboratories that need and can utilize the most precise unit of voltage obtainable.

To keep the data analysis activity at a manageable level, the transport standard should be compared with a single laboratory reference group of cells containing a number of cells such that a single measurement design may be used for a total comparison. The use of cells configured so as to require more than a single, statistically optimized measurement design to assign values to the transport standard in terms of the client's unit of voltage will result in extra charges. Large designs, i.e., those involving more than 12 cells, are undesirable as individual cell drifts can tend to mask the estimates of process precision levels. NBS can provide computer programs and design information to permit the client to perform his own data analysis where large numbers of cells are involved.

Since the amount of equipment available for this program is limited, it is vital that interested parties advise us of their intent to use the program in any calendar year by the end of the previous year.

Routine calibrations of voltage standards involve the following considerations:

(a) Unsaturated cells require approximately 3 weeks for a complete calibration. Such cells are placed in a thermally lagged enclosure and their emfs are read daily for a period of 10 days. If the measured emf fluctuates unduly or is unusually low, or if the cell shows abnormal indications, the report of calibration will reflect these circumstances. Unsaturated cells are not likely to be injured by normal transportation (mail or express) if they are packed carefully. Because of the possible hazard from freezing, shipment during very cold weather should be avoided.

(b) Saturated standard cells of the unshippable type should always be transported by messenger because such cells should never be tipped from an upright position by more than 45° in any direction. Unshippable saturated cells contained in portable, temperature-regulated enclosures should also be transported by messenger and with the enclosure activated or under power, if possible.

(c) Saturated standard cells of the shippable type housed in portable thermoregulated enclosures should be packed carefully and shipped under power if possible. Liquid-in-glass thermometers normally mounted in such devices should be removed and provided with additional rigid packing for protection against breakage. Enclosures having a nominal cell temperature of 28 °C or lower should not be transported during the summer due to the danger of over heating. Enclosures should not be energized by using the ac power mains while they are packed in shipping containers.

(d) Saturated standard cells which arrive having been maintained continuously at their nominal temperature of use will, workload permitting, undergo test immediately upon receipt for a period not to exceed 4 weeks, unless other arrangements are made. If such cells perform abnormally with respect to the typical performance of like cells in similar environments, the owner will be notified. Arrangements for further testing may be made at that time if desired. Cells will be returned as soon as possible after calibration.

(e) Saturated cells arriving at a temperature other than their nominal temperature of use will be brought to their use temperature as soon as possible after receipt. Starting the month after they are initially brought to temperature, weekly readings will be taken to observe the stability of the cells. When the cells stabilize, 10 daily readings will be taken and used to assign values to them. This process will not exceed 90 days without special arrangements being made.

(f) Solid state voltage reference devices for test must have output voltages in the range between 1.015 and 1.020 V and/or 10 V and a rated accuracy of 0.005 percent or better. Such devices will be tested under continuous power.

E. Electrical Instruments (ac-dc)

RMS ac-dc transfer standards [thermal voltage converters (TVC's) and thermal current converters (TCC's), covering the ranges 2 Hz to 1 MHz, 1 mA to 20 A, and 0.5 to 1000 V] meeting certain requirements, are accepted for calibration. Accuracies and limitations are listed in the table at the end of this section.

(a) Ordinarily only ac-dc transfer standards and thermal converters of 0.05 percent rated accuracy or better are accepted for test, which consists of ac-dc difference determinations as described below.

(b) Ac-dc difference tests consist of determinations of the differences between the quantities (current, voltage, or power) required to give the same response (output) of the transfer standard on alternating current and on reversed direct current (the average of the two directions of direct current). The alternating quantity, Q_a, required for a given response of the instrument or converter is then $Q_a = Q_d(1 + s)$ where Q_d is the average quantity required for this response on reversed direct current, as determined by dc standards, and s is the small fractional ac-dc difference.

(c) Tests are recommended at rated voltage or current on each range at 20 kHz (the upper limit for NBS' best accuracy) or at the highest frequency of interest. Additional tests are recommended at lower frequencies only if the ac-dc differences are large at the initial frequency. Since the need cannot be predicted, it is recommended that the purchase order include an allowance for a few such tests, perhaps by stating an upper limit of cost. A second test at 600 V is recommended for 1000 V ranges, for these ranges may be affected by self heating. Tests are made from 30 kHz to 100 MHz or more at NBS Boulder, Colorado (see ch. V).

(d) In addition to the high frequency tests, an ac-dc difference test (ordinarily at 20 Hz) is recommended for one range, to verify the low frequency accuracy. Thermoelements have a low frequency limit, below which they fail to integrate properly. The ac-dc difference may approach 0.02 percent at frequencies ranging from about 5 Hz for most low range thermoelements to about 60 Hz for some thermoelements with ratings above 1 A. This low frequency ac-dc difference is the same for all ranges of a multirange converter in which a single thermoelement is used with shunts or multipliers. For convenience, usually a low voltage or current range is chosen for the test.

(e) At special request, high-grade thermal voltage converters of the coaxial type, having plug-in series resistors for one or more thermoelements to form ranges from 1 to 1000 V, can be evaluated to 20 ppm at a higher cost. The dc reversal differences of the converter must be less than 200 ppm and the ac-dc differences less than 100 ppm. The design should permit intercomparisons between ranges by the user. If such intercomparisons are made, initial tests at NBS are recommended only for the lowest, middle, and highest ranges, to provide tie points and to verify the accuracy of the user's intercomparison (step-up) procedures. Any relative changes in the converters can be detected by subsequent periodic intercomparisons in the user's laboratories. If no changes are observed, retests at NBS should not be necessary.

(f) At special request, the ac-dc differences of high-grade thermal converters (thermoelements) for current measurements from 5 to 50 mA can be determined by direct comparison with the basic NBS ac-dc transfer standards, to 5 ppm from 20 Hz to 20 kHz and 10 ppm up to 50 kHz, at a higher cost. The dc reversal differences of the converters must be less than 100 ppm and the ac-dc differences less than 20 ppm.

(g) The ac-dc differences are small and very stable in well-designed, rigidly constructed ac-dc transfer standards. For such a standard, a recalibration interval of not less than 5 years is recommended if checks are made periodically by the user (by comparing it with another ac-dc transfer standard or by measuring a stable ac voltage standard with adjacent ranges of the transfer standard).

Range and uncertainties of ac-dc difference calibration

Frequency	2-5 Hz	5-20 Hz	20 Hz-20 kHz	20-50 kHz	50-100 kHz	0.1-0.5 MHz	0.5-1 MHz
Voltage limits (V)	50	100	1000	1000[1]	600	100	100
Current limits (A)	0.05	0.05	20	16[2]			
			Uncertainty (%)[3]				
Multi-range TVC's	0.02	0.01	0.005	0.01	0.01	0.02	0.03
Coax single range TVC's	.02	.01	.002[4]	.003[4]	.005[4]	.02	.03
TE (5 to 50 mA)	.02	.01	.0005[4]	.001[4]			
TCC (0.005 to 5A)	.02	.01	.005	.01			
TCC (5 to 20 A)			.01	.01			

[1] 200 V at 20 Hz
[2] 5 A at 20 Hz
[3] The lowest uncertainty applies at the crossover frequencies. Uncertainties may be increased if the ac-dc differences are large or change with self-heating.
[4] See appropriate paragraph (e or f above)

A calibration service for ac-dc wattmeters will be provided on a special test basis. Direct inquiries to address given in the Appendix.

Ac Resistors (1 to 0.001 Ω, 50 Hz to 10 kHz). Properly designed four-terminal ac resistors (having small phase angles) can be measured at current ratings not to exceed 50 A. The values for the in phase and quadrature component can be reported for frequencies up to and including 10 kHz.

F. Instrument Transformers and Comparators

1. Voltage Transformers

NBS provides routine services for measurement of complex voltage ratios (magnitude and phase angle) of transformers for primary voltages up to 50 kV at 60 Hz. The estimated limit of measurement uncertainty is 0.01 percent for ratio and 0.1 mrad (1 mrad = 3.438 min) for phase angle for stable transformers tested with low burdens. Inquiries are invited concerning related measurements at higher voltages, and at frequencies other than 60 Hz, not listed in the present appendix.

The following test information must be furnished for each transformer or for each range on a multirange transformer.

1. Frequency
2. Secondary voltages
3. Secondary burdens

Ambiguity of test burdens can be avoided if the impedance and power factor or the resistance and reactance, rather than volt-ampere rating, of each burden is specified.

Measurements are made with one side of both the primary and secondary windings connected to ground.

2. Current transformers

Normally the Bureau calibrates only current transformers of high quality for use as reference standards. The Bureau may decline requests for tests which are not to be used for establishing or checking a reference standard. If the transformer quality is stated in terms of ANSI accuracy classes, calibration will be limited to transformers stated to be in the 0.3 percent class for one or more ANSI burdens. Bureau equipment is designed primarily for testing current transformers whose rated secondary current is 5 A. Results obtained at frequencies near 60 Hz normally will be reported to an accuracy of 0.01 percent in ratio and 100 μrad (approximately 0.3 min) in phase angle.

Tests cannot be started until information is furnished concerning the following conditions: (1) test frequency, (2) secondary test currents, (3) secondary burdens, (4) ranges to be tested. It is customary to make tests at secondary currents of 0.5, 1, 2, 3, 4, and 5 A.

Transformer Burden: Current transformers should be tested with burdens equivalent to the impedance imposed when the transformer is used as a reference standard. Inclusion of tests at ANSI burdens is not recommended. The burdens listed in the Standard for Instrument Transformers, C-57.13, are for rating purposes only and differ from the instrument burdens imposed on a reference standard. Large errors in measurement can result if the values of ratio and phase angle obtained with an ANSI burden are used for the transformer when it supplies only an instrument burden.

Preferably the burden should be specified in terms of the measured resistance and inductance, including the leads to connect the instruments to the secondary of the transformer. If this measurement cannot be made conveniently, it will suffice in most cases to state the name of the maker, the type, range, and serial number of each instrument used in the burden, and the length and size of the wire of the leads used in the secondary circuit. Alternatively, the burden may be stated in terms of the volt-amperes and power factor of the secondary circuit at the test frequency.

The test equipment regularly used at the Bureau imposes a minimum test burden of about 0.03 Ω with a minimum inductance of about 10 μH.

Demagnetization: Unless otherwise specified, current transformers will be demagnetized before being tested. If it is desired to have a transformer tested as submitted (without demagnetization), this fact should be stated specifically.

Test limitation at frequencies greater than 60 Hz: At 400 Hz, the maximum current range for which tests are made is about 200 A and normally the values are reported to an accuracy of 0.02 percent for ratio and 200 μrad; for phase angle at 800 Hz there is a further reduction in the current range and accuracy.

Recalibration: At room temperature the ratio and phase angle under a specified test condition should be repeatable unless the core is magnetized. Once stability has been demonstrated, a current transformer should not require recalibration at intervals less than 5 years.

Contact resistance: Loose or dirty primary and secondary terminations may contribute appreciably to the calibration values obtained. These surfaces should be cleaned thoroughly prior to shipment for test to avoid additional errors.

G. High Voltage and Energy Measurements

1. Voltage Dividers and High Voltage Resistors

The calibration of ratio devices such as voltage dividers need not be referred to the national standards of inductance or resistance or to any other national standard. However, methods and equipment are available at the Bureau for the measurement of voltage ratios with high accuracy, and a regular calibration service is provided for certain types of voltage dividers which are sufficiently stable for use as reference standards.

Resistive Voltage Dividers and High Voltage Resistors

Resistive dividers and resistors designed for use at high voltage levels are accepted for calibration only if they are nearly corona-free at the rated operating voltage and are designed to have low voltage-coefficients and low load-coefficients.

High Voltage Pulse Dividers

Ratios of resistive, capacitive or mixed voltage dividers are determined under pulsed high voltage conditions. Determinations employ specially designed pulse dividers and calibrated Kerr cells as reference standards. Pulses applied during calibration are intended to simulate the divider's routine operation. Calibrations are made at selected voltage intervals up to 300 kV as requested.

Dividers Used to Measure High Voltage in Diagnostic X-Ray Units

The calibration of dividers used to measure the high voltage in diagnostic x-ray units consists of three measurements. These are the measurements of the variation of the ratio with a change in the frequency of the applied voltage in the frequency range of dc up to 10,000 Hz; a determination of the ratio under direct voltage at 25 kV; a measurement of any voltage induced variation of the ratio in the voltage range from 20 to 70 kVp.

2. High Voltage Capacitors and Capacitance Bridges

Calibration services are provided for capacitors and capacitance bridges having voltage and/or current ratings beyond the capability of the facilities used in providing the services described above (i.e., voltages >100 V at 60 Hz). Gas-dielectric capacitors (values to 1000 pF), and high voltage capacitance bridges can be calibrated up to 100 kV at 60 Hz. Other frequencies from 50 Hz to 10 kHz are also available at reduced voltages. Power factor correction capacitors rated up to 1000 μF and 10 kVA can also be calibrated at 60 Hz. The above calibrations are special, and advance arrangements must be made. For devices exceeding the above voltage, current, or kVA ratings, see "High Voltage Field Calibrations" in the Appendix.

3. Kerr Electro-Optical Pulse-Voltage-Measuring Systems

Calibration services are provided for Kerr cells used for electro-optical measurement of high voltage pulses. The Kerr cell constant is determined by reference to calibrated pulse-voltage measurement systems. Calibrations can be performed for Kerr cells designed for measurement of pulse voltages peaking as high as 300 kV. Service is provided on a special test basis. (Listed in the Appendix under "High Voltage and Energy Measurements.")

4. High Voltage Field Calibrations

Calibration services are provided for devices such as standard capacitors, inductive and capacitive voltage transformers, bridges, and power factor correction capacitors whose physical size and/or voltage and power ratings exceed the capabilities of NBS in-house facilities or preclude shipment to NBS. Calibration can be carried out in the client's laboratory or plant, in a mutually agreed-upon commercial, governmental, or university laboratory, or in special cases, in the field. Charges for the service will be actual expenses. These include preparation and shipping of test gear, travel and living expenses for test personnel, data analysis and report writing, and overhead. Since this is a special service, prior consultation and arrangement is essential. However, use of this service is strongly encouraged.

5. Watthour Meters

Only portable standard watthour meters (rotating standards) will be accepted for test, which consists of determinations of the percentage registration of the meter "as received." If meters are to be cleaned and adjusted this must be done before they are submitted for test. The Bureau does not undertake the cleaning and adjustment of meters and does not knowingly begin tests on faulty meters. Before tests can be started the test conditions must be completely specified by the user as to current and voltage ranges to be tested, frequency, applied voltage and current, and power factor. A guide listing a limited yet adequate schedule of tests is available at no charge. Test voltages should be chosen from the following values: 1, 2, or 4 times 110, 115, 120, 125, and 130 V (but not to exceed 480 V). Test currents should be chosen from the following values: 1, 10, or 100 times 0.5, 0.75, 1, 1.25, 1.5, 2, 2.5, 3, 3.75, 4, 5, 7.5 A (but not to exceed 100 A). Unless otherwise specified, test runs on portable standard watthour meters (rotating standards) are of approximately 100 s duration. The meters are energized for at least 1 h at rated voltage and current on one range before starting the test. Normally values are reported with an uncertainty of ± 0.05 percent.

The NBS Measurement Assurance Program (MAP) for electric energy (NBS Technical Note 930) is designed to evaluate energy measuring equipment. An NBS-owned transport standard watthour meter (WHM) is shipped to a customer, and a tie to the U.S. national energy unit is made without the down-time encountered when WHM's are calibrated at NBS. In addition, and more important, for those who calibrate reference standard WHM's, a MAP standard can be used to evaluate an entire measuring system. By request, for smallest uncertainties, the MAP transfer standard WHM's can be calibrated by means of the new Current Comparator System used to establish the unit of energy. Tests are made at 5 A, 120 V, unity and 0.5 pF, current lagging voltage.

H. Magnetic Measurements

A general discussion of magnetic principles and methods used in magnetic testing is given in NBS Monograph 47, "Basic Magnetic Quantities and the Measurement of the Magnetic Properties of Materials."

Tests in this field for the most part are made on samples which serve as standards to coordinate work in various laboratories, and thus secure uniformity in commercial testing. For this purpose it is essential that the standard bars be very uniform in their magnetic properties. Normally the Bureau does not make routine acceptance tests of magnetic materials unless these specimens are to be used, at least temporarily, as standards.

The item listed in the Appendix as "Magnetic Measurement Services" under the heading "Magnetic Measurements" covers examination of materials or instruments found to be unsuitable for test or special measurements not covered by this schedule.

Specimens submitted for normal induction and hysteresis tests should be of rectangular cross section with dimensions in the ranges shown in the table below.

Range	Width not to exceed (cm)	Thickness not to exceed (cm)	Length not less than (cm)
0 to 300 Oe	3	1	25.4
100 to 5000 Oe	3	1	7
0 to 5000 Oe	3	1	25.4

Specimens submitted for permeability measurements whose permeability is not greater than 4, may be of circular cross section, diameter not to exceed 1.27 cm, but in any event cross sectional area must be not less than 0.2 cm^2.

