NIST PUBLICATIONS

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Ionizing Radiation

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NIST Calibration Services Users Guide 1998

J. L. Marshall, Editor

Calibration Program
Office of Measurement Services
Technology Services
National Institute of Standards and Technology
Gaithersburg, MD 20899-0001

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Foreword

The NIST Calibration Services Users Guide provides detailed descriptions of the NIST calibration services, special-test services, and measurement assurance programs currently available as of the fourth quarter of 1997. This revised edition of NIST Special Publication (SP) 250 reflects important changes in services since the last edition was published. A detailed description is given of each measurement service, and a large number of NIST technical experts are cited (who may be contacted for further information concerning services or measurement problems). The current edition will be published in hard copy and maintained on the Internet. See the Calibration Program's Web Site at: http://ts.nist.gov/calibrations

A Fee Schedule listing current prices for the services described in the Users Guide is published annually as NIST SP 250 Appendix. NIST will notify users of changes in services or proposed changes in services by means of announcements in the Fee Schedule and on the Internet. In addition, information about upcoming NIST Measurement Seminars will be announced in both locations. It is important that you refer to the current issue of the Fee Schedule or the Web site in order to have up-to-date information with respect to NIST contacts.

A companion document to this guide is NIST Special Publication 260, NIST Standard Reference Materials Catalog. This document describes 1,200 Standard Reference Materials (SRM's) certified by NIST for use in industrial quality control, materials testing, environmental testing, and clinical testing applications. A copy of SP 260 may be obtained by calling (301) 975-6776, or by faxing (301) 948-3730.

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

Sharrill Dittmann
Calibration Program

Abstract

The National Institute of Standards and Technology (NIST) Calibration Services Users Guide provides detailed descriptions of NIST calibration services, measurement assurance programs, and special-test services currently available. The following measurement areas are covered: (1) dimensional; (2) mechanical, including flow, acoustic, and ultrasonic; (3) thermodynamic; (4) optical radiation; (5) ionizing radiation; (6) electromagnetic, including dc, ac, rf, and microwave; and (7) time and frequency. A separate Fee Schedule (NIST Special Publication 250 Appendix) is issued annually, providing current prices for the services offered, updates on points-of-contact, and information on NIST measurement seminars. See also the most current information at the Internet Web Site: http://ts.nist.gov/calibrations

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

Acknowledgments

Many NIST staff members contributed to the development and preparation of this guide. Over 50 members of the NIST technical staff contributed data and information that have been incorporated into the guide. Special thanks go to John Mayo-Wells, Barry Taylor, and Simone Yaniv for their efforts. Joanne Marshall served as production manager and coordinated preparation of the Users Guide. Editorial and production assistance was provided by Carroll Brickenkamp and Dawn Geraci. General support was provided by Tracy Arnold, Paula Hewitt, Denise Lockard, and Ernest Garner of the Calibration Program Staff. The NIST Publication Production staff made many valuable suggestions and typeset the final draft.

Sharrill Dittman
Chief, Calibration Program

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Chapter 1

A. Introduction

The calibration services of the National Institute of Standards and Technology (NIST) are designed to help the makers and users of precision instruments achieve the highest possible levels of measurement quality and productivity. The services listed in this Guide constitute the highest order of calibration services available in the United States. They directly link a customer's precision equipment or transfer standards to national and international measurement standards. These services are offered to public and private organizations and individuals alike.

B. Types of Calibration Services

- Calibration Services
- Special Tests
- Measurement Assurance Programs (MAPs)

NIST provides Calibration Services using well-characterized, stable and predictable measurement processes. NIST calibrates instruments and devices that are metrologically suitable as reference or transfer standards.

Special Tests are either unique or seldom-performed calibrations or measurements requested by the customer.

Measurement Assurance Programs are quality control programs for calibrating a customer's entire measurement system. In a typical MAP, a stable artifact or set of artifacts, called transfer standards, are first measured by NIST and then sent to a customer's laboratory for a series of measurements. The transfer standards are then returned to NIST for remeasurement, along with the participating laboratory's data. NIST reports its comparative findings to the customer and, when necessary, offers guidance on achieving and maintaining measurement quality.

Successful use of a NIST MAP requires that the customer make periodic measurements of in-house check standards to estimate their measurement process uncertainty and to ensure that the measurement process remains in a state of statistical control. Unless a laboratory has a measurement quality assurance program to monitor its own measurement process parameters continuously, there is no value in participating in a MAP. In fact, NIST recommends that its customers establish and use a measurement quality assurance program to monitor their measurement parameters, whether or not they participate in a MAP.

C. Other NIST Measurement Transfer Services

National Voluntary Laboratory Accreditation Program (NVLAP)

NIST does not audit, or regulate metrology laboratories as part of MAP or other calibration services. Calibration laboratories and testing facilities may be accredited by NIST under the National Voluntary Laboratory Accreditation Program (NVLAP). The basic procedures and general accreditation requirements of NVLAP are described in NIST Handbook 150. A participating laboratory may voluntarily take steps to improve or assess its measurement process. For further information about NVLAP, contact:

National Voluntary Laboratory Accreditation Program (NVLAP)
National Institute of Standards and Technology
Building 820, Room 282
Gaithersburg, MD 20899-0001
Telephone: (301) 975-4016
E-Mail: NVLAP@nist.gov
Fax: (301) 926-2884
Internet: http://ts.nist.gov/nvlap

Standard Reference Materials Program (SRMP)

Calibration assistance and alternative paths for traceability are provided by NIST's Standard Reference Materials Program. For examples:

Chemical measurement instruments are not calibrated at NIST, but NIST provides various Standard Reference Materials (SRMs), some of which are used to calibrate chemical measuring systems.

Dimensional Measurements—NIST also provides several SRMs for calibrating instruments for dimensional measurements. These include socketed ball bars and probe performance spheres for coordinate measuring machines; surface roughness blocks to calibrate stylus instruments; powders and solids to calibrate particle size measuring instruments; and magnification, linewidth measurement, and optical fiber diameter standards for instruments such as scanning electron, optical, and video microscopes.

Sieves—NIST provides a series of SRMs for evaluating and calibrating various types of particle size measuring instruments, including light and electrical zone flow-through counters, optical and electron microscopes, sedigraphs, and wire cloth sieving devices.

Thermodynamic Property Measurements—NIST offers SRMs for calibrating instruments used to determine thermodynamic properties, such as enthalpy and heat capacity, heat of combustion, heat of solution, vapor pressure of metals, and thermal expansion and resistance. Also available are defining fixed points of the International Temperature Scale, ITS(90), melting points, triple points, secondary temperature reference points, thermocouples and thermometers.

Liquid Densitities—NIST offers SRMs of certified density for the determination of liquid densities.

Photometric Measurements—In addition to calibrations and special tests, NIST also offers SRMs for spectrophotometry, including diffuse transmittance (photographic step tablets).

For further information about SRMs, contact:

Standard Reference Materials Program (SRMP)
National Institute of Standards and Technology
Building 202, Room 204
Gaithersburg, MD 20899-0001
Telephone: (301) 975-6776
E-Mail: SRMINFO@nist.gov
Fax: (301) 948-3730
Internet: http://ts.nist.gov/srm

Standard Reference Data Program (SRDP)

Very few calibrations can be conducted without quantitative information related to measurements of physical or chemical properties. NIST develops and publishes evaluated data for technical and scientific applications called Standard Reference Data (SRD). For further information about SRD, contact:

Standard Reference Data Program (SRDP)
National Institute of Standards and Technology
Building 820, Room 113
Gaithersburg, MD 20899-0001
Telephone: (301) 975-2208
E-Mail: SRDATA@nist.gov
Fax:(301) 926-0416
Internet: http://www.nist.gov/srd

Weights and Measures Program (OWM)

The NIST Office of Weights and Measures (OWM) provides measurement services to State and local governments responsible for marketplace transactions involving measurements. State weights and measures laboratories provide alternative sources for calibration services in mass, length, volume, and certain other measurement areas. For further information about OWM, contact:

Office of Weights and Measures (OWM)
National Institute of Standards and Technology
Building 820, Room 232
Gaithersburg, MD 20899-0001
Telephone: (301) 975-4004
E-Mail: jkoenig@nist.gov
Fax: (301) 926-0647
Internet: http://www.nist.gov/owm

D. Criteria for Quality Assurance

All the measurement services listed in this document meet rigorous criteria for quality assurance. Calibration Services and MAPs satisfy the most demanding and explicit requirements in that they are carried out regularly under pre-established and well-defined conditions; the measurement processes are well-characterized, stable, and statistically controlled; and quality-control procedures are well-defined and strictly followed. Furthermore, each Calibration Service or MAP is planned and documented to provide continuity of service over time.

A Special Test is so designated for one or more of the following reasons: (1) the specific type of calibration is seldom requested, thus precluding the maintenance of a large statistical base for characterizing the measurement process; (2) the requested test is unique; or (3) the service is still under development—meaning the measurement or calibration methods are still being perfected, or the quality-control documentation has not all been completed.

E. Fees

NIST recovers the costs of calibration services by charging a fee for each calibration performed. These fees range from a low of several hundred dollars to calibrate a laboratory thermometer to $75,000 or more for special tests of large microwave antenna systems.