For ac core loss and permeability, test specimens should consist of the proper number of strips 3 cm wide and either 28 or 30.5 cm long, prepared in accordance with the specifications of the American Society for Testing and Materials, A-34.

CHAPTER V

V. Electromagnetic Measurements at Radio, Microwave, Millimeter Wave and Laser Frequencies

A. Introduction

The National Bureau of Standards provides methods and standards of measurement for electromagnetic quantities used in devices and systems in the electronics and laser industries and in related fields. This support is provided as a function of frequency ranging from 30 kHz to optical frequencies. However, specific electromagnetic characteristics are usually not available as a continuous function of frequency except for limited portions of this frequency spectrum. Besides measurements requiring coherent frequency sources, pulse, noise and electromagnetic interference measurements are provided. As a result calibration and consultation services are available for voltage, power, attentuation, impedance, noise, fields and other electromagnetic quantities. Details on ranges and magnitudes for specific quantities are itemized in the service listings to follow below.

Special Instrumentation and Scheduling Requirements

In order to provide meaningful and reproducible (uncertainties minimized) electromagnetic measurements or calibrations the terminations and interfaces must be well characterized. Therefore standards, instruments, and devices submitted for calibration or evaluation, as a general rule, must be equipped with precision coaxial connectors or Electronic Industries Association standard rectangular waveguide sizes terminated with appropriate flanges. Terminations, frequency ranges, magnitudes and other details for a given type of service are stipulated in the Appendix and in service descriptions which will follow below. To improve service, reduce cost and turnaround time and facilitate planning, some of the electromagnetic services are available only on a scheduling basis. If services are available on a scheduled basis the Appendix will so indicate for the quantity listed. Further considerations on terminations are as follows:

(a) Coaxial Connectors

In coaxial systems, the use of precision coaxial connectors is strongly advocated for calibrations involving immittance, attenuation, voltage, and other quantities. Precision coaxial connectors are those which meet or exceed the electrical and mechanical specifications set forth by the Institute of Electrical and Electronic Engineers [1,2]. As a general rule only those standards and instruments so equipped can be calibrated to the highest accuracies.

For immittance, the difference in calibration uncertainties may vary by as much as a factor of 10 depending upon whether the connectors on an item are of the precision or nonprecision type.

Similar advantages are realized in attenuation measurements where the voltage standing wave ratio (VSWR) of a mated pair of connectors is highly important. A typical measurement at 4 GHz might yield the following results. With precision sexless coaxial connectors, mismatch errors, due to mated connector pairs, are of the order of 0.01 dB as compared to 0.02 dB for the improved Type N and 0.05 dB for the ordinary Type N connectors. Systematic errors in the measurement system are about 0.03 dB. Therefore the precision connector is a practical necessity for utilizing the full capabilities of the measurement system.

Calibrations involving power are not as critically dependent upon connector uncertainties because the VSWR of a connector pair need only be 1.05 or better to avoid significant uncertainties at the present state of the art. However, the use of precision connectors in power instrumentation provides assurance that connector VSWR's greater than 1.05 are not present to limit the best available performance.

References

[1] **Precision coaxial connectors (IEEE Standard 287-1968) (ANSI C16.43-1972),** (Institute of Electrical and Electronic Engineers, Inc., New York, NY).

[2] **B. O. Weinschel standardization of precision coaxial connectors,** *Proc. IEEE* **55,** 923 (June 1967).

(b) Rectangular Waveguides (Flange Terminations)

Each EIA designated waveguide size covers a range of frequencies. In general, the measurement systems provide complete and continuous coverage as appropriate for the various waveguide sizes. However, for some electromagnetic quantities an automatic network analyzer is used covering only the "center band" for each waveguide size. In other cases a series of measurements are made at a number of frequency points in a given waveguide band. Details are provided in the sections to follow, describing the quantities for which services are available. Information concerning connectors, frequencies, and magnitudes also appears in the Appendix.

A common metrology practice employs the echelon or chain system of calibration with a degradation in accuracy in each step of the chain. Each succeeding laboratory is less accurate than the one from which it received its calibration. This degradation is not necessary if an operating laboratory maintains adequate control procedures and utilizes measurement assurance programs available from NBS. It is intended that ultimately measurement assurance programs will be available for critical electromagnetic quantities to allow laboratories to maintain these units with state-of-the-art uncertainty. The rate at which such programs are established is contingent upon the demand. As measurement assurance programs become available they will be listed in the Appendix.

B. Attenuation Measurements

1. Special Attenuation Measurement Services and Consultation

The specific attenuation services listed below are available on a limited basis depending on other demands and staff availability. Measurements not listed can be provided if sufficient advance notice is given. The cost of such services must be negotiated and will, in general, be higher than other established services. Consultation by telephone or written correspondence as indicated in the Appendix is suggested. Often a measurement technique can be suggested that will permit the customer to perform his calibrations in-house with appropriate reference to other NBS supported standards. (Note the definitions given in sec. V.B.5.)

2. Attenuation Measurement of Coaxial Attenuators

Coaxial fixed and variable attenuators are measured on the NBS modified automatic network analyzer (ANA) over the frequency range indicated in the Appendix (see Attenuation in the Appendix).

All measurements are made by the substitution method, which requires that the connectors used be asexual or that the attenuator have a male connector at one port and a female connector at the other. If an adapter is required to comply with the foregoing, it must be supplied with the attenuator. The combination will be calibrated as one unit.

In addition to measurements performed on the ANA, fixed frequencies of 30 and 100 MHz are available referenced to the NBS waveguide below cutoff standards at these two frequencies.

Limits of Uncertainty

Coaxial attenuators are normally measured in a system having a characteristic impedance of 50 Ω. Because measurement limits of uncertainty are degraded by any deviation from this characteristic impedance, the types of allowable connectors are limited. Connectors having a known plane of reference, such as the sexless precision connectors or Type N connectors meeting Mil C 39012, are acceptable. Limits of uncertainty also depend upon the VSWR of the individual attenuator, quality of the attenuator and connectors, and the magnitude of the attenuation [1]. Typical systematic uncertainties range from 0.03 to 0.05 dB/10 dB.

3. Attention Calibrations of Variable Rectangular Waveguide Attenuators

Variable waveguide (usually rotary vane) attenuators are calibrated in the frequency bands indicated in the Appendix by the IF-Substitution technique referenced to 30 MHz.

It is suggested that measurements requested be held to a minimum number of settings at a single band-center frequency which should be sufficient to determine the characteristics of the device. It is further recommended that previously calibrated units not be resubmitted unless tests performed by the user indicate a shift in values.

Limits of Uncertainty

This is a function of resettability and input VSWR of the waveguide ports as well as internal leakage and quality of flanges. Devices submitted should be in the best possible condition to justify calibration and insure stability of assigned values. Typical systematic uncertainties range from 0.03 to 0.05 dB/10 dB.

4. Attenuation Measurements of Waveguide Below Cutoff (Piston) Attenuators With Coaxial Connectors

Measurements on piston (WBCO) attenuators are performed at two fixed frequencies as indicated in the Appendix (see Attenuation). These attenuators are normally quite stable and seldom need recalibration unless damaged or mechanically worn. Since any laboratory can perform independent checks to determine continuing repeatability and linearity of attenuation we do not recommend periodic recalibrations. This recommendation, in part, is also because more damage is suffered in transit than in daily use. In any measurement, the maximum power delivered to the attenuator will not exceed 400 mW. If the attenuator cannot tolerate this power level some reduction of measurement range indicated in the Appendix will be required.

Limits of Uncertainty

These attenuators are normally calibrated in a system having a characteristic impedance of 50 Ω. Since only measurements of incremental attenuation are made on this type of attenuator, Type BNC, C, TNC, and similar connectors are acceptable, but precision connectors* are preferred to reduce leakage [1]. Limits of uncertainty depend upon the quality of the attenuator and connectors, as well as upon the VSWR of the attenuator, and the magnitude of attenuation. Typical systematic uncertainties range from 0.003 to 0.005 dB/10 dB.

*Standard connector pair or waveguide joint. A "standard connector" is one which is made precisely to standard specifications for the particular type of connector under consideration. Standard connector pairs usually have low but measurable loss and reflections [1,3,4].

5. Definitions

(1) Insertion loss—The 1959 IRE standards [2] give two definitions for insertion loss, one in which system mismatch is not specified, the other in which the system is nonreflecting. The definitions contradict each other since the insertion loss of an attenuator will be different for each case. The measurement procedure for both definitions is to open the system, insert the attenuator, and note the relative power absorbed by the load (or detecting device) before and after insertion. The insertion loss in decibels is computed from these two values. If the attenuator is variable and remains in the system, the initial and final powers absorbed by the load for two settings are used. This determination is more properly called "Change in Insertion Loss."

Either definition is entirely adequate for a single, unique system, but if the loss (or gain) measurement is to be transferred from one laboratory to another, more must be specified about system conditions.

(2) Attenuation—This is defined as the insertion loss in a nonreflecting system ($\Gamma_G = \Gamma_L = 0$) where Γ_G and Γ_L are defined as the reflection coefficients of the generator and load, respectively. In actual measurement these initial conditions cannot be achieved because of imperfections in connectors or adapters and the uncertainties in reducing system reflections to zero. Since attenuation cannot be measured exactly, the more practical term "standard attenuation" is coming into more general use.

(4) Standard attenuation—This is defined as the insertion loss of a linear two-port device in a nonreflecting system which is initially connected together at the insertion point by a standard connector pair (as defined earlier) or waveguide joint, the nonreflecting condition being obtained in the standard waveguide sections to which the standard connectors or waveguide joints are attached. The standard attenuation is the ratio expressed in decibels of the powers absorbed by the load before and after insertion of the two-port device being calibrated.

(4) Incremental attenuation—Incremental attenuation is the change in attenuation of an adjustable attenuator between a reference setting (usually zero) and any other setting. The same restraints on system conditions apply as for attenuation and standard attenuation. The term "differential attenuation" is sometimes applied to this case and usually refers to two non-zero settings.

References

[1] **Microwave attenuation measurements and standards,** R. W. Beatty, *Nat. Bur. Stand. (U.S.), Monogr. 97,* 50 pages (Apr. 3, 1967).

[2] **IRE standards on antenna and waveguides: Definitions of terms,** *Proc. IRE* **47,** No. 4, 568-582 (1959 Standards 59 IRE 2.S1).

[3] **Effects of connectors and adapters on accurate attenuation measurements at microwave frequencies,** R. W. Beatty, *IEEE Trans. Instr.* **13,** 272-284 (Dec. 1964).

[4] **Insertion loss concepts,** R. W. Beatty, *Proc. IEEE* **52,** No. 6, 663-671 (June 1964).

C. Electromagnetic Fields and Microwave Antenna Measurements

Accurate measurement of antenna gain, pattern, and polarization are generally available from about 500 MHz to about 75 GHz. However, measurements of all three characteristics may not be practical for a given antenna because the measurement accuracy, capability, and cost depend on the frequency, type and size of antenna, and the parameters to be measured. Therefore, a particular measurement must be negotiated in advance. The following methods and facilities are used for these measurements.

1. Planar Near-Field Scanning Method

With this technique, gain, pattern and polarization parameters are calculated from near-field amplitude and phase measurements taken over a plane area close to the test antenna. The absolute gain can be determined to within about ±0.15 dB, the polarization axial ratio to within about ±0.10 dB/dB and side lobe levels can be obtained down to -50 or -60 dB. (The exact uncertainties will depend on the frequency, type, and size of antenna, etc.) Antennas with apertures up to about 3.5 m in diameter can be managed. Measurements can be made from 750 MHz up to 75 GHz.

References

[1] **Correction of near-field antenna measurements made with an arbitrary but known measuring antenna,** D. M. Kerns, *Electronics Letters 6,* No. 11, 346-347 (May 28, 1970).

[2] **New method of gain measurement using two identical antennas,** D. M. Kerns, *Electronics Letters* **6,** No. 11, 348-349 (May 28, 1970).

[3] **Recent experimental results in near-field antenna measurements,** R. C. Biard, A. C. Newell, P. F. Wacker, and D. M. Kerns, *Electronics Letters* **6,** No. 11, 349-351 (May 28, 1970).

[4] **Plane-wave scattering-matrix theory of antennas and antenna-antenna interactions: Formulation and applications,** D. M. Kerns, *J. Res. Nat. Bur. Stand. (U.S.),* **80B** (Math. Sci.), No. 1, 5-51 (Jan.-Mar. 1976).

2. Extrapolation Range Measurements

In this method, the received signal transmitted between a pair of antennas is measured as a function of the separation distance between the antennas. The antennas need not be identical, and no assumptions concerning the polarization are required. The method is not well suited for pattern measurements, but it is the most accurate technique known for absolute gain and polarization measurements. Above 1 GHz, the accuracies are typically ±0.10 dB for gain measurements, and ±0.05 dB/dB for polarization axial ratio measurements. There are uppersize limitations associated with existing NBS extrapolation ranges. These limitations depend on the type of antenna, the frequency, and the desired measurements and accuracies. Therefore, negotiations must be conducted prior to submitting antennas for calibration to ascertain if all requirements can be met.

Reference

[1] **Accurate measurement of antenna gain and polarization at reduced distances by an extrapolation technique,** A. C. Newell, R. C. Baird, and P. F. Wacker, *IEEE Trans. Antennas Propagat.* **AP-21,** No. 4, 418-431 (July 1973).

D. Impedance and/or Reflection Coefficient

Services provided in this category are for passive devices over the frequency range from 30 kHz to 65 GHz. Specific frequencies where calibrations are available are listed in the Appendix. Highest accuracy is guaranteed only for standards equipped with precision coaxial connectors or waveguide flanges. Standards submitted for calibration should be in good repair and except for very minor cleaning of connector surfaces, should require no precalibration maintenance. NBS does not provide repair services so that items received which require maintenance will be returned to the sender and a handling fee will be charged.

Calibration service for measuring instruments such as bridges or meters is not provided. It is recommended that the accuracy of these instruments be verified by the owner through the use of stable standards especially selected for particular values and frequencies appropriate to the instrument in question.

Measurement Conditions

All calibrations are performed under ambient laboratory conditions of 23 ±2 °C, 40 ±2 percent relative humidity, and an atmospheric pressure of approximately 625 mmHg. Services at ambient conditions outside these limits is not provided. Also the power applied to any device being calibrated does not exceed 1 W. Additional information pertaining to immittance (impedance and admittance) measurement and standards is contained in the following references.

References

Lumped Parameter

[1] **The measurement of lumped parameter impedance: A metrology guide,** R. N. Jones, *Nat. Bur. Stand. (U.S.), Monogr. 141,* 211 pages (June 1974).

[2] **Impedance of lumped circuits,** L. E. Huntley and R. N. Jones, *Proc. IEEE* **55,** No. 6, 900-911 (June 1967).

[3] **A technique for extrapolating the 1 kc values of secondary capacitance standards to higher frequencies,** R. N. Jones, *Nat. Bur. Stand. (U.S.), Tech. Note 201,* 15 pages (Nov. 1963).

[4] **A precision, high frequency calibration facility for coaxial capacitance standards,** R. N. Jones and J. E. Huntley, *Nat. Bur. Stand. (U.S.), Tech. Note 386,* 27 pages (Mar. 1970).

Coaxial

[1] **Impedance measurements in coaxial waveguide systems,** R. L. Jesch and R. M. Jickling, *Proc. IEEE.* **55,** No. 6, 912-923 (June 1967).

1. Special Measurement Services and Consultation on Measurement Problems

Regular established calibration services for impedance standards are generally described in succeeding paragraphs and specific information is provided in the Appendix (see Impedance).

2. Capacitance, Two-Terminal, Low-Loss

In the frequency range from 30 kHz to 250 MHz capacitance calibrations to a minimum uncertainty of ±0.1 percent are available from 1 pF to 1 μF depending upon frequency. The upper capacitance limit for calibration decreases as the frequency increases and is 50 pF at 5 MHz and above. (See refs. [1], [2], and [3] above.)

At 1 MHz a special high accuracy service is available for capacitors with nominal values of 50, 100, 200, 500 and 1000 pF provided they are equipped with 14 mm coaxial connectors. See Appendix (Impedance) for additional requirements. (See ref. [4]).

Reports of calibration for capacitors normally do not give conductance values. This is because capacitors of standard quality, especially those with air-dielectric, have conductance values too small to be measured accurately at the present state-of-the-art.

Reference

A technique for extrapolating the 1 kHz values of capacitance standards to higher frequencies is described by R. N. Jones in NBS Technical Note 201 (Nov. 1963). This reference describes a technique for obtaining a high frequency value of a capacitor equipped with an unshielded (banana plug) connector. The measurement technique yields effective capacitance values at high frequencies using the capacitance value at 1 kHz and the residual series inductance.

3. Capacitance Three-Terminal Low-Loss

Services are available at 100 kHz, 465 kHz and 1 MHz for capacitors having values of 10, 100, and 1000 pF. Calibration uncertainty is typically ±0.06 percent for all frequencies and values except for 1000 pF at 1 MHz where the uncertainty is nominally ±0.1 percent.