The costs of services are published in the Fee Schedule (NIST SP250 Appendix), which is updated and published annually to reflect changes in prices and services. Even so, the cost of many services may vary according to your exact calibration specifications; you must therefore provide the technical contact with an exact description of work before receiving a price quote. Please refer to Section L of this Chapter for information on obtaining a copy of the current Fee Schedule or Users Guide.

NOTE: Fees for NIST services do not include shipping costs or insurance.

F. Reports of Calibration/ Test Results

Reports on calibrations or other services are the property of the customer. Copies are supplied to other parties only as required by Federal law or requested in writing by the customer. The results of calibrations and tests performed by NIST apply only to the specific instrument or standard at the time of test unless otherwise clearly stated.

G. Traceability

The International Vocabulary of Basic and General Terms in Metrology (VIM; 1993) defines traceability as:

> The property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.

Many government regulations and commercial contracts require regulated organizations or contractors to verify that the measurements they make are "traceable" and to support the claim of traceability by keeping records that their own measuring equipment has been calibrated by laboratories or testing facilities whose measurements are part of this "unbroken chain." The purpose of requiring traceability is to ensure that measurements are accurate representations of the specific quantity subject to measurement, within the uncertainty of the measurement.

NIST reports calibration results, with the measurement values accompanied by the uncertainties associated with the methods, operators, and environment at NIST. Users of these calibration services make their own measurements with the calibrated instruments or artifacts. In addition to the uncertainty indicated by

NIST, other uncertainties are inherent in the instrument, associated with the method or protocol in using the instrument, with the operator of the instrument, and with the physical environment (pressure, temperature, humidity, etc.) in which the measurements are made. Thus, the measurements made with the calibrated instruments or artifacts by organizations outside NIST have associated total uncertainty budgets, only one component of which is the uncertainty reported by NIST.

NIST often receives calls to verify the authenticity of a NIST Report of Test number appearing on another organization's report. Although NIST can verify the authenticity of its report numbers, the number itself does not provide complete assurance or evidence that the measurement value provided by another organization is traceable. Not only should there be an unbroken chain of comparisons, each provided measurement should be accompanied by a statement of uncertainty associated with the farthest link in the chain from NIST, that is, from the facility providing the most recent measurement value. NIST does not have that information; only the facilities that provided the measurement values to the customer can provide the associated uncertainties and describe the traceability chain.

In summary, to adequately establish an audit trail for traceability, a proper calibration result must include: the assigned value, a stated uncertainty, identification of the standards used in the calibration, and the specification of any environmental conditions of the calibration where correction factors should be applied, if the standard or equipment were to be used under different environmental conditions.

NIST does not define nor enforce traceability except in its NVLAP laboratory accreditation program. Moreover, NIST is not legally required to comply with traceability requirements of other Federal agencies, nor do we determine what must be done to comply with another party's contract or regulation calling for such traceability. However, NIST can and does provide technical advice on making measurements consistent with national standards.

Although NIST supports making the user aware of traceability and provides the user with details as to how traceability is established, NIST does not allow the prominent display of its name on proprietary products or in the advertising of them. (See Section J).

H. NIST Policy on Reporting Measurement Uncertainty

To ensure that NIST uncertainty statements are consistent across the organization and with international practice, NIST policy requires that all NIST measurements be accompanied by statements of uncertainty as discussed in NIST Technical Note 1297.[1] This publication is based on the approach to expressing uncertainty in measurements recommended by the International Committee on Weights and Measures (CIPM).[2] That committee established general rules for evaluating and expressing uncertainty in measurements that are intended to be applicable to a broad spectrum of measurements. Copies of NIST TN 1297 are available upon request (see Section L) or on the web site at:

http://physics.nist.gov/Pubs/guidelines/contents.html

Throughout this publication, uncerntainties are expressed as standard uncertainties or expanded uncertainties. Standard uncertainties have a coverage factor, k, of 1, and denote a level of confidence of approximately 68 %. Unless noted otherwise, a coverage factor, k, of 2 (95 % confidence level) applies to any expanded uncertainty provided in this guide. The expanded uncertainties are exactly twice as large as the standard uncertainties.

[1] Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, NIST Technical Note 1297, 1994 Edition.
[2] Guide to the Expression of Uncertainty in Measurement, International Standards Organization (ISO), 1993 Edition.

The uncertainty of a measurement consists of two categories of components: "Type A" are those uncertainties evaluated by statistical methods, and "Type B" uncertainties are evaluated by other means, usually scientific judgment using all relevant information such as previous data, or experience with materials or instrument behaviors. Some sections of this Guide discuss and list the components of uncertainty associated with the measurements.

I. NIST Policy Regarding Use of Metric (SI) Units

In accordance with the Metric Conversion Act of 1975 as amended by Section 5164 of the Omnibus Trade and Competitiveness Act of 1988 and as required by related provisions of the Code of Federal Regulations, the National Institute of Standards and Technology (NIST) uses the modern metric system of measurement units (International System of Units—SI) in all publications. When the field of application or the special needs of users of NIST publications require the use of non-SI units, the values of quantities are first stated in the SI units and the corresponding values expressed in non-SI units follow in parentheses. Copies of NIST SP 811[3] are available upon request (see Section L) or on the web site at:

http://physics.nist.gov/Pubs/SP811/sp811.html

J. References to NIST in Advertisements

The NIST measurement or test results or reports shall not be used to indicate or imply that NIST approves, recommends, or endorses the manufacturer, supplier, or user of any instruments or standards or that NIST in any way guarantees or predicts the future performance of items after calibration or test. No reference shall be made to NIST or to reports or results furnished by NIST in any advertising or sales promotions which might indicate or imply that NIST approves, recommends, or endorses any proprietary product or proprietary material.

[3] Guide for the Use of the International System of Units (SI), NIST Special Publication 811, 1995 Edition.

K. Disclaimer

Commercial products, materials, and instruments, are identified in NIST communications and documents for the sole purpose of adequately describing experimental or test procedures. In no event does such identification imply recommendation or endorsement by NIST of a particular product; nor does it imply that a named material or instrument is necessarily the best available for the purpose it serves.

L. Questions and Inquiries

This Users Guide and the Fee Schedule (SP250 Appendix) are intended to make the task of selecting and ordering an appropriate calibration service as quick and easy as possible. Nevertheless, when questions arise you should contact NIST for immediate clarification.

General inquiries about the NIST calibration services, assistance in determining the availability of services, and requests for complimentary copies of the Calibration Services Users Guide, the Fee Schedule, Guide for the International System of Units (SP 811), and Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results (TN 1297) may be addressed to:

Calibration Program
National Institute of Standards and Technology
Building 820, Room 236
Gaithersburg, MD 20899-0001
Telephone: (301) 975-2002
Fax: (301) 869-3548
E-Mail: calibrations@nist.gov

Visit the NIST Calibration Program Web Site on the Internet:

http://ts.nist.gov/calibrations

For technical questions concerning a specific service, contact the NIST staff member responsible for that calibration area. Consult the section of the Users Guide or Fee Schedule that lists the service in question for names, addresses, e-mail and telephone numbers.

Chapter

2

A Customer Inquiries

B Prearrangements and Scheduling

C Purchase Orders

D Shipping, Insurance, and Risk of Loss

E Turnaround Time

F Customer Checklist

Ordering Instructions—Domestic Customers

A. Customer Inquiries

General customer inquiries for information or clarifications about the NIST calibration services may be directed as indicated in Section L of Chapter 1.

B. Prearrangements and Scheduling

Services should be arranged in advance, beginning with direct contact with a NIST technical staff member responsible for the desired service. Use the appropriate technical section of the Users Guide or Fee Schedule to determine whom to contact. This advance communication may answer your questions, clarify the policies and procedures briefly described here, and will permit you to schedule a tentative calibration date. Following the initial communication, you must complete and submit a purchase order and prepare to ship the item according to the procedures described below or agreed upon with the technical contact. If a calibration is scheduled far in advance, the item should not be shipped until shortly before the scheduled date; you must submit the purchase order (complete with the name and number of the desired service) before a firm calibration date can be assigned. When NIST receives your purchase order and assigns a firm service date, your order will be confirmed by the technical contact.

C. Purchase Orders

Before you ship an item for calibration, send a purchase order to the address listed in the appropriate technical section of the Users Guide or Fee Schedule. The purchase order must:

1) State both the name and number of the NIST service (listed in this Guide as the "Service ID Number") being requested. FAILURE TO INCLUDE THE ORDER NUMBER WILL SERIOUSLY IMPEDE SCHEDULING AND SERVICE.
2) Clearly identify the item(s) being sent for calibration, including any serial number(s) or model number(s).
3) Give the name, address, and telephone number of your company's procurement officer, purchasing agent or other administrative/financial authority.
4) Give the name, address, and telephone number of your company's technical contact, if different from above.
5) List separately the instructions and address for return shipment, insurance, mailing address for the calibration/test report, and billing address. (Federal or State agency requests for calibration services should be accompanied by a document authorizing that the cost of the service be billed to the agency.)
6) Clearly state any special or necessary conditions of test—such as operating frequency or temperature.
7) Clearly state your customer identification number; i.e., social security number (EIN) for individuals; tax identification number (TIN) for organizations; or agency location code (ALC) for government customers.
8) If the calibration or test report is to be handled in a special manner, give instructions on the purchase order.

NOTE: Receipt of orders by NIST does not imply acceptance of any provisions set forth in the order that are contrary to the policy, practice, or regulations of NIST or of the U.S. Government. In general, NIST will not sign any affidavits, acknowledgment forms, or other documents required by company policy governing the procurement of goods and services.

D. Shipping, Insurance, and Risk of Loss

Ship the instrument or standard to the mailing address of the technical group providing the service. Please note that the mailing address is not the same for all technical groups.

Please adhere rigorously to the following procedures:

1) Ship only items in good repair. Apparatus in disrepair will not be calibrated. If defects are found after calibration has begun, the procedure will be terminated, a report issued, and a charge levied for work completed.
2) Use strong, reusable packing materials and containers marked clearly and indelibly on the outside with the requestor's name, address, and the following notation: REUSABLE CONTAINER, DO NOT DESTROY.
3) Follow any special shipping procedures given in the technical sections of this Guide, particularly those sections covering radiation and dosimetry measurements.
4) Insure the shipments to and from NIST and clearly state the method of return shipment. NIST will not assume liability for loss or damage, unless such loss and damage result solely from the negligence of NIST personnel. If return shipment by parcel post is requested or is suitable, NIST will prepay the return shipment but will not insure it. When no shipping or insurance instructions are furnished, NIST will return the shipment by common carrier, collect and uninsured.
5) Shipments to NIST must be at FOB destinations. (Customer pays for shipping.)
6) Return shipments are sent FOB origin. (Customer pays for shipping.)

NOTE: Fees for NIST services do not include shipping costs.

E. Turnaround Time

The normal turnaround time for NIST calibration services varies greatly—usually from several weeks to several months depending on the type of service requested and the service schedule. Some services are scheduled only once or twice a year, with appointments made months in advance of the service date. To avoid unnecessary scheduling or administrative delays in the calibration process, always make arrangements with the technical contact for the service you wish to utilize prior to shipping your instrument or artifact to us.

F. Customer Checklist

Please refer to the next page in this chapter for a Customer Checklist which is intended to assist you in developing the basic information required to process an order for calibration services at NIST.

Customer Checklist for Ordering NIST Calibration Services

Information Obtained from NIST Technical Contact	Comments
NIST Contact (name/telephone)	Provide this information on your purchase order (po)
Is the service available?	Please make sure customer's technical contact discusses service with NIST technical contact before proceeding.
NIST Service Identification Number	Provide this information on your po
Estimated cost of services	Provide this information on your po
Estimated turnaround time	Many calibration services are batched. Find out when to send the instrument.
Special instructions	
Packaging instructions	
Shipping instructions	
Other precautions	
Information Supplied by the Customer on Purchase Order	
Purchase order number	
Purchase order date	
Customer's tax identification number	
Customer's mailing address	
Customer's billing address	
Name, telephone number, fax number, e-mail address of administrative or procurement contact point at customer's location	
Name, telephone number, fax number, e-mail address of technical contact point at customer's location	
Ship-to address (including NIST technical contact name)	
Return address (for shipment back to customer)	
NIST Service Identification Number	
Estimated cost	
Shipping terms (no FOB destination on return shipment)	
Special instructions from customer's technical contact	

Chapter 3

Special Instructions—Foreign Customers

A. Foreign Inquiries

Foreign customers should address all inquiries to:

Calibration Program
National Institute of Standards and Technology
Building 820, Room 236
Gaithersburg, MD 20899-0001
United States of America
Telephone: (301) 975-2002
Fax: (301) 869-3548
E-mail: calibrations@nist.gov

Visit the NIST Calibration Program Web Site on the Internet:

http://ts.nist.gov/calibrations

NOTE: Please clearly indicate your **city** and **country** on all correspondence so that we may promptly respond to your request.

B. Criteria for Providing Service

NIST is authorized to provide measurement services, including calibration services, for organizations or individuals located outside the United States. The Calibration Program must review each request for calibration services to determine if services are available in the requestor's country. Foreign customers may be asked to provide a written justification stating why NIST should perform this service if an official standards laboratory in the requestor's country can provide the requested service(s). Foreign customers must provide the following information, in writing, to the Calibration Program (see address above):

1. Identification of the item(s) to be calibrated, including serial and model numbers.
2. A detailed description of the measurements that are needed, or indicate the service identification number as given in this Guide (NIST SP250) or the Fee Schedule (NIST SP250 Appendix).
3. A description of any special requirement/circumstance that might affect the decision to provide the service. For example, will adjustments have to be made to the instrument, or will the time period be restricted in which the device is available for calibration?

C. Special Instructions

If the request for calibration service is accepted by NIST, the requesting organization will be notified of the cost of service and will be given the NIST technical staff contact that will perform the measurements. The requesting organization must then complete the following steps:

1. Contact the NIST technical staff that will perform the service to determine the time schedule.
2. Send a purchase order to the Calibration Program. Provide complete addresses, including country, for returning the instrument and for mailing the calibration or test report.
3. NIST policy requires prepayment for all NIST calibration services requested by non-U.S. organizations. Before proceeding with any service(s) we will need a check, money order or a bank wire transfer. The prepayment must be for the full amount and be drawn on a U.S. bank. The prepayment methods are as follows:

Money Orders & Prepayment Checks

Checks made payable to the National Institute of Standards and Technology (NIST) should be mailed to:

National Institute of Standards and Technology
Calibration Program
Building 820, Room 236
Gaithersburg, MD 20899-0001

Bank Wire Transfers

Federal Reserve Bank of New York
33 Liberty Street
New York, NY 10045
Phone: (212)720-5330
ABA#021030004
Account # 13060001
Account Name: Treas NYC/CTR/
BNF=/NIST/AC-13060001

Reference "Calibrations" so it will enable us to identify your payment. In addition, please be sure to pay any fees assessed for your bank wire transfers; otherwise, they will deduct it from your prepayment wire.

PLEASE NOTE: Our account number and name are of critical importance and must be referenced in order for NIST to be properly credited with your payment. It must appear in the precise manner shown to allow for the automated processing and classification of the funds transfer message. Questions on bank wiring can be directed to Randy Angleberger at (301) 975-2694, or E-Mail: randy.angleberger@nist.gov

4. Before shipping the instrument or standard to the appropriate NIST technical unit, you must arrange with a customs broker for entry of the instrument into the U.S. with transportation from the port of entry to NIST prepaid. Air freight is most satisfactory. Entry bond is required for instruments not manufactured in the U.S. If arrangements are made with a broker in the country of origin, that broker should, in turn, have a U.S. customs broker in or near the port of entry to arrange for the entry of the instrument and its transportation to NIST. Direct arrangements can be made with customs brokers located in the Washington, DC/Baltimore, Maryland, metropolitan area or in the Denver, Colorado, area, as appropriate. These brokers must arrange for transportation to the port of exit after testing/calibration has been completed.

D. Shipping Charges

The calibration fees quoted *do not* include shipping, insurance, or the services of a customs broker. You must arrange and pay for these services separately. For your information, NIST currently uses the following customs brokers:

Gaithersburg, Maryland
Laing International
P.O. Box 16144
Washington, DC 20041
Phone: (703) 471-9279
Fax: (703) 471-8436

Boulder, Colorado
G. L. Gumbert
4725 Paris Street, Suite 200
Denver, CO 80239
Phone: (303) 371-9550
Fax: (303) 373-0850

You are not required to use these customs brokers, but may select a broker of your choice.

Chapter

4

A Length Measurements

B Diameter Measurements

C Complex Dimensional Standards

D Optical Reference Planes and Roundness Standards

E Angular Measurements

F Laser Measurements

G Surface Texture

H Hydrometers

I Volume and Density

A. Length Measurements*

A.1 Gage Blocks

Technical Contacts:

Eric S. Stanfield
Tel: 301/975-3471
email: eric.stanfield@nist.gov

Howard H. Harary
Tel: 301/975-3485
email: hharay@nist.gov

Mailing Address: Building 220, Room B113, National Institute of Standards and Technology, Gaithersburg, MD 20899-0001

Service ID No.	Items
10010C	Gage Blocks

Gage Blocks (10010C)

This calibration service provides for measurement of the length of gage blocks by either mechanical comparison to NIST master gage blocks or by direct interferometry. Generally, the length is transferred from known master blocks by a systematic intercomparison procedure using mechanical comparators.

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 against both corrosion and damage by contact with other gage blocks. All defining steel surfaces should be greased and 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 likely to corrode. Sets of gage blocks should have packing inside the case and the case should be bound shut, since the clasps on cases frequently open or break during shipment.

Square or rectangular blocks up to 500 mm (20 in) long are routinely calibrated and the lengths reported in English or metric units. For blocks longer than 500 mm (20 in), the NIST technical contact should be consulted in advance to discuss alternative measurement techniques, approximate costs, and scheduling.

The reported measurement uncertainty** depends on the length of the blocks. For blocks near 2 mm (0.1 in), the expanded uncertainty** is approximately 25 nm. The uncertainty is larger for blocks significantly longer or shorter than 2 mm. A report describing the NIST gage block laboratory measurement assurance process is sent to all new customers or on request to past customers.

References—Gage Blocks

The Gage Block Handbook, T. Doiron and J. S. Beers, NIST Monogr. 180 (1995).

Drift Eliminating Designs for Non-Simultaneous Comparison Calibrations, T. Doiron, J. Res. Natl. Inst. Stand. Technol. **98** (2), 217–224 (1993).

A Gage Block Measurement Process Using Single Wavelength Interferometry, J. S. Beers, Natl. Bur. Stand. (U.S.), Monogr. 152 (1975).