Fixed value reference standards are maintained by NBS for values of 10, 100, and 1000 pF. High quality three-terminal capacitance standards should have low residual series inductance ($\leqslant 0.1$ μH). This being the case, it may be assumed that to an accuracy of ±0.10 percent, the capacitances of standards of 1 pF or less is the same at 1 MHz as it is at 1 kHz. Thus, it is unnecessary to have capacitors smaller than 10 pF calibrated at 1 MHz.

4. Inductors, Two-Terminal, High-Q

In the frequency range from 10 kHz to 250 MHz inductance calibrations to a minimum uncertainty of ±0.1 percent are available from 0.01 μH to 1 H. The upper inductance limit for calibration decreases as the frequency increases and is 1 μH at 250 MHz. In the Report of Calibration, the resistance of the inductor is also given.

5. Resistors, Two-Terminal, Low-Q

In the frequency range from 30 kHz to 250 MHz resistance calibrations to a minimum uncertainty of ±0.1 percent are available from 0.1 Ω to 10 MΩ. At higher frequencies the upper limit for resistance decreases and is 20 kΩ at 250 MHz. Calibration services for resistors less than 20 kΩ are not available at frequencies above 2 MHz.

Reports of Calibration for resistors will include the inductance or capacitance associated with the resistor. Equivalent series values are normally given for inductive resistors and equivalent parallel values for capacitive resistors.

6. Q-Standards

Standards for Q-measurements are maintained at NBS. These are high Q inductors equipped with banana plug connectors at a spacing of 1 inch on centers. These standards have inductance values of 0.25, 2.5, 25, 250, 2500 and 25,000 μH, and effective Q values from 100 to approximately 600. These serve as working standards for calibration of Q-standards of a similar type. Calibration frequencies range from 50 kHz to 45 MHz. The calibration report includes effective resonating capacitance and effective Q. Uncertainties are of the order of ±0.2 percent for capacitance and 2 percent for Q. Provisions are made for calibrating each Q-standard at three frequencies, however, adequate assurance of stability is usually provided by recalibrating only at the center frequency.

Limits of Uncertainty

Estimated limits of uncertainty are based upon a statistical analysis of previously obtained calibration data. These uncertainties are believed to result solely from sources of random error as opposed to known systematic errors.

Reference

[1] **Standards for the calibration of Q-meters, 50 kHz to 45 MHz,** R. N. Jones, *J. Res. Nat. Bur. Stand. (U.S.),* **58C** (Eng. and Instr.), No. 4, 243-248 (Oct.-Dec. 1964).

7. Standards for Distributed Parameter Measurement

Depending upon the application, lumped parameter impedance standards such as capacitors, inductors and resistors are replaced by distributed parameter devices in coaxial systems in the region of 100 to 300 MHz. This brings about the need for standards of impedance magnitude and phase angle, voltage standing wave ratio (VSWR), phase shift and length of equivalent air-dielectric transmission line. Services of this type extend from 0.1 to 8 GHz.

Coaxial Impedance Measurements

Services are available for impedance magnitude, impedance phase angle, voltage standing wave ratio (VSWR), phase shift and length of equivalent air-dielectric transmission line. (Measurement of impedance magnitude, impedance phase angle, and VSWR is provided in combination only. The length of equivalent airline is defined as the length of a section of lossless reference coaxial air line required to produce the same total phase shift as the item being measured.)

Note: The load impedance at the end of a lossless transmission line can be calculated from the VSWR present on the line and the position of a voltage minimum with respect to the load. The expression for the load impedance, Z_L, in terms of the VSWR, σ, and the phase shift, βl, is:

$$Z_L = Z_0 \frac{1-j\sigma \tan \beta l}{\sigma - j \tan \beta l}$$

where: Z_L is the characteristic impedance of the transmission line
$\beta = (2\pi/\lambda)$ is the phase constant.
l is the length of the line between voltage minimum and load

General

A short or open-circuit termination should be furnished with calibration items requiring measurement of impedance, phase shift, and length of equivalent airline in order to establish a reference plane.

The range of VSWR values given in the Appendix (see Impedance) is only representative for purposes of indicating uncertainties associated with calibrations of this type. The indicated uncertainties apply only when items to be calibrated are equipped with precision coaxial connectors. Larger uncertainties are obtained for equipment with nonprecision connectors or having higher VSWR's [1]. VSWR measurements are normally referred to 50 Ω.

The calibration services usually apply to determining the impedances or VSWR of standard terminations and mismatches, or to determining the length of sections of precision coaxial air-dielectric transmission line.

Reference

[1] **Impendance measurements in coaxial waveguide systems,** R. L. Jesch and R. M. Jickling, *Proc. IEEE* **55,** No. 6, 912-923 (June 1967).

Reflection Coefficient Magnitude Measurements of Reflecting and Nonreflecting Waveguide Ports

Waveguide ports are measured in a reflectometer system relative to a sliding short or sliding load in a precision section of waveguide. The detection system involves mixing to an IF frequency of 30 MHz and referencing level changes to a precision waveguide-below-cutoff attenuator.

Measurements in waveguide bands below 18 GHz are performed on the NBS modified automatic network analyzer (ANA) while those above 18 GHz are performed on manual fixed-frequency systems.

It is suggested that measurements requested be held to a single band center frequency which should be sufficient to determine the characteristics of the device. It is further recommended that previously calibrated units not be resubmitted unless tests performed by the user indicate a shift in values.

The reflectors must be fitted with standard waveguide flange-type connectors. The faces of these flanges should be machined flat and smooth and should not contain protrusions or indentations. Considerable care must be exercised in keeping the mating connector flange surfaces smooth and clean. Accurate alignment of the interior surfaces of the joining waveguides at the flange junction also is very important. The back of the flange which makes contact with the connecting bolts should be nominally flat and free of soft materials including paint. The connecting holes of the flange should be symmetrically and accurately aligned to the rectangular waveguide opening. These precautions must be observed when using a waveguide port in a precision measurement system.

The term nonreflecting as used here indicates that the waveguide port has been designed or adjusted with the intent to produce a reflection coefficient magnitude, $|\Gamma|$, equal to zero. Although most waveguide ports for such applications cannot produce a reflection coefficient magnitude identically equal to zero, their reflection coefficient magnitudes often approach zero very closely. Useful information is gained by evaluating the extent to which this can be accomplished.

Limits of Uncertainty

Assigned limits as noted in the Appendix depend upon the quality of the flanges as well as the numerical value of reflection coefficient magnitude. Systematic errors assigned by NBS vary with waveguide size and relate to absolute dimensions of the precision waveguide sections and internal surface finish.

Reference

[1] **A guide to the use of the modified reflectometer technique of VSWR measurement,** W. J. Anson, *J. Res. Nat. Bur. Stand. (U.S.),* **65C** (Eng. and Instr.), No. 4, 217-223 (Oct.-Dec. 1961). (The measurement technique utilized in reflection measurements is described in this paper.)

E. Laser Power and Energy

The National Bureau of Standards develops and maintains the U.S. National Standards for measurement of laser power and energy. These standards are isoperibol type calorimeters which compare the absorbed laser radiation to an equivalent quantity of electrical energy. Limited calibration services and Measurement Assurance Programs (MAP's) are available for laser power and energy measurements.

1. NBS Laser Standards

The national standards for laser power and energy are three types of isoperibol type calorimeters. These calorimeters compare the absorbed laser radiation to an equivalent quantity of electrical energy. These calorimeters are maintained in a measurement system such that other laser power or energy meters can be calibrated against the national standards. The accuracy of these calibrations is about 1 to 5 percent depending on the power (or energy) and wavelength at which the calibration is performed.

2. NBS Laser Power and Energy Dissemination Services

The laser power and energy measurement services consist of limited calibration of power or energy meters and Measurement Assurance Programs (MAP's). The MAP's are implemented by means of transfer standards which have been evaluated and characterized relative to the national standards. The characteristics of these transfer standards are well understood, and their associated accuracies are not significantly different from the accuracies associated with direct comparisons to national standards.

F. Noise Temperature Measurements

Definition

The Effective Noise Temperature, T_{ne}, is proportional to the power emerging from the output port of the coaxial or waveguide noise source when it is connected to a nonreflecting load. The noise temperature, T, of the noise source is analogous to the available power [1,2] from a source and is obtained when corresponding reflection coefficients for source and load are complex conjugates of each other (characteristic impedances being chosen real). The relationship between the noise temperature and effective noise temperature is

$$T_{ne} = T[1-|\Gamma|^2]$$

where $|\Gamma|$ is the reflection coefficient magnitude of the coaxial or waveguide noise source, and T_{ne} and T are in kelvins.

General

Coaxial Noise Sources:

(1) Effective noise temperature measurements are made on one-port devices that serve as coaxial noise sources under conditions of continuous, unmodulated operation.

(2) In noise sources utilizing a gas-discharge tube, the tube should be securely fitted into a mount terminated at the cathode end with a suitable matched load. Direct current required for the tube should not exceed 300 mA but should be sufficient to prevent excessive plasma oscillations. Complete information on the operating current of the tube and a wiring diagram of the noise source must be supplied.

(3) In noise sources utilizing a temperature-limited diode, the diode should be securely fitted into a mount terminated at the cathode end with a suitable matched load. Complete information on the operating current of the tube and a wiring diagram of the noise source must be supplied.

(4) Each type of noise source must be fitted with a 14-mm precision output connector. A 14-mm adapter is acceptable if it is securely attached to the existing coaxial connector on the mount.

Rectangular Waveguide Noise Sources:

(1) Effective noise temperature measurements are made on waveguide noise sources (usually a gas-discharge tube) under conditions of continuous, unmodulated operation.

(2) The direct current required for normal operation of the gas discharge tube should not exceed 200 mA but should be sufficient to prevent excessive plasma oscillation.

(3) Complete information on the operating current of the tube and a wiring diagram of the noise source must be supplied. In some cases it is necessary to request appropriate electrical connectors to be supplied with the unit for use during calibration.

(4) The gas-discharge tube should be secured in a terminated waveguide noise-tube mount.

References

[1] **Basic theory of waveguide junctions and introductory microwave network analysis,** D. M. Kerns and R. W. Beatty, Chapter in *International Series of Monographs on Electromagnetic Waves* **13,** 150 pages (Pergamon Press, Inc., New York, NY, 1967).

[2] **Measurement of effective temperatures in microwave noise sources,** J. S. Wells, W. C. Daywitt, and C. K. S. Miller, *IEEE Trans. Instr. Meas.* **IX-13,** No. 1, 17-28 (Mar. 1964). (This reference describes the method of measurement and error analysis.)

[3] **Some applications of the Josephson effect,** R. A. Kamper, *Nat. Bur. Stand. (U.S.), Tech. Note 381,* 63 pages (Oct. 1969). (This technical note contains a discussion of noise thermometry at very low temperatures.)

G. Phase Shift

1. Special Phase Shift Measurement Services and Consultation

The specific phase shift services listed below are available on a limited basis depending on other demands and staff availability. Measurements not listed can be provided if sufficient advance notice is given. The cost of such services must be negotiated and will, in general, be higher than the established phase shift services. Consultation by telephone or written correspondence is suggested as indicated in the Appendix. Often a measurement technique can be suggested that will permit the customer to perform calibrations in-house with appropriate reference to other NBS-supported standards.

2. Coaxial Devices

Fixed and variable coaxial two ports are measured on the NBS modified automatic network analyzer (ANA) over the frequency range indicated in the Appendix. In addition, measurements can be performed with reference to a precision variable air line at 30 MHz.

Because of the specialized nature of passive or active coaxial phase shifting components, it is requested that prior discussions be held before submission of any devices to NBS.

Limits of Uncertainty

The limits of uncertainty stated are the sums of systematic, mismatch, and random errors. Their relative values are dependent upon the particular standard under calibration. The VSWR of the device and the quality of the connectors will contribute to the uncertainties of calibration.

Items to be calibrated must be fitted with connectors having a known plane of reference such as the sexless precision connectors, or Type N connectors meeting Mil C 39012.

General

The phase angle measured is $\psi + 360\, n$, where n is an integer. The value of n is not determined.

Definitions

(1) **Characteristic insertion phase shift (phase change)**—is the phase change of a wave incident upon the load before and after insertion of a two-port device between the generator and load of a stable nonreflecting system.

(2) **Characteristic phase shift difference (phase change)**—is the phase change of a wave incident upon the load from an initial to a final condition (setting) of a two-port device between the generator and load of a stable nonreflecting system.

Note: The following conditions apply: (1) The frequency, the load impedance, and the generator characteristics (internal impedance and available power) have the same values before and after the device is inserted or changed; (2) the joining devices (connectors or adapters) belonging to the system all conform to a given set of standard specifications (the same specifications must be used by different laboratories if measurements are to agree precisely); (3) the nonreflecting conditions are to be obtained in uniform, standard sections of transmission line on the system sides of the connectors at the place of insertion; (4) this definition is not for phase shift in general, but for a particular phase shift which is characteristic of the device under measurement.

3. Waveguide Devices

In a rectangular waveguide the measurement services are limited to phase shift difference. Measurements are made on continuously variable waveguide phase shifters with the zero value of the scale as the normal reference position. Since 360 mechanical degrees of rotation represent 720 electrical degrees, attention should be given to the relationship between dial indication and actual mechanical position of the rotating vane assembly.

Measurements are performed for phase angle values from 0° to 720°.

Variable phase shifters should have a repeatability of dial setting better than ±0.5° and an input VSWR less than 1.4 at each waveguide port.

It is suggested that measurements requested be held to a minimum number of settings at a single band center frequency which should be sufficient to determine the characteristics of the device. We further recommend that previously calibrated units not be resubmitted unless tests performed by the user indicate a shift in values.

Limits of Uncertainty

The estimated limits of uncertainty range from ±0.1° to ±1.0° for input VSWR values of the phase shifter waveguide ports in the range 1.1 to 1.4.

Reference

[1] **Evaluation of a microwave phase measurement system,** D. A. Ellerbruch, *J. Res. Nat. Bur. Stand. (U.S.),* **69C** (Eng. and Instr.), No. 1, 55-65 (Jan.-Mar. 1965).

H. Power Measurements

Available calibration services are restricted to thermistor-type bolometer units having a nominal resistance of either 100 or 200 Ω at a bias current between 3.5 and 15 mA.

Thermistor-type bolometer units have shown adequate stability over long periods of time (approx. 10 yr) and warrant long recalibration intervals. Two- or three-year recalibration intervals are recommended once the intrinsic stability of a bolometer unit has been verified.

Assistance is available for applying published, technically valid measurement techniques in lieu of previously available calibration services for coaxial and waveguide calorimeters, power meters, and bolometer coupler units. The attainable limits of measurement uncertainty using these techniques are comparable to those of the previously available calibration services for these devices.

Reference

[1] **Accurate microwave high power measurements in using a cascaded coupler method,** K. E. Bramall, *J. Res. Nat. Bur. Stand. (U.S.),* **75C** (Eng. and Instr.), Nos. 3 and 4, 181-186 (July-Dec. 1971).

Services Available

Effective Efficiency

The effective efficiency is the ratio of the bolometrically substituted dc power in the bolometer unit to the cw rf/microwave power absorbed by the bolometer unit. The principal emphasis is on those calibrations and other tests requiring such accuracy as can be obtained only by direct comparison with NBS standards. However, in order to maintain efficient utilization of specialized equipment and skilled personnel, when workload permits NBS may calibrate devices requiring lesser accuracy but suitable for working standards in plant or laboratory. Also, upon request, special measurements not listed in SP250 may be made. Inquiries should describe clearly the measurement desired and indicate the scientific or economic basis for the requirement.

Calibration Factor

The calibration factor is the ratio of the bolometrically substituted dc power in the bolometer unit to the cw rf/microwave power incident upon the bolometer unit.

Amplitude Reflection Coefficient (See pt. 3 below for pulsed power)

Amplitude reflection coefficient is the ratio of the reflected amplitude to the amplitude of the incident wave.

Calibration factor, effective efficiency, and reflection coefficient are included in the Report of Calibration for all single frequency measurements. (For details see Appendix under Power Measurements, Electromagnetic Single Frequency.)

Effective efficiency and reflection coefficient are included in the Report of Calibration for all multiple frequency broadband measurements. (For details, see Appendix under Power Measurements, Electromagnetic Multiple Frequency Broadband.)

The above services are restricted to the following conditions and equipment (except for special calibrations).

Power Level: 10 mW (nominal)

Bolometer Units

Connector Types: Coaxial—type N to 18 GHz
7 mm precision to 18 GHz
(Measurements will be performed only in frequency bands appropriate to connector type.)
Waveguide:—WR15, and WR28 to WR284

(1) Single Frequency Measurements

10 MHz to 1 GHz
Specify frequency for waveguide WR 15 (50.0-75.0 GHz) and WR28 to WR42

(2) Multiple Frequency Broadband Measurements

Schedule of Services

To improve service, reduce cost and "turnaround" time and facilitate planning, measurements will be conducted according to the following schedule. Purchase orders and devices should arrive at NBS/Boulder prior to the first day of the month in which calibration is desired.