* See Chapter 1, Section C for information on dimensional measurement artifacts available through the Standard Reference Materials Program.

** See Chapter 1, Section H for more information about uncertainty.

A. Length Measurements
A.2 Line Standards

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Service ID No.	Items
10020C	Line Standards

Line Standards (10020C)

Line scales are calibrated on an instrument called a Line Scale Interferometer (LSI). The NIST LSI consists of a scanning electro-optical line detector, a high precision one-axis motion system, and a high accuracy heterodyne interferometer for determining the displacement of the test artifact beneath the line detector. The wavelength of a stabilized helium-neon laser corrected for temperature, humidity, and atmospheric pressure is used as the length standard. The instrument is housed in a temperature controlled chamber in which all environmental properties are carefully monitored.

The minimum line spacing on a line standard is 1 μm and the maximum line spacing of 1 m can be measured on this instrument. The line width can be varied from 1 μm to 100 μm, 2 μm to 10 μm being optimum. The maximum overall length of a line standard should not exceed 1020 mm, and the maximum width of any part of the standard should not exceed 150 mm.

The accuracy of the calibration of a line standard depends significantly on the shape and optical properties of the graduation lines, the background, and the flatness of the graduated surface. The accuracy of the calibration will be optimum if the lines are uniform, have straight parallel edges, uniform reflectivity, are 2 μm to 10 μm wide and are between 20 μm to 100 μm long, if there is good contrast between the line and the background, and if the graduated surface of the artifact is flat within 10 μm. Expanded uncertainties* of 1nm can be achieved for intervals of 1 mm or less. For intervals of about 1 m, standard uncertainties* of 50 nm can be achieved.

References—Line Standards

NIST Length Scale Interferometer Measurement Assurance, J. S. Beers and W. B. Penzes, Natl. Inst. Stand. Technol., NISTIR 4998 (Dec. 1992).

Length Scale Measurement Procedures at the National Bureau of Standards, J. S. Beers, NBSIR 87-3625 (1987).

* See Chapter 1, Section H for more information about uncertainty.

A. Length Measurements
A.3 Surveying Tapes

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Service ID No.	Items
10030C	Surveying and Oil Gaging Tapes
10040S	Special Tests of Surveying Leveling Rods

Surveying and Oil Gaging Tapes (10030C)

The calibration of surveying tapes and oil gaging tapes is carried out in a laboratory that houses two permanent working standards, a laser interferometer, and a 50 m (200 ft) stainless steel bench. For the most part, measurements are performed using a laser system that is referenced against a cube-corner retroreflector attached to a microscope, which is used manually for line location. The laboratory is maintained at 20 °C, but a control system can vary the chamber temperature from 15 °C to 40 °C for special tests. Calibration of tapes will normally be made with the tape under tension and supported on a horizontal flat surface. Unless otherwise requested, the total length and each 15 m or 50 ft subinterval will be measured and reported. Each interval calibrated on a surveying tape will have computed lengths for two (single catenary), three, four, and five equidistant points of support.

The laser standard is capable of calibrating tapes with scribed graduations with a relative expanded uncertainty* of 2×10^{-6}. Calibrations made with respect to the stainless steel tape bench are normally reported with a relative expanded uncertainty of 10×10^{-6}. A NIST serial number will be engraved on each calibrated tape for identification.

Special Tests of Surveying Leveling Rods (10040S)

Leveling rods are currently calibrated using either of two methods. One method involves the comparison of the rod to a 3 m standard at the intervals of 1 m, 2 m, and 3 m (Other intervals can be accommodated.). A second system provides automated measurement at multiple intervals and automatic report generation. Both systems incorporate a 7 m one-dimensional measuring machine with a helium-neon laser interferometer interfaced to a minicomputer. The automated system uses a motorized carriage and a photoelectric microscope for automatic edge detection of the graduations. Measurements can be made on virtually any type of linear scale or leveling rods with scribed, engraved, or painted graduations. The expanded uncertainty* for high-quality new Invar leveling rods is 50 μm and 100 μm for used rods. Current studies suggest that these may be lowered in the future to near 20 μm and 50 μm, respectively. The length of intervals will be reported as measured at 25 °C unless otherwise requested. The report can be supplied in either written or digital form.

* See Chapter 1, Section H for more information about uncertainty.

A. Length Measurements
A.4 Other Length Standards

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Service ID No.	Items
10050S	Special Tests of Length Standards

Special Tests of Length Standards (10050S)

Measurements on end standards with spherical ends, gage blocks of unusual shape or exotic materials, or measurement of standards between* 24 in and 240 in can sometimes be done, but agreement with the technical contact should be made before sending material.

* This is a special test when customer requests characterization in inches rather than SI units.

A. Length Measurements
A.5 Sieves*

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Service ID No.	Items
10060S	Special Tests of Sieves

Special Tests of Sieves (10060S)

Sieves are tested using a high accuracy optical projector. The average wire diameter of both the warp and shoot wires are determined by measuring 20 or more wires at five different positions along the diameter of the sieve. The average opening is found by measuring the average pitch of the wires and subtracting the average wire diameter. These results are compared with the tolerances in the ASTM E-11 specifications. The frame dimensions are also checked.

*See Chapter 1, Section C for information on calibration materials available from the Standard Reference Materials Program.

A. Length Measurements

A.6 Algorithms Testing and Evaluation Program for Coordinate Measuring Systems

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Service ID No.	Items
10070S	Special Test of CMS Software: NIST-Generated Data Sets (Basic Service)
10071S	Special Test of CMS Software: NIST-Generated Data Sets (Per Geometry Evaluated)
10080S	Special Test of CMS Software: Customer-Generated Data Sets (Basic Service)
10081S	Special Test of CMS Software: Customer-Generated Data Sets (Per Geometry Evaluated)

General Information (10070S–10081S)

The Algorithm Testing and Evaluation Program for Coordinate Measuring Systems (ATEP-CMS) evaluates the performance of data analysis software used in coordinate measuring systems (CMSs). Tested software is treated as a filter that transforms point coordinate data into feature parameters according to a defined transfer function. NIST evaluates the accuracy of the filter under conditions typical of those found in industrial practice. NIST independently compares the output of the software under test to predetermined corresponding reference values. NIST uses orthogonal-distance least squares algorithms and supports the following geometry types: circle, line, plane, sphere, cylinder, cone and torus. In the Special Tests, the reported measurement uncertainty is determined by the effects of computational roundoff and convergence settings used to generate the reference fits, the propagation of these effects through the comparison algorithms, and sampling uncertainty due to the number of data sets used to perform the test.

Special Test of CMS Software: NIST-Generated Data Sets (10070S–10071S)

The customer and NIST will agree on general guidelines for determining the ranges of parameters (geometry types, form errors, measurement errors, sampling plans) to be used in defining the customer's test experiments.
NIST then provides the customer with NIST-generated data sets based on these guidelines. The customer produces fit results from their data analysis software using the NIST-generated data sets. NIST generates fit results from the same data sets using the ATEP-CMS reference algorithms. The two sets of fit results are then compared by NIST. NIST then provides the customer with a Report of Special Test containing results of the test and the combined standard uncertainty.

Special Test of CMS Software: Customer-Generated Data Sets (10080S–10081S)

NIST receives customer-generated data sets and corresponding fit results from the data analysis software to be tested. NIST then generates fit results from the same data sets using the ATEP-CMS reference algorithms. The two sets of fits are then compared by NIST. NIST then provides the customer with a Report of Special Test containing results of the test and the combined standard uncertainty.

References—Algorithm Testing and Evaluation Program for Coordinate Measuring Systems

Methods for Performance Evaluation of Coordinate Measuring System Software, ASME B89.4.10-199x, ASME, New York, NY (1997).
Algorithm Testing and Evaluation Program for Coordinate Measuring Systems: Testing Methods, C. Diaz, Natl. Inst. Stand. Technol., NISTIR 5686 (1995).
Evaluation of Software for Coordinate Measuring Systems, C. Diaz and T. Hopp, Proc. Of the 1995 SME Clinic, CMMs Week, June 5-8, Soc. of Manuf. Eng., Dearborn, MI; also in Proc. Of the 1995 Interface Symp., June 21-24, Interface Foundation of North America, Carnegie Mellon Univ., Pittsburgh, PA (June 1995).
Testing Coordinate Measuring Systems Software, C. Diaz and T. H. Hopp, Proc. 1994 Natl. Conf. Stand. Lab. Ann. Workshop and Symp. (Aug. 1994).
Concept for an Algorithm Testing and Evaluation Program at NIST, C. Diaz, Natl. Inst. Stand. Technol., NISTIR 5366 (Jan. 1994).
Computational Metrology, T. H. Hopp, Manufacturing Review **6** (4), 295–304, ASME, NY (1993).

B. Diameter Measurements

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Service ID No.	Items
11010S	Special Tests of Cylindrical Diameter Standards (i.e., Plug and Pin Gages)
11020C	Measuring Wires for Threads and Gears
11030S	Special Tests of Spherical Diameter Standards: Balls
11040S	Special Tests of Internal Diameter Standards: Ring Gages
11050S	Special Tests of Length and Diameter
11060S	Special Tests of Step Gages

Special Tests of Cylindrical Diameter Standards (i.e., Plug and Pin Gages) (11010S)

Plain plug gages (not threaded) are calibrated using a laser-interferometer-based micrometer. The uncertainty of the diameter is dependent on the geometry of the artifact, particularly the roundness. Please consult the technical contacts listed above about auxiliary measurements needed to assure a satisfactory level of accuracy.