Type N	Oct., Jan., Apr., July
7 mm precision	Nov., Feb., May, Aug.
Waveguide	Dec., Mar., June, Sept.

Coaxial

1-2 GHz	50 MHz intervals
2-4 GHz	100 MHz intervals
4-8 GHz	200 MHz intervals
8-12.4 GHz	200 MHz intervals
12.4, 12.75-18 GHz	250 MHz intervals

Waveguide

WR284	2.6-4.0 GHz	6 frequencies
WR187	4.0-5.8 GHz	100 MHz intervals
WR137	5.8-8.0 GHz	100 MHz intervals

WR112	7.0-10.0 GHz	200 MHz intervals
WR90	8.2-12.4 GHz	200 MHz intervals
WR75	10.0-15.0 GHz	250 MHz intervals
WR62	12.4-18.0 GHz	250 MHz intervals

Limits of Uncertainty

Effective efficiency and calibration factor: The estimated limits of uncertainty will vary from approximately ±0.7 to 2 percent depending on the frequency and the characteristics of the unit being calibrated such as connector type, reflection coefficient, and repeatability.

Reflection coefficient: The estimated limits of uncertainty are ±0.005.

(3) Rf and Microwave Coaxial Peak Pulse Power Meters and Power Meter-Directional Coupler Combinations

Services Available

(1) Input peak pulse power versus scale reading of terminating-type instruments.

(2) Input and/or output peak pulse power versus scale reading of feed-thru instruments.

Frequency range (GHz)	Peak power range (W)
0.3 to 0.5	0.001 to 2500
0.95 to 1.25	.001 to 5000
4.0 to 4.4	.001 to 2000
8.2 to 10	.001 to 10000

The uncertainties of these measurements are typically ±3 percent. The ±3 percent uncertainty is based on:

(a) ±1 percent on the cw power measurement
(b) ±1 percent on cw-pulse power comparison circuits
(c) ±1 percent on the calibration of range-extending directional couplers

These errors are independent, and should be treated as such.

General

Calibrations are made with pulsed rf waves modulated by a baseband trapezoidal pulse. Limits of other basic parameters of the pulses are as follows:

Pulse duration range	0.5 to 10 μs
Pulse repetition rate range	100 to 1600 pps
Maximum duty factor	0.0033

Instruments submitted for calibration should have a nominal impedance of 50 Ω, and be fitted with Type N, BNC, HN, or 7 or 14-mm precision connectors. If other connectors are used, degradation of the above mentioned uncertainty limits could result.

I. Voltage Measurements

Services are available for two types of electromagnetic voltage measuring devices as follows:

1. Voltage Measurements of Thermal Voltage Converters (TVC's)

The TVC category also includes other devices using thermal detectors such as Rawson RF Voltmeters, Thermal Transfer Standards, RF Voltage Standards and AC-DC Transfer Standards.

Services Available: rf-dc Difference

The rf-dc difference is defined as the percentage difference between the rf and dc output voltages required for the same thermocouple output, i.e.,

$$\text{rf-dc difference (\%)} = \left(\frac{V_{rf}-V_{dc}}{V_{dc}}\right)\times 100$$

Frequency (MHz)	rf voltage range (V)	Estimated limits of uncertainty* (±%)
0.03	0.1 to 200	0.05
.1	.1 to 200	.05
.3	.1 to 200	.05
1	.1 to 200	.05
3	.1 to 200	.1
10	.1 to 200	.1
30	.1 to 200	.2
100	.1 to 200	1.0

*No rf-dc differences greater than ±20 percent will be reported. This normally limits the calibrations to 100 MHz and below.

For high frequency TVC's with a built-in "T" connector, the services available are:

Frequency (MHz)	rf voltage range (V)	Estimated limits of uncertainty (±%)
10, 30, 100 200, 300, 400 500, 600, 700 800, 900, 1000	0.1 to 7.5	1

Calibrations having ±1 percent accuracy are performed only on the new high frequency thermal voltage converters with a "T" connector incorporated in the converter housing. The measurement reference plane is at the Type "N" male output connector. Other types of TVC's calibrated above 100 MHz will have accuracies of 3 to 5 percent.

General

Most converters have rf-dc differences within ±0.01 percent of zero at 1 MHz and below. All converters having previous calibration history that are submitted for recalibration should be evaluated at 1 MHz and results compared to prior data. If the difference is negligible, no further calibrations are usually necessary below 1 MHz.

Many years of experience in calibration of micropots and TVC's have shown that these are very stable devices even for periods of up to 10 years. Thus, in most cases, a 2-year or longer recalibration cycle is recommended. An exception might be the micropots which operate below 100 μV.

Assurance of device stability can be obtained by intercomparison of micropots or TVC's with others which are adjacent in voltage. For example, a 0.3 to 1 V TVC can be compared with a 1 to 3 V TVC at 1 V, etc.

2. Voltage Measurements of rf Micropotentiometers

Service Available: rf-dc Difference

The rf-dc difference is defined as the percentage difference between the rf and dc output voltages required for the same thermocouple output, with the resistive element terminated in 50 Ω.

Any frequency within band (MHz)	rf voltage range (μV)	Estimated* limits of uncertainty (±%)
0.01 to 100	1 to 100,000	1
100 to 500	1 to 100,000	3
500 to 1000	1 to 100,000	5

*For rf-dc differences greater than ±20 percent, estimated limits of uncertainty are larger than those listed.

Rf micropotentiometers are usually calibrated at their nominal rated output voltages. Frequencies suggested for a normal calibration are 5, 100, 300, 400, 500, 700, 900, and 1000 MHz.

Rf micropotentiometers having resistive elements greater than 10 mΩ, in combination with thermoelement housings between 5 and 100 mA, usually have rf-dc differences within ±1 percent of zero at 5 MHz. Since the rf-dc difference approaches zero below 5 MHz, a calibration at 50 kHz would suffice to determine interpolated points of interest between 50 kHz and 5 MHz, with no appreciable loss of accuracy.

An rf-dc difference of about ±5 percent at 1 MHz usually results from a combination using a 1 mΩ element. Interpolation below 1 MHz is not recommended in this case.

J. Baseband Pulse Parameters

Pulse characteristics are important in a variety of applications. As a result NBS offers the following pulse measurement services.

1. Impulse Generator Spectrum Amplitude

In response to calibration needs from the electromagnetic interference (EMI) community, NBS has developed a measurement service to calibrate the broadband spectrum amplitude output from impulse generators. Such a generator can then be used as a transfer standard of broadband impulsive noise for field calibration of spectrum analyzers and field intensity meters. The NBS calibration service uses the time domain measurement/Fourier transformation computation (TD/FFT) method for calibration of impulse generators. A wideband (dc-18 GHz) sampling oscilloscope is used to measure the time domain waveform from the impulse generator. A dedicated minicomputer then computes the spectrum amplitude, $S(f)$, versus frequency using the fast Fourier transform (FFT).

Many of the limitations concerning the frequency range and spacing of the calibration service are related to the FFT. With an oscilloscope it is not possible to observe waveforms from $t=-\infty$ to $+\infty$. One can only observe a waveform within a limited time window. For this particular measurement service time windows of 10, 20, 50, 100, and 200 ns are available. Within the time window the sampling oscilloscope measures 1024 separate, uniformly spaced, values of the waveform. This sampled data is then transformed to the frequency domain using the FFT. Due to the mathematics of the FFT, the lowest frequency resulting from the computation is the reciprocal of the time window (i.e., 50 ns →20 MHz). The other frequency components are harmonics of the fundamental (i.e., 20, 40, 60, 80 MHz . . .). The highest frequency component is $1/(2\ \Delta t$, where Δt is the time domain sample spacing and $\Delta t = T/N$. T is the time window and N is the number of sampled data values in the time window. For the 50 ns window Δt is 48.8 ps and f_{max} is 10.24 GHz. Due to various accuracy considerations the time window is chosen such that at least 10 data points are obtained on the major feature of the impulse waveform. Fewer data points rapidly introduce significant errors in the computations. As an example an impulse of 500 ps duration would be measured over a 50 ns time window with a Δt of 48.8 ps and a resulting spectrum amplitude data table starting at 20 MHz. Another significant limitation on the choice of the time window is the requirement that no other spurious pulses occur outside of the window and that the waveform be completely relaxed and resting on the baseline at the beginning and end of the time window. If these criteria cannot be met then the generator is rejected for calibration.

Another major requirement is the necessity to trigger the sampling oscilloscope in advance of the impulse to be measured. As noted in the first reference in the next paragraph most impulse generators use a mercury switch and thus do not furnish a suitable trigger signal. For these generators a delay line triggering arrangement is used. A time window of 200 ns is the broadest that can be used with this arrangement. This sets the 5 MHz lower limit on the service capabilities given below. This limit can be extended to broader time windows and lower frequencies if the generator is an electronic generator with a suitable trigger pulse and adjustable delay.

Several techniques are available for measuring spectrum amplitude. For a summary see: J. R. Andrews, "Impulse generator spectrum amplitude measurement techniques," *IEEE Trans. Instr. & Meas.*, **25**, No. 4, (Dec. 1976) p. 280 ff. For other details on spectrum amplitude measurements, see J. R. Andrews, M. G. Arthur, **Spectrum amplitude definition, generation and measurement,** *Nat. Bur. Stand. (U.S.), Tech. Note 694.*

Eighty percent of the impulse generators calibrated at NBS are of the mercury switch variety with an impulse duration of the order of 0.5 ns and adjustable amplitude. NBS impulse generator spectrum amplitude measurement service capabilities are as follows:

Parameter	Limits	Notes
Maximum impulse amplitude without attenuators	±400 mV	1, 2, 3
Maximum impulse amplitude with external attenuators	±1.2 mV	3,4
Spectrum amplitude	-15 dBμV/MHz $<[S(f)-S_0]<$ +5 dBμV/MHz	5, 6, 7
$S(f)$ uncertainty	Nominally $f \leqslant 1$ GHz, ±0.6 dB 1 GHz $< f \leqslant 4$ GHz, ±1.2 dB 4 GHz $< f \leqslant 6$ GHz, ±2.0 dB	5, 6, 7 8 & 9
Frequency range	5 MHz to 6 GHz	5, 6, 7 & 10
Frequency spacing	Δf=5,10,20,50, or 100 MHz	5, 10
Frequency uncertainty	of the order of ±1%	7
Load impedance	50.0 Ω	
Load impedance uncertainty	Nominally ±0.1 Ω at dc VSWR <1.3 up to 6 GHz	8, 11
Trigger pulse magnitude	>100 mV	12
Trigger pulse transition time	<5 ns	12
Trigger to impulse delay	75 ns $< t_t <$ 100 ns	12
Trigger to impulse jitter	<20 ps	12

Notes

(1) The impulse generator is characterized by its impulse output waveform into 50 Ω of peak amplitude (V_{pk}), 50 percent level duration (τ), and low frequency spectrum amplitude ($S_0 \sim 2V_{pk}\tau$).

(2) Impulse generator with an adjustable amplitude impulse output will be calibrated with the generator adjusted to give a peak amplitude in the range of 200 to 400 mV.

(3) Impulse generators with fixed outputs greater than ±400 mV must have the impulse attenuated to the 200-400 mV level by 50 Ω wideband coaxial attenuators.

(4) Either customer supplied or NBS attenuators may be used.

(5) Depends upon actual generator characteristics.

(6) Data will not be given in the first spectrum null or at frequencies above. Typically 100 data points are supplied.

(7) Subject to revision.

(8) Only for impulse amplitudes less than ±400 mV.

(9) If external attenuators and/or a 6 dB tee and delay line are used then the uncertainty associated with the attenuator calibration is added to these values.

(10) Lower frequencies (<5 MHz) are available as a special test.

(11) Depends upon input impedance of external attenuators when used.

(12) If the impulse generator does not supply a trigger output or if the trigger output does not have the proper characteristics then a 6 dB tee and a delay line will be used to provide a suitable trigger pulse.

2. Pulse Transition Duration

Pulse transition duration (rise time) measurements for step function pulse generators and low pass filters are also available. Both measurements use an 18 GHz bandwidth, 20 ps transition time sampling oscilloscope to measure the pulse waveform. The observed waveform is computer processed to determine the transition duration. In the case of filters a 15 ps tunnel diode pulse generator is used as the source. For details on specific services, see the Appendix under pulse generator transition duration and low pass filter transition duration respectively.

3. Other Pulse Measurements

Pulse techniques are also used to measure attenuation and phase and time delay.

Wideband attenuation or gain measurements on coaxial networks, using pulse techniques, provide data over a 0.05 to 12.5 GHz frequency range, and 0 to 40 dB loss or gain range. This is accomplished by use of the NBS Time Domain Automatic Network Analyzer. It consists of a 20 ps transition time pulse generator, a 20 ps sampling oscilloscope and a minicomputer. Two waveforms are measured, one with the generator connected to the oscilloscope and the other with the unknown network inserted between the generator and the oscilloscope. The minicomputer provides the spectrum data for the two waveforms using the fast Fourier transform. The ratio of the two spectra is the attenuation or gain of the network.

Pulse time delay is also measured using the same generator and oscilloscope. A coaxial trombone line stretcher is connected in the trigger circuit between the generator and oscilloscope. The length of the line stretcher is adjusted to center on the 50 percent point on the pulse leading edge. The change in length of the line stretcher for this adjustment with the unknown alternately inserted and removed from the signal channel between the generator and oscilloscope is used to compute time delay. For details on services available, see the Appendix under Attenuation, Phase Shift, and Power, respectively. For information on Pulsed rf Power measurements, see section V.H.

K. Electromagnetic Interference Measurements

An electromagnetic interference (EMI) program in process is currently developing measurement methods and instrumentation for the evaluation of susceptibility and emission of devices, components, subsystems and small systems. Large subsystem and system measurements will be addressed on an individual case basis. The objective of the test methods under development is to achieve repeatable (to <0.5 dB) and accurate EMI measurements, exceeding the accuracies called for in Mil. Standards 461 and 462.

This program is also directed toward developing measurement methods and instrumentation for the evaluation of the electromagnetic (EM) environment primarily to assess the electric and magnetic fields in the near-field area of intentional or unintentional emitters to establish the EM ambient environment. Where necessary methods and instrumentation for far-field measurements will be developed. This work will also concern itself with display methods and statistical measures for EM ambient environment evaluation.

Another area this program is directed to is electromagnetic radiation hazards. The measurements needed to support this area are very nearly the same as those for EMI; therefore, only minor changes in instrumentation and measurement techniques are needed for hazard measurements.

NBS does not provide routine calibrations for electromagnetic interference, although a limited number of measurements are available by special arrangements. Instead, consulting and advisory services are available.

CHAPTER VI

VI. Time and Frequency

Direct inquiries to the Time and Frequency Program in Boulder (address and phone number as stated in the Appendix).

The National Bureau of Standards develops and maintains the U.S. National standards of frequency and time. It disseminates frequency and time from these standards via radio broadcasts from Colorado and Hawaii and experimentally from satellites. In addition, frequency and time calibration services using network television and time are also available. A limited service of direct comparison of a customer's signal source (precision oscillator) or clock with the NBS frequency and time standard is also provided as well as direct noise measurements of precision oscillators. The current basic frequency standards operate at 5 MHz, however, NBS' frequency technology permits comparisons ranging from several hertz to about 900 THz. Consultation on atomic clocks and frequency standards, precision oscillators infrared and optical coherent sources, stabilization and intercomparison is available. NBS conducts scientific comparisons with the frequency and time standards of other nations and NBS standards provide data for the development of International Atomic Time (TAI).

A. NBS Frequency Standard

The General Conference of Weights and Measures, at its 13th General Meeting (1967), adopted the following definition for the second in the International System (SI) of Units.

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

NBS maintains equipment, known as the NBS Frequency and Time Standard (NBS FTS) for realizing this definition of the second with an accuracy of 1×10^{-13}.

B. NBS Time and Frequency Dissemination Services

Services available from radio broadcasting stations and time and frequency calibration services using network television are detailed in NBS Special Publication 432. This publication is revised from time to time as changes are introduced.

For experimental services available from satellites see:

[1] **Dissemination of time and frequency by satellite,** R. L. Easton, L. C. Fisher, D. W. Hanson, H. W. Hellwig, and L. J. Rueger, *Proc. IEEE* **64**, No. 10, 1482-1493 (Oct. 1976).

[2] **A satellite-controlled digital clock,** J. V. Cateora, D. D. Davis, and D. W. Hanson, *Nat. Bur. Stand. (U.S.), Tech. Note 681,* 46 pages (June 1976).

C. Direct Signal Source Calibration Services

NBS does not routinely calibrate signal sources or clocks, however, upon request special measurements may be made. Special requests will be considered for oscillator frequency and noise measurements. Inquiries should describe clearly the measurement desired and the importance or significance of making a direct comparison with the NBS FTS. The signal source to be measured should have a power output of 20 mW (into a matched load) or greater. For details on nominal frequencies at which calibrations can be readily done depending on workload, see Appendix under the heading "Frequency Measurements."