Measuring Wires for Threads and Gears (11020C)

This service provides for measurement of the diameter of thread and gear measuring wires by either comparison to NIST master wires or absolute calibration with a laser-interferometer-based micrometer. Both types of calibrations are carried out under a measurement assurance program based on the measurement of control wires.

All measuring wires submitted for test should be in substantially new condition, each wire should be appropriately bottled, and the bottle should be labeled with an identification number. In shipping wires, extreme care should be taken to prevent corrosion; all wires should be properly greased and their bottles rigidly contained inside an appropriate packing case.

Thread measuring wires for 60° and 29° threads are tested for compliance with the latest specifications in commercial use. These wires are calibrated, and the deformed diameter under standard conditions (as called out in the H28 Screw Thread Standard) are reported.

The primary elements of uncertainty are based on the reproducibility of the check standards and estimates of the uncertainty in the deformation corrections. For wires in good condition the expanded uncertainty* is 0.10 μm (4 μin).

Special Tests of Spherical Diameter Standards: Balls (11030S)

Ball diameters are determined from multiple comparisons in random orientations with either NIST master balls or calibrated gage block stacks. The ball diameter reported is the undeformed size as calculated with the Hertz relations. For calibrations at a specific orientation or with roundness traces to reduce the geometric components of uncertainty, the technical contact listed should be contacted before the calibration is submitted.

Special Tests of Internal Diameter Standards: Ring Gages (11040S)

Ring gages are calibrated by mechanical comparison to a calibrated gage block stack. The gage block stack is calibrated by multicolor interferometry to minimize the uncertainty due to wringing and geometry variations in the stack. The diameter is measured at one marked orientation. The technical contact listed should be consulted about calibrations needed in different orientations or roundness traces needed for a fuller determination of the ring geometry, if needed.

* See Chapter 1, Section H for more information about uncertainty.

Special Tests of Length and Diameter (11050S)

NIST has a wide variety of state-of-the-art metrology equipment and can provide services associated with dimensional quality control as special tests. A three-dimensional measuring machine is available for calibration of two- and three-dimensional ball plates, two-dimensional grid plates, and other artifacts of complex shape. Please consult with the technical contacts listed.

Special Tests of Step Gages (11060S)

Step gages having flat parallel faces can be measured in lengths up to 1.2 m (60 in). These tests are performed at the NIST Gaithersburg site or at the DOE Y-12 plant in Oak Ridge, TN. All of these calibrations are made under the metrological control of the Dimensional Metrology Group and use NIST calibrated check standards in a Measurement Assurance Program.

References—Diameter Measurements

Federal Standard H-28, Screw Thread Standards for Federal Services, English and metric versions. These handbooks are available from the General Services Administration (GSA).

American National Standard B1.2, ANSI, New York.

On the Measurement of Thread Measuring Wires, B. N. Norden, Natl. Bur. Stand. (U.S.) Report 10987 (Jan. 1973).

Measurements of Cylindrical Standards, R. C. Veale, Natl. Bur. Stand. (U.S.), NBSIR 73-136 (1973).

On the Compression of Cylinders in Contact with a Plane Surface, B. Norden, Natl. Bur. Stand. (U.S.), NBSIR 73-243 (1973).

C. Complex Dimensional Standards

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Service ID No.	Items
12010C	API Threaded Plug and Ring Gages
12020S	Special Tests of Threaded Plug and Ring Gages
12030S	Special Tests of Two Dimensional Gages
12040S	Special Complex Dimensional Tests, by Prearrangement

API Threaded Plug and Ring Gages (12010C)

NIST provides calibration and certification services for API threaded plug and ring gages, casing, tubing and line pipe plug and ring gages, and sucker rod gages. NIST is the custodian of the American Petroleum Institute (API) Grand Master rotary thread gages. These Grand Master gages are maintained and have been recalibrated at NIST for more than 60 years. They can be considered an international standard since all API Regional Master Gages throughout the world are referenced to NIST. Foreign product manufacturers can have their Reference Master Gages calibrated by NIST or by one of the other national standard laboratories listed below:

National Physical Laboratory, Teddington, England

National Research Laboratory of Metrology, Ibaraki, Japan

National Measurement Laboratory, Lindfield, N.S.W., Australia

Laboratory National d'Essais, Paris, France

Instituto Nacional de Technologia Industrial, Buenos Aires, Argentina

National Institute of Metrology, Beijing, People's Republic of China

As required, the API laboratory is temperature controlled at 20 °C. Parameters measured for plug gages are length of plug, taper, pitch diameter, major diameter, thread lead, lead and following thread half-angles, depth of thread, pitch line width, and radius of curvature.

Parameters measured for ring gages are length of ring, taper, thread lead, minor diameter, lead and following thread half-angles, counter bore, depth of thread, pitch line width, radius of curvature, and standoff.

Elements of rotary gages, buttress gages, extreme line casings, and large casing and tubular gages are measured on a coordinate measuring machine with an expanded uncertainty* of 2.5 μm (0.0001 in) for diameters under 254 mm, increasing to 5.0 μm (0.0002 in) as the gage diameter increases to 500 mm. Profile measurements are made on a contour tracing machine with an expanded uncertainty of 12.5 μm (0.0005 in).

All gages received must be marked with the API monogram and the API registration number. If not so marked, the gages will be returned to the customer uncalibrated. 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 of Calibration.

* See Chapter 1, Section H for more information about uncertainty.

Special Tests of Threaded Plug and Ring Gages (12020S)

NIST will provide special tests of threaded plug and ring gages in the areas listed for API gages (12010C). The accuracy of these calibrations is determined substantially by the quality of the artifact, but high quality artifacts yield uncertainties approximately the same as API gages.

Special Tests of Two-Dimensional Gages (12030S)

NIST can provide special tests of two-dimensional gages, ball plates or grid plates, with dimensions up to 600 mm × 600 mm (24 in x 24 in). The accuracy of the calibration depends substantially on the quality of the gage, but expanded uncertainties* of 1 μm or less are obtainable for high quality artifacts.

* See Chapter 1, Section H for more information about uncertainty.

Special Complex Dimensional Tests, by Prearrangement (12040S)

For requirements not covered by the services described above, special arrangements may be made by contacting Howard Harary (301) 975-3485.

References—Complex Dimensional Standards

On Characterizing Measuring Machine Geometry, R. J. Hocken and B. Borchardt, Natl. Bur. Stand. (U.S.), NBSIR 79-1752 (1979).

Three Dimensional Metrology, R. J. Hocken, et al., Annals of the CIRP, 26/1 (1977).

D. Optical Reference Planes & Roundness Standards

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Service ID No.	Items
13010S	Special Tests of Optical Reference Planes (Flats)
13020S	Special Tests of Roundness
13030S	Special Tests of Roundness Calibration Specimens

Special Tests of Optical Reference Planes (Flats) (13010S)

Optical reference planes are tested interferometrically, with the test surface horizontally supported on three equally spaced pads located at 0.7 of the radius from the center. The measurement is performed along two marked orthogonal diameters. The technical contact listed should be consulted for these calibrations.

Roundness Calibration Specimens and Measurements, Special Tests of Roundness (13020S and 13030S)

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

NIST will provide special tests of roundness calibration specimens by request. Please consult with the technical contacts listed.

References—Optical Reference Planes

The Calibration of an Optical Flat by Interferometric Comparison to a Master Optical Flat, C. P. Reeve, Natl. Bur. Stand. (U.S.), NBSIR 75-975 (Dec. 1975).

E. Angular Measurements

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Service ID No.	Items
14010C	Angle Gage Blocks
14020S	Special Tests of Optical Polygons
14030S	Special Tests of Rotary and Indexing Tables
14040S	Special Tests of Wedges
14050S	Special Angular Measurements, by Prearrangement

Angle Gage Blocks (14010C)

Angle blocks are measured in an angle comparator system consisting of a special chamber and two autocollimators. The blocks are placed in the chamber to minimize air currents and stray light effects. The test blocks are compared to NIST master angle blocks following an intercomparison method to eliminate thermal drift. Measurements are made in both top up and bottom up positions. Check standard blocks are measured during the procedure and used for process control. Standard size block sets include (1, 3, 5, 20, and 30)' sizes; (1, 3, 5, 20, and 30)" sizes; as well as 1°, 3°, 5°, 15°, 30°, and 45° sizes.

The expanded uncertainty* for this calibration is approximately 0.18" for ideal blocks, however, this value varies with the condition and geometry of the test block gaging surfaces. Customer angle blocks with poor gaging surfaces blocks can have uncertainties as high as 0.3" to 0.4". Angle blocks with dimensions other than standard (1 in by 2 (2.54 cm by 5.08 cm) in measuring faces) require different measurement methods and generally result in higher uncertainties.

All angle blocks submitted for calibration should be in substantially new block condition and each marked with an identification number. In shipping angle blocks, the same care exercised in gage block shipment should be used.

Special Tests of Optical Polygons (14020S)

Optical polygons are calibrated using an indexing table stack, an autocollimator and circle closure measurement techniques. Currently only polygons with nominally equal integer angles between faces can be measured. For example, a 12 sided polygon with nominally 30° angles between faces can be measured, but a 13 sided polygon with nominally 27.69° between faces cannot be measured. Check standard optical polygons are used for process control.