For the current primary cesium standard NBS-6, the accuracy, $\Delta f/f$ has been determined to be $\pm 1 \times 10^{-13}$, which includes one sigma estimates of the possible random errors in frequency associated with the measurement of various parameters of the standard. The stability of the standard becomes a factor in measuring stability of other precision oscillators. The contribution to the overall measurement uncertainty due to the instability imposed by fluctuations of NBS-6 when paired with a similar oscillator depends on measurement averaging time and can be expressed as

$$\sigma_y(\tau) = 1 \times 10^{-12}\ \tau^{-1/2}.$$

where $\sigma_y(\tau)$ is the two-sample deviation of the frequency fluctuations and τ = the length of the frequency comparison in seconds. The measurement limit is 10^{-14}. Noise measurements are expressed in the time domain by measurements of the two-sample deviation $\sigma_y(\tau)$ or in the frequency domain by measurement of phase noise $s_\phi(f)$. For specific details on the noise services available see the Appendix under the heading "Oscillator Noise Measurements."

In addition, time measurement services are also available for time pulses at the rate of one pulse per second. See the Appendix under the heading "Time Pulses."

References

[1] **Clocks and measurements of time and frequency,** H. Hellwig, *Proc. 1976 WESCON,* Session 32, pp. 1-4 (Institute of Electrical and Electronics Engineers, New York, NY, Sept. 1976).

[2] **The National Bureau of Standards Atomic Time Scale: Generation, stability, accuracy and accessibility,** D. W. Allan, J. E. Gray, and H. E. Machlan, *Nat. Bur. Stand. (U.S.), Monogr. 140,* Chap. 9, 205-231 (May 1974).

[3] **Design principles and characteristics of frequency and time standards,** H. Hellwig, *IEEE Trans. Nucl. Sci.* **NS-23,** No. 6, 1629-1635 (Dec. 1976).

[4] **Results on limitations in primary cesium standard operation,** D. J. Wineland, D. W. Allan, D. J. Glaze, H. W. Hellwig, and S. Jarvis, Jr., *IEEE Trans. Instrum. Meas.* **IM-25**, No. 4, 453-458 (Dec. 1976).

CHAPTER VII

VII. Thermodynamic Quantities

The Thermodynamic Quantities program provides measurement services in the areas of thermometry, pressure and vacuum, humidity, and cryogenic measurements as described in the sections which follow.

A. Thermometry

The National Bureau of Standards employs the International Practical Temperature Scale as the basis for its calibration activities in thermometry. However, the NBS temperature calibrations are not limited to those which are specified in the IPTS; non-"standard" sensors may be calibrated, and calibrations beyond the limits of the IPTS may also be provided. In all cases, however, great care is taken to make such calibrations consistent with the IPTS.

The platinum resistance thermometer and the platinum-10 percent rhodium versus platinum thermocouple are the specified interpolating instruments inthe IPTS for the range 13.81 K to 630.74 °C and 630.74 to 1064.43 °C, respectively. NBS offers calibrations for both of these instruments throughout their respective ranges. In addition to these calibrations, NBS routinely provides many other calibration services. These include calibrations of:

° many liquid-in-glass laboratory thermometers

° thermocouple thermometers of many types, from cryogenic temperatures to 1750 °C

° germanium resistance thermometers and other thermometers used in cryogenics to temperatures below 1 K.

Moreover, in collaboration with its thermometry research and development staff, NBS provides special at-cost calibrations of thermistor thermometers, of certain industrial types of resistance thermometers, and of a variety of thermometry systems.

Whenever there exists a desire to calibrate contact thermometry equipment over the temperature range 0.1 to 2000 K, the user is invited to contact the temperature calibration staff as indicated in the Appendix.

1. Laboratory Thermometers

Kinds of Thermometers Accepted for Calibration

Thermometers belonging to the large and varied group which may be classed as laboratory or "chemical" thermometers are regularly accepted. Many of these are of the liquid-in-glass type with either solid-stem or enclosed scale. Other acceptable types include such special-purpose thermometers as Beckmann and calorimeter thermometers.

Ordinary household or meteorological thermometers will not, in general, be accepted unless the scale is graduated on the glass stem itself and the thermometer can be readily detached from its mounting for insertion in a testing bath.

Every thermometer submitted must be uniquely identified by a serial number and must pass a preliminary examination for fineness and uniformity of graduation; for cleanliness of the mercury and capillary bore; for freedom from moisture, gas bubbles, and cracks in the glass; for adequacy or omission of gas filling where needed; for insufficient annealing; and for misnumbered graduations. When these or other serious defects are found, the thermometer is returned untested.

Shipping Instructions

Shipping charges, both to and from the Bureau, must be assumed by the applicant. Return shipments are made by the Bureau in accordance with its judgment of the best method of shipping unless specific instructions are received. Such instructions should be supplied at the time that arrangements are being made for the test. If a test number has been assigned prior to the shipment, this number should appear on the shipping container. If a test number has not been assigned at this time, a purchase order, or letter should be sent under separate cover. In either case, the shipment should include a packing list.

All possible care will be taken in handling thermometers at the Bureau, but the risk of damage either in shipment or in testing must be assumed by the applicant. The applicant should consider the nature of the equipment shipped and pack it accordingly, with appropriate labeling. Attention is called to the availability of security express in shipping thermometers.

Details of the procedures used in calibrating laboratory thermometers may be found in NBS Monograph 150, "Liquid-in-Glass Thermometry," U.S. Government Printing Office, Washington, D.C. 20402, 1976.

2. Thermocouples, Thermocouple Materials and Pyrometer Indicators

Methods of Calibration

In order to calibrate thermocouples to yield temperature versus emf relationship on the International Practical Temperature Scale, they must be so calibrated that their indications agree with those of the standard platinum resistance thermometer in the range −259.34 to 630.74 °C, the standard platinum-10 percent rhodium versus platinum thermocouple in the range 630.74 to 1064.43 °C, and the optical pyrometer above 1064.43 °C.

The temperature-emf relationship of a homogeneous thermocouple is a definite physical property and, therefore, does not depend upon the details of the apparatus or method employed in determining this relation. Consequently, there are numerous methods of calibrating thermocouples, the choice of which depends upon the type of thermocouple, temperature range, accuracy required, size of wires, apparatus available, and personal preference.

Services Offered

A listing of the thermocouple calibration services is given in the Appendix under the title "Thermocouples and Thermocouple Materials."

° Only the bare wires are required to perform the thermocouple calibrations.

° It is preferable not to send insulating and protecting tubes as the rate of breakage of these in shipment is high.

° If the thermocouple is furnished mounted (as in a protection tube assembly) a nominal charge will be made for dismantling the mounting and the various parts will be returned to the sender without reassembling them.

° Thermocouple length requirements listed in the Appendix are exclusive of lead wire. Lead wire need not be sent with thermocouples.

° All thermocouple calibration data furnished in reports will be on the basis of a reference junction temperature of 0 °C or 32 °F. The calibration results will be given in degrees C or F, as requested by the customer.

° The calibration or test of a thermocouple will not be undertaken if, in our opinion, it will not yield the specified accuracy or if it possesses such unusual characteristics as to prevent the carrying out of the calibration or test at a reasonable cost. Only unused base-metal thermocouples and thermocouple materials will be accepted for test.

° Inquiries concerning other types of thermocouples, e.g., tungsten-rhenium types, are welcome. NBS will attempt, whenever possible, to meet reasonable calibration requests. The fees for the work accepted will be based on the actual costs incurred. The technical staff should make the inquiry directly with information on the nature of the thermocouple and the type of calibration required so that services that are needed can be determined expeditiously.

3. Resistance Thermometers

The National Bureau of Standards offers calibrations of the standard platinum resistance thermometers which are specified for use as interpolation instruments in the text of the International Practical Temperature Scale of 1968 as amended 1975 (see the journal Metrologia, Vol. 12, pp. 7-17, 1976). In addition, less-precise resistance thermometers and thermistor thermometers are calibrated on the International Practical Temperature Scale, but with correspondingly reduced precision limits.

Standard Platinum Resistance Thermometers

To qualify for testing, either long-stem or capsule platinum resistance thermometers must meet several conditions:

° They must reasonably be expected to meet the requirements of the IPTS-68 for a standard interpolating instrument (i.e., a four lead resistor of high-purity platinum hermetically sealed in a protecting tube).

° They must be compatible with the NBS highest-precision calibration equipment (see the Appendix for further information and contact point).

The user may choose any of several types of calibration, as listed in the Appendix. He may also specify the form of the resulting calibration, $R(t)$, $[R(t)/R(O)]$, or $[R(t) - R(O)]$ versus temperatures based on the IPTS-68.

A minimum charge (see Appendix) is made on all standard platinum thermometers received. This charge will cover, in part, the cost of receiving and returning thermometers which, for some reason, are found to be unsuitable for test.

It is very important that, insofar as possible, resistance thermometers be protected from any mechanical shock which will alter their calibration. To be shipped, the thermometer must be softly supported within a case but not be free to rattle. This necessitates the use of packing material that does not become compacted. The thermometer case should in turn be softly packed inside a shipping container. The outside shipping container must be sufficiently rigid and strong not to appreciably deform under the treatment usually given by shippers. Styrofoam is not sufficiently rigid to be used as an outside container. Thermometers will not be returned in containers which are obviously unsuitable, such as those closed by nailing. Suitable containers will be provided, for a fee, when thermometer shipping container is not satisfactory for re-use.

"Non-Standard" Resistance Thermometers, Thermistors, and Other Thermometers

Industrial and laboratory-grade resistance thermometers which are not suitable for work at the highest precision may be calibrated also. In this case, the calibration will be referred to the IPTS-68, but the measurement precision and the equipment to be used will be appropriate to the quality of the sensor. Some thermometers may require a stability test before calibration.

These comments apply, as well, to thermistor thermometers, quartz thermometers, and other temperature sensors. These instruments may be offered for calibration on an "At Cost" basis. Special requirements for testing should be discussed with the NBS staff indicated in the Appendix.

4. Thermometer Systems

The National Bureau of Standards offers a service of analysis and calibration of thermometry systems, including sensors, reference baths, data loggers, and the like on an "At Cost" basis. This testing should be discussed with the appropriate NBS staff member well in advance of need, since it generally involves a complex relationship of the laboratory environment to the several component parts of the measurement apparatus.

5. Training

Twice a year, in spring and fall, Precision Thermometry Seminars are held at NBS. These seminars include 2 days of instruction and laboratory practice in platinum resistance thermometry, and 1 day each for thermocouple thermometry and liquid-in-glass thermometry. A fifth day is utilized for general tours and further laboratory consultation. The instruction is given by the NBS temperature calibration staff, and hands-on laboratory experience is included.

6. Radiation Thermometry

The calibration services available for optical pyrometers and ribbon filament lamps are listed in the Appendix under the title "Radiation Thermometry."

B. Pressure and Vacuum Measurements

The National Bureau of Standards develops and maintains primary and secondary standards of pressure and provides calibration services for a wide variety of instruments against these standards. These services are supplemented by extensive consultations, training of industrial personnel, measurement assurance programs, evaluation of the performance of transfer standards, special tests and services, and research and development sponsored by industrial organizations or government agencies.

1. Piston Gages

The effective area and the pressure coefficient of piston gages are determined by comparison with NBS standards. A detailed report containing all the data taken and giving a full account of the numerical evaluation of the data is issued for each gage calibrated. If customer weights are not available, NBS owned weights can be used. The mass of small parts, such as pistons and small weight tables, can be determiend as part of the calibration service. The mass of larger weights must be known before they are used for the piston gage calibration. Bases for some types of piston gages are available at NBS. In these cases only the piston cylinder assembly needs to be shipped to NBS.

2. Controlled Clearance Piston Gages

The effective area, the pressure coefficient of the area, and the jacket pressure coefficients are determined. A detailed report containing all the data taken and giving a full account of the numerical evaluation of the data is issued for each controlled clearance piston gage calibrated. Since these calibrations are very time-consuming, NBS should be contacted in advance for scheduling.

3. Barometers

Mercurial barometers in which both menisci are observable are calibrated by comparison with a standard mercury manometer or a suitable transfer standard. A table of corrections to be applied to the barometer readings is issued.

4. Manometers

Mercury manometers in which both menisci are observable are calibrated by comparison with a standard manometer or a piston gage transfer standard. A table of corrections to be applied to the manometer readings is issued.

5. Pressure Gages

Indicating pressure gages with aneroids, bourdon tubes or other transducing elements are calibrated against suitable standards. A variety of gases or liquids can be used as pressure transmitting fluids. Gage, absolute or differential pressures can be applied. A table of corrections to be applied to the indicated pressure is issued.

6. Pressure Transducers

Absolute, differential, or gage pressure transducers are calibrated against suitable standards using a variety of liquids or gases as pressure transmitting fluids. Either the transducer only or the transducer with the associated instrumentation can be calibrated. The results are generally expressed as a polynomial in the indicated pressure. A detailed report containing the data taken and giving a full account of the numerical evaluation of the data is issued.

7. Vacuum Gages

Low and medium vacuum gages are calibrated by comparison with mercury or oil manometers, or with suitable transfer standards. Various gases such as N_2, H_2, He, and Ar can be used as the pressure transmitting medium. The results are generally expressed as a polynomial in the indicated pressure. A detailed report containing the data taken and giving a full account of the numerical evaluation of the data is issued.

8. Pressure Transducer Characterization

An extensive testing service is offered to characterize the long term performance of pressure transducers. The test includes several calibrations, pressure cycling, temperature cycling, hysteresis and relaxation measurements, dependence on external parameters, etc. A detailed report with all data taken and a shorter synopsis of the findings from the test are offered for each transducer tested. Special tests can be set up for parameters or ranges not covered by the standard test.

9. Training

Training courses on pressure measurements with piston gages are held several times a year at NBS. These and other courses are also held upon request at other locations. These courses help to acquaint users of pressure standards and transfer standards with methods used at NBS and with the interpretation of calibration reports. Particular attention is paid to the assessment of uncertainties and the propagation of errors in the calibration chain.

10. Miscellaneous Tests and Services

Research and development projects in pressure and vacuum are sometimes carried out for industrial associations and government agencies. Upon request, subject to available resource constraints, NBS may provide measurement assurance services, assist in the investigation of accidents, assess the measurement capabilities of other laboratories, or provide consultation on pressure and vacuum measurements.

References

[1] **Pressure measurements and services at NBS,** P. L. M. Heydemann, presented at the Fluid Power Testing Symposium, Milwaukee, WI (1976). Available from NBS at the address listed in the Appendix.

[2] **Piston gages,** P. L. M. Heydemann and B. E. Welch, Chapter 4 in *Experimental Thermodynamics, Vol. II. Experimental Thermodynamics of Non-Reacting Fluids,* B. Le Neindre and B. Vodar, Eds., Part 3, pp. 147-202 (Butterworth and Co., London, England, 1975).

[3] **Ultrasonic manometers for low and medium vacua under development at NBS,** P. L. M. Heydemann, C. R. Tilford, and R. W. Hyland, *J. Vac. Sci. Technol.* **14,** 597 (1977).

[4] **Ultrasonic and dilatometric measurement at very high pressures,** P. L. M. Heydemann and J. C. Houck, *Nat. Bur. Stand. (U.S.), Spec. Publ. 326,* pp. 11-22 (Mar. 1971).

[5] **NBS pressure transducer characterization service,** V. E. Bean. Available from NBS at the address listed in the Appendix.

[6] **The National Measurement System for pressure,** P. L. M. Heydemann, *NBSIR 75-931,* 42 pages (Sept. 1976). Order from NTIS as PB261030, $4.50.

C. Humidity Measurements

The National Bureau of Standards provides calibration services for a wide variety of humidity-measuring instruments. Calibrations are performed by subjecting the instrument under test to atmospheres of known moisture content produced by the NBS two-pressure humidity generator and the NBS low frost-point humidity generator.

1. Dew-Point Hygrometers

Dew-point hygrometers can be calibrated over the dew/frost-point range of 80 to −80 °C. Under special cases the range of the calibration can be extended to frost-points of −100 °C.

2. Electric Hygrometers

Hygrometers classified under this category are sensors which sorb water vapor as a function of relative humidity and associated with this sorption is a corresponding change in an electrical parameter (i.e., resistance, capacitance). The range of calibration is 3 to 98 percent RH over the temperature range −55 to 80 °C.

3. Psychrometers

A limited number of types of wet-dry bulb psychrometers (aspirated hygrometers) can be calibrated at the National Bureau of Standards. The staff of the Humidity Group should be consulted for the special features of the psychrometer which are necessary before the instrument can be calibrated at NBS.

4. Coulometric Hygrometers

Coulometric hygrometers are devices which electrolyze the water into gaseous oxygen and hydrogen by the application of a voltage in excess of the thermodynamic decomposition voltage and measure this electrolysis current. The range of calibration is 1 to 820,000 ppm by volume.

5. Pneumatic Bridge Hygrometer

Pneumatic bridge hygrometers are instruments which measure the variation of pressure drop across two combinations of nozzles, operating at critical flow, with a desiccant between one pair of nozzles. The range of calibration in mixing ratios, (gram water vapor/gram dry air), is 0.0005 to 0.015.

References

The following references are available from NBS at the address shown in the Appendix under "Humidity Measurements."

[1] **The NBS standard hygrometer,** A. Wexler and R. W. Hyland, *Nat. Bur. Stand. (U.S.), Monogr. 73,* 35 pages (May 1964).

[2] **The NBS two-pressure humidity generator, Mark 2,** S. Hasegawa and J. W. Little, *J. Res. Nat. Bur. Stand. (U.S.),* **81A** (Phys. and Chem.), No. 1, 81-88 (Jan.-Feb. 1977).

[3] **Low frost-point humidity generator,** L. Greenspan, *J. Res. Nat. Bur. Stand. (U.S.),* 77A (Phys. and Chem.), No. 5, 671-677 (Sept.-Oct. 1973).

[4] **Vapor pressure formulation for water in range 0 to 100 °C. A revision,** A. Wexler, *J. Res. Nat. Bur. Stand. (U.S.),* **80A** (Phys. and Chem.), Nos. 5 and 6, 775-785 (Sept.-Dec. 1976).

[5] **Vapor pressure formulation for ice,** A. Wexler, *J. Res. Nat. Bur. Stand. (U.S.),* **81A** (Phys. and Chem.), No. 1, 5-20 (Jan.-Feb. 1977).

[6] **A correlation for the second interaction virial coefficients and enhancement factors for moist air,** R. W. Hyland, *J. Res. Nat. Bur. Stand. (U.S.),* **79A** (Phys. and Chem.), No. 4, 551-560 (July-Aug. 1975).

D. Cryogenic Measurements

The National Bureau of Standards has the only Federal program dedicated exclusively to providing complete measurement and data services necessary to support the Nation's very-low-termperature science and technology. This includes programs to: (1) develop accurate and reliable cryogenic measurement methods; (2) measure properties of cryogenic liquids and solids; (3) gather, evaluate, and compile the world's literature on research and development at cryotemperatures; (4) perform scientific and engineering research, as well as consulting services, for Federal agencies and other public institutions; and (5) aid in developing codes, standards, and recommended practices for safe handling of liquefied gases. The cryogenic information generated and other assistance is disseminated via publications, consulting and advisory services and scientific and engineering research performed for public institutions. Routine cryogenic calibrations are not provided, but special cryogenic measurement problems will be considered especially if they relate to on-going program objectives. For additional information contact the points of contact indicated in the Appendix under "Cryogenics."

1. Cryogenic Data

Continuous surveys are made of most of the world's literature on low-temperature science and technology. All data and references concerning cryogenic properties of materials and cryogenic engineering are systematically catalogued and stored on magnetic tape for computer retrieval. As a result a complete, up-to-date bibliography can be compiled on any subject within the data bank's scope. Critically evaluated data on the thermophysical properties of cryogenic fluids, metals, alloys and dielectrics are also available.

2. Liquefied Natural Gas Program

In view of industry's increased use of liquefied natural gas for supplemental base fuel loads and relieving peak loads, LNG technology is burgeoning. Therefore, NBS is helping to establish an efficient, consistent, and safe LNG technology base. The thermophysical properties of LNG components and their mixtures are being measured and defined. A Liquefied Natural Gas Materials and Fluids User's Manual is available. The book is designed to provide in user format technical data and related information for the effective generation, utilization and transportation of LNG.

3. Cryogenic Measurements

Consulting and advisory services are available on measurements associated with cryogenic techniques, instruments, transducers and the characteristics of materials subjected to cryogenic measuring devices, such as cryogenic mass and volume flow, liquefied natural gas, cryoelectronics, fluids, solids, etc.

References

[1] **The Cryogenic Data Center, an information service in the field of cryogenics,** N. A. Olien, *Cryogenics* **11,** No. 1, 11-18 (Feb. 1971).

[2] **NBS-CGA cryogenic flow measurement program,** J. A. Brennan, R. W. Stokes, C. H. Kneebone, and D. B. Mann, (Proc. ISA International Instrumentation Automation Conf. and Exhibit, New York, NY, Oct. 28-31, 1974), Paper in *Advances in Instrumentation* **29,** 612-1/612-13 (Instrument Society of America, Pittsburgh, PA, 1974).

[3] **Progress report on cryogenic flowmetering at the National Bureau of Standards,** J. A. Brennan, J. F. LaBrecque, and C. H. Kneebone, *Proc. 1st Biennial Symp. Instrumentation in the Cryogenic Industry, Houston, TX, Oct. 11-14, 1976,* **1,** 621-1/621-16 (Instrument Society of America, Pittsburgh, PA, 1976).

[4] **Cryogenic liquid-measuring devices, National Code on Specifications, Tolerances, and other technical requirements,** *Nat. Bur. Stand. (U.S.), Handbook 44.*

[5] **Superconducting devices for metrology and standards,** R. W. Kamper, Chapter 5 in *Superconductor Applications: Squids and Machines,* B. B. Schwartz, and S. Foner, Eds., pp. 189-247 (Plenum Publ. Corp., New York, NY, 1977).

[6] **Thermophysical properties data research on compressed and liquefied gases at the NBS Cryogenics Division,** D. E. Diller, (Proc. Cryogenic Engineering Conf., Advances in Cryogenic Engineering, Kingston, Ontario, Canada, July 22-25, 1975), Paper M-7 in *Advances in Cryogenic Engineering* **21,** 522-531 (Plenum Press, New York, NY, 1976).

CHAPTER VIII

VIII. Optical Measurements

A. Radiometry and Photometry

The National Bureau of Standards provides radiometric and photometric calibrations of three classes: Basic, gage, and special. Basic calibrations are those considered fundamental to all work in radiometry and photometry, and for which documentation of uncertainties relative to the International System of Measurements exists. Gage calibrations are those routinely available calibrations for which uncertainties have only been documented relative to NBS standards. Basic and gage calibrations are offered as fixed fee items, listed in the Appendix, and require only a purchase order identifying the item number. Details of the calibration procedure and a summary of the documentation of the uncertainties are provided in each calibration report. The listed Basic and Gage calibrations are performed under rigid, pre-determined conditions and are, therefore, restricted as to lamp type, measuring geometry, wavelength points, etc., and requests for departure from these conditions will be considered as special calibrations.

Special calibrations are those having unique requirements not satisfied by the listed basic and gage items, and are considered as small research efforts. Agreement to accept such requests are handled on a case-by-case basis. Fees are charged on an actual cost basis, with an estimate of cost, delivery time, and uncertainty being provided after receipt of a description of the desired test, and before actual work commences. The request for a special calibration should include the following information:

(1) Detailed description of desired calibration
(2) Uncertainty required (SI units, NBS standards)
(3) Manner in which the calibrated device will be used
(4) The consequences of this calibration not being provided by NBS.

1. Basic Radiometric Calibrations

(a) Special radiance standard, ribbon filament lamp (30A/T24/13).

Lamps of this type are calibrated at 33 wavelengths from 225 to 2400 nm, for a target area 0.6 mm wide by 0.8 mm high, and at a radiance temperature of about 2675 K at 225 nm, 2495 K at 650 nm, 2415 K at 800 nm and 1620 K at 2400 nm, with approximate uncertainties relative to SI units of spectral radiance of 4.5 percent at 225 nm, 1 percent at 650 and 800 nm, and 1.5 percent at 2400 nm. The lamp requires about 40 A dc at 12 V. An interpolation formula allows calculation at all wavelengths except in regions of absorption bands. The lamp is normally provided by NBS.

(b) Spectral radiance standard, fixed temperature blackbody (500-700 K).

Submitted blackbodies are calibrated at eight wavelengths from 1.5 to 14 μm, for a target size no larger than 2 mm wide by 4 mm high, and one aperture between f/8 and f/23. Physical dimensions may be no larger than 10 in (25.4 cm) wide by 20 in (50.8 cm) long by 6 in (15.24 cm) high to center of cavity aperture. Approximate uncertainties relative to SI units of spectral radiance range from 2 percent at 1.5 μm to 1 percent at 14 μm.

(c) Spectral irradiance standard, quartz-halogen 1000 watt type FEL lamp.

The lamp is calibrated at 24 wavelengths from 250 to 1600 nm, at a distance of 50 cm, and at a spectral irradiance of about 0.2 W/cm^3 at 250 nm, 220 W/cm^3 at 900 nm and 115 W/cm^3 at 1600 nm, with approximate uncertainties relative to SI units of 2.5

percent at 250 nm, 1 percent at 650 nm, and 1 percent at 1600 nm. The lamp is normally supplied by NBS, and requires about 8 A dc at 110 V. An interpolation formula allows calculation of the value at any wavelength except in regions of absorption bands.

(d) Spectral irradiance standard, deuterium lamp.

The lamp is calibrated at 16 wavelengths from 200 to 350 nm, at a distance of 50 cm, at a spectral irradiance of about 0.5 W/cm^3 at 200 nm, 0.2 W/cm^3 at 250 nm and 0.06 W/cm^3 at 350 nm. The approximate uncertainty relative to SI units is 6 percent, the approximate uncertainty in relative spectral distribution is 2.5 percent. The lamp is normally supplied by NBS and requires 300 ma at about 100 V.

2. Basic Photometric Calibrations

(a) Luminous intensity standards.

100-W (90-140 cd), 500-W (approximately 700 cd) and 1000-W (approximately 1400 cd) tungsten filament lamps with C-13B filaments in inside-frosted bulbs and medium bipost bases are supplied by NBS calibrated at either a set current or a specified color temperature in the range 2700-3000 K. Approximate uncertainties are 4 percent relative to the SI unit of luminous intensity and 1.5 percent relative to NBS standards.

(b) Luminous flux standards (geometrically total).

25-W vacuum tungsten lamps and 60-, 100-, 200-, and 500-W gas filled tungsten lamps submitted by customers are calibrated. Lamps must be base-up burning and rated at 120 V. Approximate uncertainties are 4.5 percent relative to SI units and 1.5 percent relative to NBS standards.

3. Radiometric and Photometric Gage Calibrations

The currently available calibration services are listed in the Appendix under the title "Radiometric and Photometric Gage Calibrations."

4. Special Calibrations

Electrical Substitution Radiometry

NBS provides a service for transferring photodetector absolute response measurements at several discrete wavelengths in the 250 to 1150 nm wavelength range.

B. Spectrophotometric Standards

1. Standards of Spectral Transmittance For Checking the Photometric Scale of Spectrophotometers

These are either 30 mm polished glass disks or 51 mm polished glass squares, 2 to 3 mm thick, designated as cobalt blue, copper green, carbon yellow, and selenium orange (disks will be supplied unless otherwise specified). The report includes: (1) values of transmittance at 25 °C at certain wavelengths from 390 to 750 nm, (2) the estimated uncertainty of each value, and (3) the effect of temperature change on transmittance at each wavelength.

2. Didymium Glass Standards for Checking Wavelength Calibrations

Didymium glass standards are available for checking the wavelength calibration of General spectrophotometers having 10 nm triangular bandpass. These are made of polished Corning 5120 glass, 51 × 51 mm, 3.0 mm thick. The report includes a table of wavelengths of minimum transmittance.

3. *Holmium Oxide Glass Standards*

Holmium oxide glass standards are available for checking the ultraviolet and visible wavelength calibrations of recording spectrophotometers having a bandpass less than 2 nm. These are made of polished Corning 3130 glass, 51 x 51 mm, 2.5 mm thick. The report includes a table of wavelengths of minimum transmittance.

4. *Working Standards of Spectral Reflectance Factor*

Working standards of spectral reflectance factor are available for use on spectrophotometers with 6° from perpendicular irradiation and diffuse reception. The standards consist of white structural Vitrolite glass, 102 × 102 mm, 8 mm thick or 38 × 51 mm, 11 mm thick. The report includes a table of spectral reflectance factors relative to perfect diffuser at every 10 nm.

5. *Spectrophotometric Measurements*

The measurements of spectral transmittance, spectral reflectance, or spectral reflectance factor, covered under this item are intended primarily for information purposes and specimens so tested should not be accepted as "standards."

Measurements of spectral transmittance can be made for the wavelength region 0.19 to 2.5 μm. One or more of the following spectrophotometers will be used, depending upon the wavelength region to be covered: NBS Reference Spectrophotometer for Transmittance; Cary Model 14; General Electric. All measurements are made at room temperature for certain samples.

Measurements of spectral reflectance factor, relative to some accepted reference surface, can be made for the wavelength region 0.25 to 2.5 μm. One or more of the following spectrophotometers will be used, depending upon the wavelength region to be covered: NBS reference spectrophotometer for Diffuse Transmittance and Reflectance; Cary Model 14 or General Electric. All of these instruments permit the measurement of directional-hemispherical reflectance factor, while the first instrument also permits the measurement of 0°-45° reflectance factor. All measurements are made at room temperature.

Accuracy and precision estimates will be given, dependent upon the optical characteristics of the submitted specimens.

Measurements will be made on an actual cost basis, subject to a nominal minimum charge. Arrangements for measurements must be completed before shipment of specimens. The decision to perform the measurements and the instruments to be used will rest with NBS and refusal may be made after inspection of the specimens. Specimens not accepted for measurement will be returned, the cost of examination or the minimum charge will be applicable.

C. Image Optics and Photography

1. *Refractive Index*

The index of refraction of a solid, transparent optical material is measured at visible wavelengths of calibrated emission lines of cadmium, helium, and mercury. Ordinarily measurements are made at room temperature, near 22 °C. Specimens submitted for test must be in one of the geometrical forms described below.

(1) Test specimens may be in the form of a prism, with two rectangular surfaces polished optically flat within one-eighth wavelength. The minimum linear requirements for these surfaces are approximately 25 mm (length) × 13 mm (height). The optimum refracting angle varies from 70° for index $n = 1.4$ to 50° for index $n = 1.9$.

(2) Test specimen may be in the form of a rectangular slab approximately 25 mm × 13 mm × 5 mm, such as is commonly used for the adjustment of an Abbe refractometer.

The two surfaces must be polished optically flat within approximately one wavelength and intersect at 90° to form an unbeveled edge. The index of the specimen should not exceed $n = 1.8$.

Generally tests are based on correspondence regarding the exact nature of the requirements. Do not ship materials to the Bureau until arrangements for test have been completed. (See Appendix for NBS point of contact.)

Measurements will be made on an actual cost basis.

2. Optical Lens Evaluation: Pupil Functions, Optical Transfer Function, and Aberrations

When submitting lenses for optical transfer function measurements, the nominal focal plane, *f*-number, wavelength, and type of test (infinite or finite conjugate) must be specified. Lenses up to 20 cm in diameter can be tested; however, lenses from 10 to 20 cm in diameter may require a mounting fixture to accompany the lens.

The monochromatic, on-axis modulation transfer function (MTF) and phase transfer function (PTF) of a lens can be measured for a single, or series, of focal-plane positions. The pupil function, or deviations of the wavefront from the reference plane, and maximum values of aberrations (spherical, coma, focus defect, and astigmatism) can be also determined.

3. Photographic Calibrations (e.g., Step Tablet Transmission Visual Density on Photographic and Radiographic Materials)

Diffuse transmission density is measured in accordance with ANSI Standard PH2.19-1959. Calibrated step tablets, both photographic and radiographic, are available through the Office of Standard Reference Materials.

In special cases, measurements may be made by arrangement. ANSI Standard Diffuse Visual Transmission Density, Type VI-b, is measured on step tablets of 21 steps or less. Tablets submitted for calibration must be free of scratches, fingerprints, abrasions, and foreign matter and must have steps of uniform density. Tablets not suitable as standards are not accepted for calibration.

References

[1] **Conditions for microdensitometer linearity,** R. E. Swing, *J. Opt. Soc. Am.* **62,** No. 2, 199-207 (Feb. 1972).

[2] **A wide-angle retroflector,** A. W. Hartman, *NBS Report 10832* (July 1972).

]3] **The measurement of the thicknesses of thin films: The Dyson interferometer,** D. A. Swyt, *NBS Report 10918* (Sept. 1972).

[4] **Basic considerations of densitometer adjustment and calibration,** R. E. Swing, *NBS Report 10970* (Dec. 1972).

[5] **Lens testing with a simple wavefront shearing interferometer,** D. Nyyssonen and J. M. Jerke, *Appl. Optics* **12,** 2061-2070 (Sept. 1973).

[6] **The optics of densitometry,** R. E. Swing, *Opt. Eng.* **12,** No. 6, 185-198 (Nov./Dec. 1973).

[7] **Basic considerations of densitometer adjustment and calibration,** R. E. Swing, *NBSIR 75-682,* 18 pages (Feb. 3, 1975). Order from NTIS as COM 75-10524, $4.00.

[8] **The calibration of photographic edges at NBS,** R. E. Swing, *NBSIR 75-699,* 37 pages (Apr. 22, 1975). Order from NTIS as COM 75-11016, $4.50.