The expanded uncertainty for this calibration is approximately 0.14"; however, this value varies with the condition and geometry of the polygon faces.

Special Tests of Rotary and Indexing Tables (14030S)

Indexing tables (limited, fixed-increment, high repeatability) and rotary tables (continuous increment, low repeatability) are calibrated using an autocollimator and reflecting target, an indexing table stack, and circle closure techniques. The standard set of angular increments is every 30°. Additionally, every 5° of the first 30° interval, and every 1° of the first 5° interval can be measured. Check standard indexing tables are used for process control during the measurement procedure.

The expanded uncertainty* for this calibration is approximately 0.14"; however, this value varies with the locking mechanism repeatability and the scheme of angles chosen to be measured.

* See Chapter 1, Section H for more information about uncertainty.

Special Tests of Optical Wedges (14040S)

Optical wedges are calibrated using an autocollimator, a reflecting target, the test wedge and a repeated reversal measurement series. Fixed angle and adjustable wedges can be calibrated. The wedge is inserted between the autocollimator and reflecting target and measured. The wedge is removed, rotated 180° about the same base, re-inserted and measured. In this reversal technique the difference in the two measurements is equal to twice the actual angle. Check standard wedges are measured for process control.

The expanded uncertainty* for this calibration is approximately 0.12"; however, this value varies with condition and geometry of the wedge surfaces.

Special Angular Measurements, by Prearrangement (14050S)

For angular measurement requirements not covered by the services described above, special arrangements may be made by contacting Engineering Metrology Staff (301) 975-3471. Requests for service will be discussed and honored if current equipment and means are available.

Artifacts such as optical squares (pentaprisms), apex angle measurements of prisms, true squares, and polygons not already described, typically fall into this category.

References—Angular Measurements

Uncertainty and Dimensional Calibrations, Ted Doiron, John R. Stoup, NIST Journal of Research (In Press).

The Calibration of Angle Blocks by Intercomparison, C. P. Reeve, Natl. Bur. Stand. (U.S.), NBSIR 801967 (1980).

The Calibration of Indexing Tables by Subdivision, C. P. Reeve, Natl. Bur. Stand. (U.S.), NBSIR 75-750 (1975).

* See Chapter 1, Section H for more information about uncertainty.

F. Laser Measurements

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Service ID No.	Items
14510S	Laser Frequency/Wavelength

Laser Frequency/Wavelength (14510S)

The frequency (or, equivalently, the vacuum wavelength) of a red He-Ne laser is determined by comparison to an iodine-stabilized He-Ne laser. The attainable accuracy of this technique is ultimately limited by the uncertainty in the wavelength of the iodine stabilized laser. The relative standard uncertainty* of the laser vacuum wavelength at NIST is 5×10^{-11}. The relative expanded uncertainty is 1×10^{-10} . The relative expanded uncertainty can be reduced to 5×10^{-11} on special requests. As a practical matter, however, the uncertainty of a comparison is usually determined by the limited reproducibility of the laser under test.

* See Chapter 1, Section H for more information about uncertainty.

G. Surface Texture

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Service ID No.	Items
15010C	Roughness Calibration Specimens
15020C	Surface Roughness Comparison Specimens
15030C	Step Height Measurements
15040S	Special Roughness Tests

Roughness (15010C–15040S)*

NIST provides measurement services for roughness calibration specimens, other types of roughness specimens, and step height calibration specimens (see standards ASME B46.1-1995 and ISO 5436).

Surface roughnesses up to 10 μm Ra and step heights up to 50 μm are measured by means of a computerized stylus instrument system. Using an interferometrically measured step, the system is calibrated at each value of magnification employed during a measurement. Certain horizontal parameters are calibrated using a laser interferometer. A number of other statistical parameters and functions may also be calculated, including the rms roughness, average slope, average wavelength, skewness, amplitude density function, autocorrelation function, and power spectral density.

In measurements of roughness, surface profiles are taken according to American National Standard, ASME B46.1-1995, using a 0.8 mm cutoff length and a traversing length of 4 mm. In step height measurements, straight lines are fitted by the method of least squares to the top and bottom of the profile of the step, and the step height is calculated from the vertical difference of the lines at the middle of the step transition. The uncertainty in the NIST calibration for step height or Ra depends on a number of factors, the most important being the step or Ra value itself. The expanded uncertainties** range approximately from 0.4 μm at a step height of 50 μm to 0.5 nm at a step height of about 8 nm. Comparable uncertainties are achieved for measurements of Ra.

References—Surface Texture

Stylus-laser surface calibration system, T. V. Vorburger, J. F. Song, C.H.W. Giauque, T. B. Renegar, E. P. Whitenton, and M. C. Croarkin, Precision Engineering **19**, 157 (1996).

Methods of Characterizing Surface Topography, T. V. Vorburger, Tutorials in Optics, D. T. Moore, ed. (Optical Society of America, Washington, DC, 1992).

Standard Reference Specimens in Quality Control of Engineering Surfaces, J. F. Song and T. V. Vorburger, J. Res. Natl. Inst. Stand. Technol. **96**, 271 (1991).

Surface Finish Metrology Tutorial, T. V. Vorburger and J. Raja, NISTIR 89-4088 (National Institute of Standards and Technology, Gaithersburg, MD, June 1990).

Surface Texture, J.F. Song and T. V. Vorburger, ASM Handbook **18**, 334.

* Also see Chapter 1, Section C for Standard Reference Materials to calibrate stylus instruments that measure surface roughness.

** See Chapter 1, Section H for more information about uncertainty.

H. Hydrometers

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Service ID No.	Items
16010C	Reference Standard Hydrometers

Reference Standard Hydrometers (16010C)

NIST provides measurement services for reference hydrometers. These reference standard hydrometers are generally used as laboratory standards to calibrate other hydrometers. Reference hydrometers should be made of smooth, transparent glass, free of bubbles or other imperfections. The hydrometer should bear an inscription which indicates the purpose of the instrument. This inscription should denote the reference temperature at which it is to be used. The maker's name or trade mark and an identification number should be inscribed on the hydrometer scale. Hydrometers accepted for calibration must conform to specified requirements. The technical contacts listed above can give guidance on these requirements.

Reference hydrometers accepted for calibration include specific gravity, proof spirit for alcohol solutions, API degrees for petroleum measurements, degrees Baume heavy and degrees Baume light, and other arbitrary scales, all subject to discussion with the technical contacts. Specific gravity hydrometers cover the specific gravity range of 0.65 to 2. The hydrometer scale should be divided into 0.001, 0.0005, 0.0002, or 0.0001 units of specific gravity. Proof spirit hydrometers cover the range of 0 to 200 proof. The alcohol hydrometer scale should be divided in whole, half, fifth or tenth percents.

Visual inspection should be made by the customer before shipping to NIST for calibration. The hydrometer should be packed in a safe reusable shipping container.

NIST will provide a three-point calibration on these reference hydrometers. Additional points can be provided at an additional charge if requested. The calibration at NIST consists of comparing NIST master hydrometers directly with the customer's hydrometers in a liquid of low surface tension.

Hydrometer Facilities Uncertainty: The expanded uncertainty* for NIST master hydrometers depends on stem scale. Components of the expanded uncertainty* include the Type A Standard Uncertainty, composed of the imprecisions of such process components as scale readings, thermal gradient of the calibration fluid, etc., and Type B Standard Uncertainty, based on direct comparisons to solid density standards (plummets), density of water, and precision mass standards.

References—Hydrometer Measurements

Testing of Hydrometers, J. C. Hughes, Natl. Bur. Stand. (U.S.), NBS Circular 555.

ASTM Standard E100-81 Standards Specifications for ASTM Hydrometers, Annual Book of ASTM Standards 14.01.

An Improved High-Precision Calibration Procedure for Reference Standard Hydrometers, H. A. Bowman and W. H. Gallagher, J. Res. Natl. Bur. Stand. (U.S.) 73C (June 1969).

* See Chapter 1, Section H for more information about uncertainty.

I. Volume and Density

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Service ID No.	Items
17010C	Volume Standards
17020S	Special Tests of Volume Standards
17040S	Special Tests of Density: Liquids

Volume Standards (17010C)

The procedure used 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. The quality of the markings and the care exercised in reading or setting the liquid level are major factors in test calibration and usage. NIST does not provide routine calibration services for glassware; however, NIST will accept factory standards and replacement glassware for the State Weights and Measures Offices or Departments, in the range of 10^{-2} L to 5 L, which conform to specified requirements. The technical contacts given above can give guidance on these requirements.

NIST provides a calibration service for metal volumetric test measures. The volumetric test measures which are accepted for calibration should be free from dents, rust, etc. Special care should be taken by the customer to insure the cleanliness of the inside of the test measures. Should the test measure be equipped with a bottom drain valve, it is the customer's responsibility to insure that the valve be in proper working condition. These test measures should bear an inscription which indicates the nominal value of its volume, the thermal coefficient of expansion, an identification number, and its reference temperature. The scale plate should be legible in that the scale division can be estimated to one-tenth of a single division. A scale calibration is provided; however NIST does not adjust scales. The zero index or the scale should, therefore, be adjusted prior to the calibration. The slicker-plate-type volume standards should be adjusted by the manufacturer.

Normally NIST will accept for calibration, test measures with sizes in the range of 5 L to 7600 L or 1 gal to 2000 gal. The calibration procedure for these test measures consists of determining the contained volume or delivered volume by either gravimetric determinations, which is the result of direct comparisons with mass standards, or by the use of transfer standards, for which volumes have been predetermined. The reported result for the calibrated volume is the arithmetic mean of two independent observations. The reported volume is corrected to a requested reference temperature.

Volume Facilities Uncertainty: The uncertainty for NIST volume standards will vary with the instrument size and design. Relative expanded uncertainties* range from 0.003 % to 0.065 %.

Special Tests of Volume Standards (17020S)

Special tests may be made on volume standards other than those mentioned above. The technical contacts cited above should be contacted regarding testing.

* See Chapter 1, Section H for more information about uncertainty.

Special Tests of Density Liquids* (17040S)

Currently NIST is involved in a research project to improve its capabilities to measure liquid density. Contact the technical contacts cited above.

References—Volume and Density Measurements

ASTM Standard 694-83 Standard Specifications for Volumetric Ware, Annual Book of ASTM Standards 14.02.

The Equivalence of Gravimetric and Volumetric Test Measure Calibration, R. Schoonover, Natl. Bur. Stand. (U.S.), NBSIR 74-454 (Feb. 1987).

Calibration of Small Volumetric Laboratory Glassware, J. Lembeck, Natl. Bur. Stand. (U.S.), NBSIR 74-461 (Oct. 1974).

Procedures for the Calibration of Volumetric Test Measures, J. F. Houser, Natl. Bur. Stand. (U.S.), NBSIR 73–287 (Aug. 1973).

Testing of Volumetric Standards, J. C. Hughes and B.C. Keysar, Natl. Bur. Stand. (U.S.), NBS Monograph 62 (Apr. 1963).

Testing of Glass Volumetric Apparatus, J. C. Hughes, Natl. Bur. Stand. (U.S.), NBS Circular 602 (Apr. 1959).

* See Chapter 1, Section C for information about the Standard Reference Materials Program. NIST offers Standard Reference Materials of certified density.

Chapter

5

A Flow Measurements

B Flow Measurements at Cryogenic Temperatures

C Airspeed Instruments

D Mass Standards

E Force Measurements

F Vibration Measurements

G Acoustic Measurements

H Ultrasonic Reference Block Measurements

I Ultrasonic Transducer Measurements

J Acoustic Emission Transducer Measurements

Mechanical Measurements

A. Flow Measurements

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Service ID No.	Items
18010C	Gas Flow Meters
18020C	Water Flow Meters
18030C	Hydrocarbon Flow Meters
18040C	Transfer Standards
18050S	Special Tests Using Gas or Liquid Flows

Gas Flow Meters (18010C)

NIST provides calibration services for gas flow meters using piston provers, bell provers, and a Pressure-Volume-Temperature-time (PVTt) system. Throughout this section, flow rates are quoted at standard conditions of P = 101 325 Pa and T = 20 °C. The piston and bell provers cover flow ranges from 3.7×10^{-5} m^3/min to 1.4 m^3/min (1.3×10^{-3} ft^3/min to 51 ft^3/min). Gases available for calibration work in the piston and bell provers are: dry air, nitrogen, carbon dioxide, and argon. The piston and bell provers have connections for meters with Swagelok™, A/N, or National Pipe Thread fittings from 0.64 cm to 5 cm (1/4 in to 2 in) in diameter.

The PVTt system permits calibrations with dry air for flows from 0.86 m^3/min to 78 m^3/min (30 ft^3/min to 2740 ft^3/min). Calibrations are normally performed using a set of critical flow nozzles as working standards.

Pipe diameters from 5 cm to 20 cm (2 in to 8 in) with ASA 150 lb flanges* are available and arrangements for other connections can be made upon request. Straight runs of piping of up to 18 m are available.

Meters can be tested if the flow range, gas, and piping connections are suitable, and if the system to be tested has precision appropriate for calibration with the NIST flow measurement uncertainty. The relative expanded uncertainty* for the NIST gas flow systems is 0.22 % or better. A normal flow calibration includes five different flows, with five averages of the meter readings and the standard flow made at each flow, with this entire test sequence repeated on a second day. It is helpful if the customer specifies the flow set points and the instrumentation requirements of the meter (pressure, temperature, full scales required, etc.).

Water Flow Meters (18020C)

The water flow facility consists of a reservoir, pumps, meter runs, and weigh tanks. The system operates as a constant flow facility and uses timed collections of water to compute the average flow through the meter being calibrated. The relative expanded uncertainty** for these facilities is 0.12 %. Flows up to 38 m^3/min (10,000 gal/min) can be provided in pipes up to 40.6 cm (16 in) in diameter. Pipe connections should be ASA 150 lb steel flanges, Victaulic™ couplings, or adapters thereto. The normal testing sequence is the same as that described for gas flow meters.

Hydrocarbon Flow Meters (18030C)

Calibrations of hydrocarbon flow meters can be performed using a surrogate liquid for JP-4 and JP-5 jet fuels. Both volumetric and gravimetric systems can be used over the flow range from

* ASA 150 lb flanges is a commercial designation for these connectors.

** See Chapter 1, Section H for more information about uncertainty.

3.5×10^{-5} m^3/min to 1.5 m^3/min (0.01 gal/min to 400 gal/min). The relative expanded uncertainty* for the hydrocarbon flow system is 0.12 %. Preferred piping connections are A/N fittings, ASA 150 lb flanges, and National Pipe Threads up to 7.6 cm (3 in) in diameter.

Transfer Standards (18040C)

Transfer standards are available for *in situ* calibrations of flow meters or flow standards at the customer site. Details about this calibration service can be obtained from the technical contacts listed at the beginning of this section.

Special Tests Using Gas or Liquid Flows (18050S)

Special tests for liquid and gas flows are available. Examples include interlaboratory comparisons, round robin tests, and proving other fluid measurement systems. Tests to establish or maintain realistic flow measurement traceability for flow facilities can be designed and performed for specific situations. Details about this calibration service can be obtained from the technical contacts listed at the beginning of this section.

Special tests can be done using gas mixtures that simulate auto exhaust. These tests can range from 0.06 m^3/min to 6.2 m^3/min (2 ft^3/min to 220 ft^3/min) where temperatures can range from 20 °C to 400 °C; relative expanded uncertainties are 1 % or better.

Special tests are also available through Service ID No. 30063S. These tests which use nitrogen can be done in the range from 10^{-8} mol/s to 10^{-3} mol/s (2×10^{-4} cm^3/s to 20 cm^3/s) with relative expanded uncertainties* that range from 0.1 % to 0.05 % (low to high range, respectively.) The range of flow rates are quoted at standard conditions of P = 101 325 Pa and T = 20 °C. Specific details should be discussed with the technical contacts listed above or with Stuart Tison at (301) 975-2857.

* See Chapter 1, Section H for more information about uncertainty.

References—Flow Measurements

Flowmeter Calibration Facility for Heated Gas Mixtures, J. D. Wright and P. I. Espina, NCSL Proc., Atlanta (1997).

Flow Metrology: Standards, Calibrations, and Traceabilities, G. E. Mattingly, Flow Measurement: Practical Guides for Measurement and Control, D. W. Spitzer, ed., ISA, Research Triangle Park, 1991.

Gas Flow Metrology, G. E. Mattingly, NCSL Newsletter **29** (1), 9–16 (Jan. 1989).

NBS Primary Calibration Facilities for Air Flow Rate, Air Speed, and Slurry Flow, K. R. Benson, N. E. Mease, G. Kulin, and G. E. Mattingly, Proc. Intl. Flow Meas. Symp., Washington, DC, 1986, Amer. Gas Assoc., Arlington, VA.

The National Measurement System for Fluid Flow, W. C. Haight, P. S. Klebanoff, F. W. Ruegg, and G. Kulin, Natl. Bur. Stand. (U. S.), NBSIR 75-930 (Aug. 1976).

B. Flow Measurements at Cryogenic Temperatures

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Service ID No.	Items
18800S	Special Tests of Cryogenic Liquid Flow

Special Tests of Cryogenic Liquid Flow (18800S)

Measurement services are provided for cryogenic liquid flow. A dynamic weighing system is used to measure totalized mass flow and, with liquid density provided by the NIST Standard Reference Database 12: Thermophysical Properties of Pure Fluids, volumetric flow. Mass flow measurements are performed using liquid nitrogen at flow rates of 1 kg/s to 10 kg/s, over a pressure range of 0.4 MPa to 0.76 MPa, and a temperature range of 80 K to 90 K. The relative expanded uncertainty* within this flow range, is 0.17 %. For volumetric flow rate measurement, the uncertainty in fluid density must also be included. The relative expanded uncertainty for volumetric flow rate is 0.53 %. Lower flow rates may be possible, but the uncertainty at these flows is undetermined.

* See Chapter 1, Section H for more information about uncertainty.

References—Flow Measurements at Cryogenic Temperatures

Uncertainty Analysis of the NIST Nitrogen Flow Facility, J. L. Scott and M. A. Lewis, Natl. Inst. Stand. Technol. Tech. Note 1364 (Apr. 1994).