[9] **Semiconductor measurement technology: Optical and dimensional measurement problems with photomasking in microelectronics,** J. M. Jerke, *Nat. Bur. Stand. (U.S.), Spec. Publ. 400-20,* 42 pages (Oct. 1975).

[10] **Interferometric lens testing,** J. M. Jerke and D. Nyyssonen, Air Force Avionics Laboratory (see [5]).

[11] **Development of dimensional measurement techniques from 1 to 10 micrometers and application to optical microscope measurements,** J. M. Jerke, *Meeting of Society of Photographic Scientists and Engineers, Proceedings* (Feb. 1975).

[12] **An improved photographic edge-artifact,** W. R. Smallwood and R. E. Swing, *NBSIR 76–1129,* 49 pages (Aug. 1976). Order from NTIS as PB274712, $4.50.

4. Microcopy Resolution Test Charts

Microcopy resolution test charts conforming to ISO Standard 3334, NMA Standard MS104–1972, and MIL-M-9868D, are available through the Office of Standard Reference Materials.

5. Special Microdensitometer Measurements

Microdensitometric scans of photographic images are made with an instrument whose physical configuration can be varied to include sample and image scanning, over and underfilled optics, with objectives whose numerical apertures range from 0.08 to 0.90 and sampling apertures as small as 1 μm. The output is recorded on chart paper. Densities are calibrated as diffuse (visual).

6. Photographic Edge Artifacts and Calibrations

Photographic edge-artifacts containing 10 density steps and 3 edges with user-specified contrasts are produced and calibrated. The materials are high resolution film or plates, depending on requirements. Microdensitometric analysis of each edge, incorporating user-specified instrument configuration, is optional; the reported parameter is equivalent acutance.

CHAPTER IX

IX. Ionizing Radiation

The National Bureau of Standards carries out an extensive program of research directed towards state-of-the-art measurement of ionizing radiation. Measurement services are available as described in the sections which follow for neutron sources and dosimetry, for radioactivity, and for dosimetry of x-rays, gamma-rays, and electrons. Requests for additional information concerning NBS capabilities and services related to ionizing radiation should be directed to the points of contact listed in the Appendix.

A. Neutron Sources and Dosimetry

The National Bureau of Standards provides neutron source calibrations as well as thermal neutron irradiations of foils and simple dosimeters in its thermal neutron density of 4000 neutrons/cm²/s. Due to an expansion in our neutron dosimetry and neutron reaction rate standardization programs, we are now able to offer sample irradiations in fast neutron spectra as well as in thermal-neutron fields of much greater intensity and purity.

As a special measurement service, the following neutron fields are available for irradiations:

(1) ^{252}Cf spontaneous fission neutrons to a free-field fluence up to 10^{13} neutrons/cm^2 specified to an accuracy of ± 2 percent (1σ) or better depending upon sample size and arrangement.

(2) ^{235}U cavity fission neutron field to a fluence of up to 2×10^{15} neutrons specified to an accuracy of approximately ± 5 percent (1σ).

(3) A 24 keV Iron-Aluminum filtered beam to a fluence of 5×10^{11} neutrons to an accuracy of about 10 percent.

(4) A 2 keV Scandium filtered beam to a fluence of 2×10^{11} neutrons to an accuracy of about 5 percent.

(5) A 144 keV Silicon filtered beam to a fluence of 10^{12} neutrons to an accuracy of 10 percent.

(6) An external thermal neutron beam at the NBS reactor with free-field fluxes of up to 2×10^7 neutrons/cm²/s specified to an accuracy of ± 3 percent (1σ) or better depending upon sample size.

(7) A cavity thermal neutron field with a near-isotropic neutron flux of about 10^{11} neutrons/cm²/s specified to an accuracy of ± 5 percent (1σ) or better.

1. Laboratory Standard Neutron Sources

The National Bureau of Standards provides a calibration service for laboratory standard neutron sources. By calibration and certification of such standards, accuracy and intercomparability are promoted in the measurements of neutron flux which play an important part in current research. The service should be of particular assistance to those concerned with fundamental nuclear experiments, design and control of nuclear reactors, problems of protection from neutron radiation, and industrial applications of neutron sources.

The emission rate of neutron sources of 10^5 to a few times 10^8 neutrons/s are calibrated against the NBS primary Ra-Be photoneutron standard source by the manganous sulfate bath technique. The neutron emission rate for more intense sources up to about 10^{10} neutrons/s are calibrated by comparing their strength indirectly to the NBS standard source.

The induced saturated manganese-56 activity of the bath is counted with two scintillation counters at a well-shielded remote location by continuously pumping a fraction of the bath volume to them. One scintillation counter samples the activity at the center of the volume and the second views a fraction of the same volume through a collimator. The first counter operates at about 100 counts/s for the standard source of about 10^6 neutrons/s and is paralyzed for the most intense sources. The second counter operates at about 4000 counts/s for sources of about 10^{10} neutrons/s but close to background for the standard source. Relative counter efficiencies are obtained with an intermediate source of 10^8 neutrons/s.

About 1 month should be allowed for the calibration of such a laboratory standard.

Advance arrangements must be made for the calibration of laboratory standards. The following information must be furnished:

(1) A diagram showing the source location in the shipping container and instructions for removal of the source, if necessary.

(2) A description of any special markings on the source.

(3) The dimensions of the source, including the relative internal location of the active ingredients.

(4) The nature and amount of radioactive materials and the ratio of neutron producing ingredients.

(5) The kind of metal enclosing source and, if possible, the number of grams of each element.

(6) The date the source was sealed.

Sources accepted for calibration must be sealed, packed, and shipped in such a way that leakage and contamination will be avoided. From 1 to 2 months should be allowed for completion of the calibration.

References

[1] **The correction factor for fast neutron reactions on sulfur and oxygen in the manganous-sulfate-bath calibration of neutron sources,** W. M. Murphey, *Nucl. Instr. Methods* **37,** No. 1, 13-21 (1965).

[2] **Calculation of thermal neutron absorption in cylindrical and spherical neutron sources,** V. Spiegel, Jr., and W. M. Murphey, *Metrologia* 7, No. 1, 34-38 (Jan. 1971).

[3] **Absolute calibration of the National Bureau of Standards photoneutron source: III. Absorption in a heavy water solution of manganous sulphate,** R. H. Noyce, E. R. Mosburg, Jr., S. B. Garfinkel, and R. S. Caswell, *J. Nucl. Eng.* **17,** No. 7, 313-319 (1963).

[4] **Absolute calibration of the National Bureau of Standards photoneutron standard: I.,** J. A. DeJuren, D. W. Padgett, and L. F. Curtiss, *J. Res. Nat. Bur. Stand. (U.S.),* **55,** p. 63 (Aug. 1955).

[5] **Absolute calibration of the National Bureau of Standards photoneutron standard: II. Absorption in manganese sulfate,** J. A. DeJuren and J. Chin, *J. Res. Nat. Bur. Stand. (U.S.),* **55,** p. 311 (Dec. 1955).

2. Thermal Neutron Dosimeters

NBS can provide calibration of a set (one to three) of thermal neutron dosimeters in the standard thermal neutron flux with and without cadmium covers. The response to gamma rays in the thermal flux is not provided.

3. Neutron Irradiation of Foils

The NBS neutron physics laboratory also maintains a standard moderating geometry supplying a uniform thermal neutron density of about 4000 thermal neutrons/cm²/s for indirect calibration of unknown thermal neutron densities by irradiation of foils. The standard thermal neutron density is produced by two 1 g Ra-Be (a,n) sources permanently fixed in a moderation geometry of paraffin and graphite. The exposure cavity is in graphite.

Four foils, no larger than 2 × 3.4 cm each, can be irradiated at one time. Information on the cadmium ratio of gold foils of various thicknesses in this density is provided with the calibration. Therefore, a separate cadmium-covered foil irradiation usually is not necessary but will be provided if requested. Foils usually are placed in the flux on a Monday and removed the following Monday and shipped by air mail to the laboratory requesting the calibration.

If a specific date for the calibration is required, submit an advance request to NBS as indicated in the Appendix. Otherwise, foils will be irradiated as time is available in the standard flux.

References

[1] **Results of the intercomparisons of the thermal neutron flux density unit, (1966-1968),** E. J. Axron, *Metrologia* **6,** No. 1, 25-32 (1970).

[2] **Analysis of results of the Bureau International des Poids et Mesures thermal neutron flux density intercomparison,** W. M. Murphey and R. S. Caswell, *Metrologia* **6,** No. 4, 111-115 (Oct. 1970).

[3] **Absolute calibration of the NBS standard thermal neutron density,** J. A. DeJuren and H. Rosenwasser, *J. Res. Nat. Bur. Stand. (U.S.),* **52,** p. 93 (Feb. 1954).

[4] **A recalibration of the NBS standard thermal neutron flux,** E. R. Mosburg, Jr., and W. M. Murphey, *Reactor Sci. and Tech. J. Eng.* **14,** Pt. A/B, 25-30 (1961).

B. Radioactivity

1. Calibration of Gamma-Ray-Emitting Radioactive Samples

Gamma-ray-emitting radioactive samples which conform to the physical, chemical and activity level specifications for measurement at the National Bureau of Standards are calibrated in a 4π ionization chamber. Solutions should be 5 ml in volume and flame-sealed in glass vials or ampoules (free of high Z elements) of outer diameter 16.0±0.5 mm, wall thickness approximately 0.5 mm. Ampoules, for this purpose, may be obtained from NBS.

Gamma-ray-emitting radionuclides for which calibrations can be obtained, and their activity ranges are:

50 to 100 μCi, Na-22, Sc-46, CO-60, Y-88, Ag-110m-Ag-110
100 to 300 μCi, Mn-54, Fe-59, Zn-65, Se-75, Sr-85, Nb-95, Sn-113-In-113m, I-131, CS-137-Ba-137m, Ta-182 Au-198, Hg-203
600 μCi, K-42, Co-57, Ce-139, Ce-141, Hg-197
10 to 30 μCi, Na-22, Na-24, Sc-46, Co-60, Y-88, Ag-110m-Ag-110
30 to 80 μCi, Mn-54, Fe-59, Zn-65, Se-75, Sr-85, Nb-95, Sn-113-In-113m, I-131, Cs-137-Ba-137m, Ta-182, Au-198, Hg-203
60 to 100 μCi, K-42, Co-57, Ce-139, Ce-141, Hg-197
200 to 1000 μCi, Cr-51, Cd-109

2. Calibration of Alpha-Particle-Emitting Samples

Alpha-particle-emitting samples that conform to the physical activity specifications for measurement are calibrated in the National Bureau of Standards 2π-proportional or

1π-scintillation counters. The preparation and calibration of polonium-210 sources, the calibration of alpha-particle samples in both the 2π-proportional and the 1π-scintillation counters, for 2π count-rate or activity, respectively, are covered under this service. The list of calibrations currently available is given in the Appendix under the title "Radioactivity."

Chemically and physically stable samples that conform to the specifications listed below can be measured for total particle count rate into a 2π geometry using the NBS 2π proportional counter.

(1) Source diameter should not exceed 10 cm.

(2) Source thickness should be such that more than 99.5 percent of the emitted alpha particles have an energy greater than 400 keV.

(3) Activity should not exceed 0.3 μCi.

(4) Activity should not be less than 20 pCi.

Samples that are chemically and physically stable can be measured for activity in the NBS 1π counter if they meet the specifications outlined in (1), (2), and (3) above. Activity should not be less than 3 nCi.

Samples that are chemically and physically stable and meet the specifications outlined above can be measured in both the 2π-proportional and the 1π-scintillation counters.

Polonium-210 sources will be prepared on request, due to the relatively short half life, 138.4 days. These sources will consist of a practically weightless deposit of polonium-210 on a monel disk 2.54 cm in diameter and 0.16 cm thick and will be calibrated in either 2π or 1π geometry.

(1) Activity range: 0.5-3.0 nCi.

(2) Polonium-210 restricted to a 0.3 cm diameter area in the approximate center of disk.

(3) These sources are unsuitable for prolonged use in a vacuum, due to possible loss or transfer of source material.

(4) The total activity of these sources will be such that they may be ordered under the general licensing provisions of the Atomic Energy Act of 1954.

3. Calibration of Beta-Ray-Emitting Radioactive Samples

Beta-ray-emitting radioactive samples that conform to the physical, chemical, and activity level specifications for measurement are calibrated in either the National Bureau of Standards 2π windowless proportional flow counter, or in the National Bureau of Standards 2π ionization chamber. See the Appendix under "Radioactivity" for the current list of services.

Chemically stable solutions of the following radionuclides in the specified activity ranges can be measured in the National Bureau of Standards 2π windowless proportional flow counter.

(1) 1-10 μCi/ml chlorine-36, strontium-yttrium-90.

(2) 2-20 μCi/ml thallium-204.

(3) 5-50 μCi/ml calcium-45, promethium-147.

(4) 10-100 μCi/ml sulfur-35.

Solutions should be approximately 5 ml in volume and flame-sealed in glass vials or ampoules.

Chemically stable solutions of the following radionuclides in the specified activity ranges can be measured in the National Bureau of Standards 2π ionization chamber.

(1) 2-20 μCi/ml phosphorus-32. Solution should be neutral or weak acid with not more than 0.2 mg/ml total solids.

(2) 2-20 μCi/ml strontium-89, strontium-yttrium-90. Solution should be weak HCl (1N or less) with not more than 0.2 mg/ml total solids.

Solutions should be approximately 5 ml in volume and flame-sealed in glass vials or ampoules.

C. Dosimetry of X-Rays, Gamma-Rays, and Electrons

1. X-Ray and Gamma-Ray Measuring Instruments

X-ray measuring instruments are calibrated in terms of exposure by a substitution method in an x-ray beam at a point where the exposure rate has been determined by means of a standard free-air ionization chamber. In order to provide instrument calibration over a wide range of x-ray energies, many combinations of voltage and filtration are available. These are listed in the Appendix under "Lightly Filtered X-Rays," "Moderately Filtered X-Rays," or "Heavily Filtered X-Rays." The calibration techniques requested should be appropriate to the particular instrument submitted.

Gamma-ray measuring instruments are calibrated in terms of exposure or absorbed dose at points in the collimated cobalt-60 and cesium-137 gamma-ray beams that have been standardized by means of graphite cavity chambers or a graphite calorimeter. Exposure rates and absorbed dose rates at the time of calibration are computed from the original beam standardization data and appropriate decay corrections. Ionization chambers submitted for an exposure calibration should have sufficient wall thickness to provide electron equilibrium for the gamma-ray energy selected. Ionization chambers submitted for an absorbed-dose calibration must be suitable for calibration in a phantom.

An ionization chamber submitted with an associated electrometer marked in terms of exposure or absorbed dose is calibrated by providing a dimensionless correction factor for the electrometer scale; special arrangements should be made for the calibration of an ionization chamber to be submitted with an associated electrometer not marked in terms of exposure or absorbed dose. An ionization chamber submitted without an associated electrometer is calibrated in terms of exposure, or absorbed dose, per unit charge. Calibration can be based on measurements for positive or negative polarizing potential, or the mean of measurements for both positive and negative potentials, as requested. The ratio of ionization currents for full and half polarizing potentials and the corresponding ionization current, will be stated.

Ionization chambers are tested, prior to calibration, for leakage, radiation-induced leakage, stabilization time, short-term stability, recombination loss, connection to the atmosphere, and guard electrode insulation (if applicable). Chambers found unsuitable for calibration will be returned with a statement of the reason for rejection. A charge may be made for time incurred in the tests. A statement of the performance specifications that the chambers are required to meet will be furnished on request to the address given in the Appendix.

Irradiation of passive dosimeters, for readout by the user, is available for the techniques listed in the Appendix. These irradiations are generally in terms of exposure; for passive dosimeters suitable for insertion in a phantom, irradiation in terms of absorbed dose can be provided by in-phantom irradiation using cobalt-60 gamma-rays.

X-ray penetrameters, of the Ardran-Crookes type, can be calibrated using x-ray generating potentials up to 250 kV. These penetrameters are used for measurement of the generating potential of diagnostic x-ray units.

For details of the currently available services, see the Appendix under the title "X-Ray and Gamma-Ray Measuring Instruments."

2. Gamma-Ray and Beta-Particle Sources

Sources submitted to the Bureau for dosimetry calibration are subject to the following conditions:

(a) Financial responsibility: Except for negligence by Bureau personnal, the Bureau assumes no responsibility for loss damage to the sources while in its possession. The risk should be covered by insurance.

(b) Period of measurement: Inquiry should be made as to scheduling and turnaround time before the source is submitted.

(c) Preparation: Sources submitted for calibration must be sealed so that there can be no escape of any radioactive material, including any gaseous decay products. The sources, shielding, and packaging must be free of contamination. Contaminated or leaking sources cannot be measured and may cause considerable loss of time and damage to laboratory facilities. Sources must have been sealed for a sufficient time to be substantially in radioactive equilibrium with their decay products when these contribute to the emitted radiation.

(d) Packaging for shipment: Packages must be in compliance with the regulations of the Department of Transportation regarding the shipment of radioactive substances by rail. These regulations are enforceable by law and prospective shippers of these substances need to be familiar with them. Copies of regulations can be obtained from the Operations Division, Office of Hazardous Materials, Department of Transportation, Washington, D.C. 20590. Postal regulations prohibit mailing radioactive materials which require a caution label under DOT regulations. This effectively prohibits placing in the mail sources for dosimetry calibration.

(e) ossession of licensed materials: In submitting a source for calibration, it will be necessary for the submitter to certify that he is duly authorized to possess the source under license by the applicable authority. In the case of individuals residing in a State which has entered into agreement with the Nuclear Regulatory Commission, State regulations are applicable to all sources including radium. In the case of other individuals, NRC regulations are applicable (radium is not licensed by the NRC). This certification may be by letter, by a suitable statement on the purchase order covering the calibration fee, or by a clear copy of the submitter's Possession License for the source.

Calibration in terms of exposure rate at 1 m is provided for gamma-ray sources of cobalt-60, cesium-137, and iridum-192; a similar service is planned for radium and possibly for other radionuclides. Radium is calibrated in terms of mass of equivalent radium content measured relative to the National Radium Standard through comparison of the gamma radiation from the specimen and the standard; where the details of encapsulation of the specimen are known, corrections can be made to obtain milligrams of radium content. Calibration in terms of absorbed dose rate is provided for suitable encapsulated beta-particle sources; the dose rate to a low-atomic-number material (graphite or plastic) is determined by measurement with an extrapolation chamber, or with a suitable ionization chamber calibrated against the extrapolation chamber. For details of the current available services, see the Appendix under the title "Gamma-Ray and Beta-Particle Sources."

3. Dosimetry of High-Energy Electron Beams

Dosimeters will be provided to users requesting assistance with absorbed-dose measurements in high-energy electron beams. The dosimeters employed will consist of ferrous sulfate (Fricke) solution in radiation-resistant silica-glass spectrophotometer cells. The users will irradiate all but two of the furnished dosimeters to between 50 and 80 Gy (5000 and 8000 rad) to water at electron energies between 5 and 50 MeV, employing the irradiation geometry (field size, phantom, position of dosimeter in phantom) given in the "Protocol for Dosimetry of High-Energy Electrons," Physics in Medicine and Biology **11**, 505 (1966).

After irradiation, the dosimeters will be returned to the Bureau for spectrophotometric evaluation of the ferric-ion concentration in terms of absorbed dose in the phantom, using the G-value given in the Protocol. Twice a year the Bureau provides this service, which consists of the preparation and shipment of four Fricke dosimeters, two as controls and two for irradiation, and evaluation of the ferric-ion content in terms of absorbed dose in the phantom. For details, see the Appendix under the title "Dosimetry of High-Energy Electron Beams."

D. Radiochromic Dosimetry (High-Dose Gamma-Ray Calibrations)

Dosimeters of maximum size 2 × 10 cm are irradiated with cobalt-60 gamma rays in the range 1 to 600 kGy (0.1 to 60 Mrad) to water. The optical density can be determined by a spectrum scan in both the visible and ultraviolet regions. If desired the temperature dependence of gamma-ray response can be determined. For details see the Appendix under the title "Radiochromic Dosimetry (High-Dose Gamma-Ray Calibrations)."

CHAPTER X

X. Computer Science—Magnetic Disk Calibration

The National Bureau of Standards conducts research and provides technical services designed to aid Government agencies in improving cost effectiveness in the conduct of their programs through the selection, acquisition, and effective utilization of automatic data processing equipment; and serves as the principal focus within the executive branch for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. For information on this program, either write or call NBS at the address listed in the Appendix.

Magnetic Disk Calibration

Magnetic disk calibration services in three density levels, are offered in support of related Federal Information Processing Standards and American national and international standardization activities. They include calibrating signal amplitude at the three recording densities described below:

Low Density: 1,100 bpi at track 200, 100 tpi

Low density magnetic disk surfaces of the type used in the six-high disk pack (ANSI Standard X3.46-1974) will be calibrated relative to the Primary Standard Amplitude Reference Surface held in repository at NBS. Submissions will be calibrated at 0.625 MHz on track 000 and at 0.625 MHz and 1.25 MHz on track 200 along specified areas located by scribe marks on these tracks. The customer can elect to have NBS place the necessary scribe marks on a submitted surface or provide NBS with an already inscribed surface.

Medium Density: 2,200 bpi at track 200, 100 tpi

Medium density magnetic disk surfaces of the type used in the eleven-high disk pack (ANSI Standard BSR X3.58) and the one-high single disk cartridge (ANSI Standard X3.52-1976) are calibrated relative to the medium density Primary Standard Amplitude and Data Reference Surfaces held in repository at NBS. Submissions are calibrated at specified areas located by scribe marks on track 000 and track 200. The customer can elect to have NBS place the necessary scribe marks on a submitted surface or provide NBS with an already inscribed surface. A 2311-type amplitude test head will be used to calibrate a submitted surface at 0.625 MHz on both of these tracks. A 2314-type data test head is used to calibrate a submitted surface on track 200 at both 1.25 and 2.5 MHz.

High Density: 4,040 bpi at track 410, 192 tpi

High density magnetic disk data surfaces of the type used in the twelve-high disk pack (ANSI Standard BSR X3.63) are calibrated with respect to the Primary Standard Reference Data Surface held in repository at NBS. Submissions are calibrated using a data test head at both 1.6 and 3.2 MHz along the entire area of tracks 000 and 410.

Fees for these services are listed in the Appendix in the section on "Computer Science."

CHAPTER XI

XI. Miscellaneous Services

The National Bureau of Standards provides many other services in addition to the calibration and testing programs to which this publication is primarily addressed.

A. Standard Reference Materials

The Standard Reference Materials Program of the National Bureau of Standards provides science, industry, and government with a central source of well-characterized materials certified for chemical composition, or for some chemical or physical property. These materials are designated Standard Reference Materials (SRM's) and are used to calibrate and evaluate measuring instruments, methods, and systems or to produce scientific data that can be referred readily to a common base. Approximately 900 SRM's currently available from NBS are described in the Catalog of NBS Standard Reference Materials, NBS Special Publication 260, and its supplement.

All of the Standard Reference Materials (SRM's), Research Materials (RM's), and Special Reference Materials (GM's) listed in SP260 bear distinguishing names and numbers by which they are permanently identified. Each SRM, RM, or GM bearing a given designation is of identical characterization with every other sample bearing the same designation, within the limits required by the use for which it is intended; or if necessary, it is given a serial number and an individual calibration.

New SRM's are prepared each year and are announced through supplements to SP260 as well as directly to prospective users. These supplements are issued periodically and provide a complete list of the available SRM's, their prices, and descriptions of SRM's issued since the latest catalog was printed.

Areas in which materials are available are listed below. Request for additional information or copies of SP260 should be addressed to the Office of Standard Reference Materials, at the address shown in the Appendix.

Standard Reference Materials (SRM's)

Chemical Composition Standards

Steels (chip form): Plain carbon, low and high alloys, stainless and tool.

Steels (granular form): Special ingot irons, low alloy, stainless, speciality, high-temperature alloys, and tool.

Steelmaking Alloys

Cast Irons (chip form)

Cast Steels, White Cast Irons, Ductile Irons, and Blast Furnace Irons (solid form)

Nonferrous Alloys (chip form): Aluminum, cobalt, copper, lead, magnesium, nickel, nickel oxide, selenium, tin, titanium, zinc, and zirconium

Nonferrous Alloys (solid form): Copper, lead, nickel, tin, titanium, zinc, and zirconium

Gases in Metals

High-Purity Metals

Electron Probe Microanalytical Standards

Primary, Working, and Secondary Standard Chemicals

Microchemical Standards

Clinical Laboratory Standards

Biological Standards

Environmental Standards: Gases, liquids, solids, permeation tubes, and trace elements in fossil fuels

Industrial Hygiene Standards

Forensic Standards

Hydrocarbon Blends

Metallo-Organic Compounds

Fertilizers

Ores

Cements

Minerals, Refractories, Carbides, and Glasses

Trace Element Standards

Nuclear Materials: Plutonium and uranium assay and isotopic standards, neutron density standards, and fission track glass standards

Isotopic Reference Standards

Physical Property Standards

Ion Activity Standards: pH and pD standards, and ion selective electrodes

Mechanical and Metrology Standards: Coating thickness, glass, elasticity, density, and polymer

Heat Standards: Superconductive thermometric fixed point devices, freezing points, melting points, calorimetry, differential thermal analysis, vapor pressure, thermal conductivity, thermal expansion, thermocouple materials

Magnetic Standards: Magnetic susceptibility

Optical Standards: Spectrophotometry, thermal emittance, reflectance, refractive index

Radioactivity Standards: Alpha-particle, beta-particle, gamma-ray, and electron capture standards, contemporary standard for carbon 14 dating laboratories, environmental standards, low energy photon sources, and solution standards

Metallurgical

Mossbauer

X-Ray Diffraction

Permittivity

Reference Fuels

Resistivity

Engineering Type Standards

Standard Rubber and Rubber-Compounding Materials

Reference Magnetic Computer Tapes

Sizing Standards: Glass spheres for particle size, turbidimetric and fineness (cement)

Color Standards: The ISCC-NBS centroid color charts, light-sensitive papers, light-sensitive plastic chips

X-Ray and Photographic Standards

Surface Flammability Standards

Smoke Density Chamber Standards

Water Vapor Permeance

Internal Tearing Resistance Paper

Tape Adhesion Testing Standard

Research Materials (RM's)

High-Purity Materials, SEM Resolution Test Specimen, Phosphors

Special Reference (GM's)

Hydrogen in Steel, Nickel and Vanadium in Residual Oil, Cellular Plastics, and Absorbent Clay, (ASTM D2007)

Computer Programs for Metric Conversion

B. Proficiency Sample Programs

In 1936, the first reference sample program was initiated for cement as part of the NBS Research Associate Program of the Cement Reference Laboratory of the American Society for Testing and Materials (ASTM) Committee C-1. In 1966, this program was revised to essentially its present form wherein two pairs of samples for physical tests and two pairs of samples for chemical analyses are distributed each year. Similar programs for bituminous, soils, aggregates, and portland cement concrete and bituminous concrete were then established in rapid succession, the last in 1974. These programs are under the sponsorships of ASTM and the American Association of State Highway and Transportation Officials.

In 1969 a bimonthly collaborative reference program for paper and board testing was sponsored by the Technical Association of the Pulp and Paper Industry and a program for control of the quality of shipping container components was established for the Fourdrinier Kraftboard Institute. This latter program involves monthly reports but weekly testing by the participants. A quarterly program for the rubber industry was developed in 1970 with the help of ASTM Committee D011, and a color and appearance program, of interest to many industries and users, was sponsored by the Manufacturers Council on Color and Appearance. This quarterly program presently includes tests for gloss, color and color difference, and retroreflectivity.

More recently (1975) a thrice yearly program on flammability testing of children's sleepwear was developed for ASTM Committee D13.52, and a nonquantitative program on the identification of forensic materials is being conducted for the Justice Department and the Forensic Science Foundation.

Each field of testing has its special problems and each sponsoring organization its own goals. Hence, no two of the existing programs are identical, but each has been designed to meet the specific needs. Inquiries concerning the establishment of new programs are invited.

TAPPI Paper and Board (6 times per year)

Bursting strength, tearing strength, tensile breaking strength, elongation to break, tensile energy absorption, folding endurance, stiffness, air resistence, grammage, smoothness, surface pick strength, K&N ink absorption, pH, opacity, blue reflectance (brightness), specular gloss (75°), thickness, concora (flat crush), ring crush

FRBG Container Board (48 times per year)
Mullen burst of linerboard, concora test of medium

MCCA Color and Appearance (4 times per year)
Gloss at 60°, color and color difference, retroreflectivity

Rubber (4 times per year)
Tensile strength, ultimate elongation and tensile stress, hardness, mooney viscosity, vulcanization properties

ASTM Textiles (3 times per year)
Flammability (FF3-71 and FF5-74) (children's sleepwear)

ASTM Concrete (2 times per year)
Physical (4 characteristics)

AASHTO Bituminous
Asphalt cement (2 times per year), cutbacks (once a year)

AASHTO Aggregates (2 times per year)
Coarse (once a year); Fine (once a year)

C. National Voluntary Laboratory Accreditation Program

In a notice published in the Federal Register on February 25, 1976, (41 FR 8163-8168), the Secretary of Commerce promulgated procedures for the operation of a National Voluntary Laboratory Accreditation Program (NVLAP). As announced in that notice, the goal of this program is to provide in cooperation with the private sector a national voluntary system to examine upon request the professional and technical competence of private and public testing laboratories that serve regulatory and nonregulatory product evaluation and certification needs. The program will accredit those laboratories that meet the qualifications established under the mentioned procedures. Section 7.4(b) of those procedures sets out the requirements to be met by those persons who seek to have the Secretary find that there is a need to accredit testing laboratories which render services regarding a specific product so that it may be ascertained whether such product meets the requirements of applicable standards.

For additional information write to National Voluntary Laboratory Accreditation Program at the address given in the Appendix.

D. Standards Information Services

The Standards Information Services (SIS) maintains a reference collection of some 200,000 engineering standards issued by U.S. technical societies, professional organizations, and trade associations; State purchasing offices; U.S. civilian government agencies; and the major foreign national and international standardizing bodies. The collection is open to the public Monday through Friday from 8:30 a.m. to 5:00 p.m.

SIS publishes general and special indices of standards. Information services consists of responding to inquiries by searching Key-Word-In-Context (KWIC) Indices to determine whether there are any published standards, specifications, test methods, or recommended practices for a given item, product, or material. Inquirers are referred to the appropriate source to obtain copies of standards. SIS neither sells nor distributes standards.

Inquiries or requests for additional information should be directed to the address listed in the Appendix.

E. Standard Reference Data

The National Standard Reference Data System (NSRDS) is a nationwide program established to make critically evaluated data in the physical sciences available to the technical community. It publishes compilations of critically evaluated data, critical reviews and bibliographies. A complete listing of the publications of the NSRDS is available from the Office of Standard Reference Data (OSRD). The OSRD responds in a limited way to queries within the scope of the program by providing references, referrals, documentation, or data, as available. The program's monthly newsletter is available on request. Inquiries or requests for further information should be directed to the address listed in the Appendix.

F. Technical Publications

The Office of Technical Publications maintains a general correspondence and inquiry service on the technical activities of the National Bureau of Standards. Inquiries of a general nature and not covered by the services listed above should be directed to the address listed in the Appendix.

G. NBS Measurement Seminars

Each year NBS holds several measurement seminars and workshops. Participation is open to a limited number of persons from measurement and standards laboratories who meet appropriate prerequisites relating to education, work experience, and current professional activity. Seminars last from 1 to 5 days and comprise lectures, group discussions, and/or laboratory demonstrations. Names may be added to the mailing list for the seminar brochures by writing or telephoning the office listed in the Appendix.

INDEX

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Changes in Calibration and Measurement Services

As services are initiated or discontinued, or fees are changed, announcements will appear in the appendices of SP 250. If you wish to be placed on the mailing list to receive these updates as they are issued, please complete the post card below, detach it, and mail to the National Bureau of Standards.

If you have previously submitted a card to the Bureau, it is not necessary to furnish a duplicate card, unless your address has changed.

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Please place the foregoing name on your special mailing list to receive appendices of Special Publication 250, Calibration and Related Measurement Services of the National Bureau of Standards, as they are issued.

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NBS TECHNICAL PUBLICATIONS

PERIODICALS

JOURNAL OF RESEARCH—The Journal of Research of the National Bureau of Standards reports NBS research and development in those disciplines of the physical and engineering sciences in which the Bureau is active. These include physics, chemistry, engineering, mathematics, and computer sciences. Papers cover a broad range of subjects, with major emphasis on measurement methodology, and the basic technology underlying standardization. Also included from time to time are survey articles on topics closely related to the Bureau's technical and scientific programs. As a special service to subscribers each issue contains complete citations to all recent NBS publications in NBS and non-NBS media. Issued six times a year. Annual subscription: domestic $17.00; foreign $21.25. Single copy, $3.00 domestic; $3.75 foreign.

Note: The Journal was formerly published in two sections: Section A "Physics and Chemistry" and Section B "Mathematical Sciences."

DIMENSIONS/NBS

This monthly magazine is published 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.

Annual subscription: Domestic, $12.50; Foreign $15.65.

NONPERIODICALS

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 special 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 world-wide program coordinated by NBS. Program under authority of National Standard Data Act (Public Law 90-396).

NOTE: At present the principal publication outlet for these data is the Journal of Physical and Chemical Reference Data (JPCRD) published quarterly for NBS by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements available from ACS, 1155 Sixteenth St. N.W., Wash., D.C. 20056.

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 the 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. NBS administers this program as a supplement to the activities of the private sector standardizing organizations.

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