Progress Report on Cryogenic Flowmetering at the National Bureau of Standards, J. A. Brennan, J. F. LaBreque, and C. H. Kneebone, Proc. 1st Biennial Symp. Instrumentation in the Cryogenic Industry, Houston, TX, Oct. 11–14, 1976, **1**, 621, Instr. Soc. of America, Pittsburgh, PA (1976).

NBS-CGA Cryogenic Flow Measurement Program, J. A. Brennan, R. W. Stokes, C. H. Kneebone, and D. B. Mann (Proc. ISA Intl. Instrument. Automation Conf. and Exhibit, New York, NY, Oct. 28-31, 1974), Paper in Adv. in Instrument. 29, 612.1 (Instr. Soc. of America, Pittsburgh, PA, 1974).

Cryogenic Flow Research Facility Provisional Accuracy Statement, J. W. Dean, J. A. Brennan, D. B. Mann, and C. H. Kneebone, Natl. Bur. Stand. (U.S.), Tech. Note 606 (July 1971).

C. Airspeed Instruments

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Service ID No.	Items
19010C	Pitot-Static Tubes 1.3 m/s to 67 m/s (3 mph to 150 mph)
19020C	Low Airspeed Instruments 0.76 m/s to 10.2 m/s (15 fpm to 2,000 fpm)
19030S	Meteorological Airspeed Instrumentation 1.3 m/s to 67 m/s (3 mph to 150 mph)
19040S	Special Tests of Airspeed Instruments

Airspeed Instruments (19010C–19040S)

Calibration of airspeed measuring devices is performed in one of two special wind tunnels, as described in the Proceedings of the 1992 Measurement Science Conference. The differential pressure measured from ellipsoidal-nosed Pitot-static tubes provides the basis of airspeed measurement in these facilities. Pitot-static tubes and meteorological instruments are calibrated in the NIST Dual Test Section Wind Tunnel. Low velocity airspeed measurements are made using Laser Doppler Velocimetry (LDV) in the NIST Low Velocity Airflow Facility, described in NBS Technical Note 989. Calibration of the LDV is done using the Pitot-static tube at velocities which produce a sufficiently large differential pressure in the tube that the uncertainty in the pressure does not propagate unacceptable levels of error into the velocity determination. Use of the LDV capability in the low velocity range, where the Pitot-static tube has large measurement uncertainties due to the inability to measure accurately the associated small differential pressures, allows considerably improved measurement uncertainty. Air density values in the tunnels are computed from pressure, temperature, and humidity measurements in the settling chambers of the tunnels.

Details on the range and expanded uncertainty of the currently offered NIST airspeed calibrations are shown in Tables 5.1 and 5.2.

Special tests of airspeed instruments can be arranged. Examples include *in-situ* calibrations of airspeed instrumentation, proving other airspeed measurement systems, and tests where appropriate scaling will allow the results to be applicable to fluids other than air. Details can be obtained and arrangements made through the technical contacts cited above.

Table 5.1. Uncertainty* of the NIST Low Velocity Airflow Measurement Facility

Velocity (m/s)	Velocity (mi/h)	Relative Expanded Uncertainty (%)
0.15	0.33	4.0
0.25	0.56	2.4
0.5	1.1	1.2
1 to 10	2.2 to 22	0.6

* See Chapter 1, Section H for more information about uncertainty.

Table 5.2. Uncertainty* of the NIST Airflow Measurement Capabilities in the Dual Test-Section Wind Tunnels

Velocity (m/s)	Velocity (mi/h)	Relative Expanded Uncertainty (%)
0.4	1	8.0
1	2	3.8
2	5	1.3
3	6	0.6
5	11	0.45
10	22	0.31
15 to 67	34 to 150	0.28

* See Chapter 1, Section H for more information about uncertainty.

References—Airspeed Measurements

Air Speed Calibrations at the National Institute of Standards and Technology, N. E. Mease, W. G. Cleveland, Jr., G. E. Mattingly, and J. M. Hall, Proc. 1992 Meas. Sci. Conf., Anaheim, CA (1992).

A Low Velocity Airflow Calibration and Research Facility, L. P. Purtell and P. S. Klebanoff, Natl. Bur. Stand. (U.S.), Tech. Note 989 (May 1979).

D. Mass Standards

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Note: For weights larger than 30 kg (50 lb), contact J. G. Keller prior to shipment.

Service ID No.	Items
22010C	Weight Set (1 mg to 100 g)
22020C	Weight Set (1 mg to 1 kg)
22030C	Weight Set (2 kg to 30 kg)
22040C	Single Weights (1 mg to 1 kg)
22060C	Single Weights (2 kg to 30 kg)
22080C	Single Weights (> 30 kg to 1200 kg, 2 double substitution weighings)
22100C	Single Weights (> 1200 kg to 30,000 kg)
22110C	Single Weights (> 30 kg to 1200 kg, calibrated in a weighing design)
22130C	Single Weights for Deadweight Pressure Testers 5.9 kg to 22.7 kg (13 lb to 50 lb)
22140C	Single Weights for Deadweight Pressure Testers > 22.7 kg (> 50 lb)
22150C	Single Weights for Deadweight Pressure Testers < 5.9 kg (<13 lb)
22170S	Special Mass Measurement Services
22180M	Measurement Assurance Program for Mass

Mass (22010C-22110C)

NIST maintains the national standard for mass in the form of the prototype kilogram (K20) and provides services to support the parts of the national measurement system that rely directly or indirectly on mass measurements. These services include the calibration of suitable weight sets. Figure 5.1 shows the traceability to the SI unit of mass for the unit of mass as disseminated by NIST. A calibration consists of establishing a mass value and the appropriate uncertainty for that value for each weight that has been designated to be a reference standard. It is desirable, but not necessary, that a weight meet the adjustment tolerances established for NBS Classes A, B, M, S, S-1, or equivalent prior to submission. Weights are available from manufacturers, many of whom can directly furnish documentation suitable for meeting quality assurance contracts and requirements.

NIST calibrates individual weights or sets in the range of 1 mg to 30 kg or 0.45 kg to 22.7 kg (1 lb to 50 lb) in decimal subdivisions. If the weights are designated as reference standards, they must be of design, material, and surface finish comparable to NBS Classes A, B, M, S, or S-1. These include ASTM Type I and II, classes 1, 2, 3, 4, and OIML E1, E2, F1 and F2. NIST also calibrates large mass standards 27.3 kg to 27 300 kg (60 lb to 60 000 lb) if the design, material, and surface finish are 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.

In the absence of instructions from the customer, weights will be cleaned prior to calibration. If weights are to be calibrated "as found" (without cleaning), and returned without cleaning, customers should note this in their instructions to NIST. If weights are to calibrated "as found" and calibrated again after cleaning, double the fee will apply. 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, or on the density computed from measured volumes, or, in the absence of this information, on estimated density values.

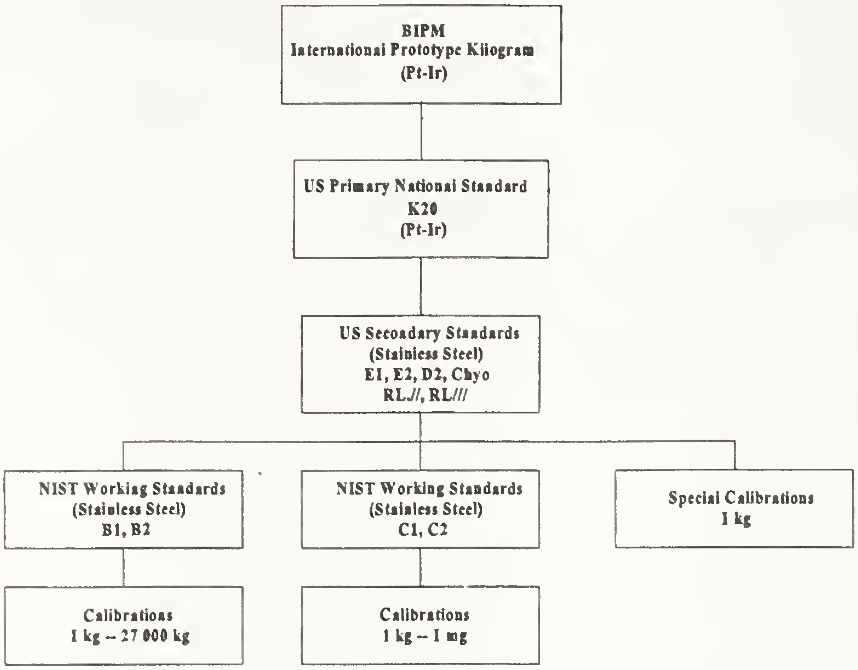

Figure 5.1 Traceability to the SI Unit of Mass.

However, 1 kg mass standards fabricated from stainless steel and of one-piece construction will have their density determined as part of a "first-time" calibration at NIST. The apparent mass corrections are computed for 20 °C with reference to Normal Brass (density 8 400 kg/m^3 at 0 °C and volume coefficient of expansion 0.000054/ °C) and to stainless steel (density 8 000 kg/m^3 at 20 °C) in a conventional air density of 1.2 kg/m^3. Apparent mass corrections to any other basis can be furnished if requested. Typical relative standard uncertainties* range from 50×10^{-9} at 1 kg, up to 330×10^{-6} at 1 mg, and 0.2×10^{-6} at 10 kg. Figure 5.2 shows the NIST uncertainties for normal calibrations of mass standards over the range 10^{-8} kg to 10^4 kg.

* See Chapter 1, Section H for more information about uncertainty.

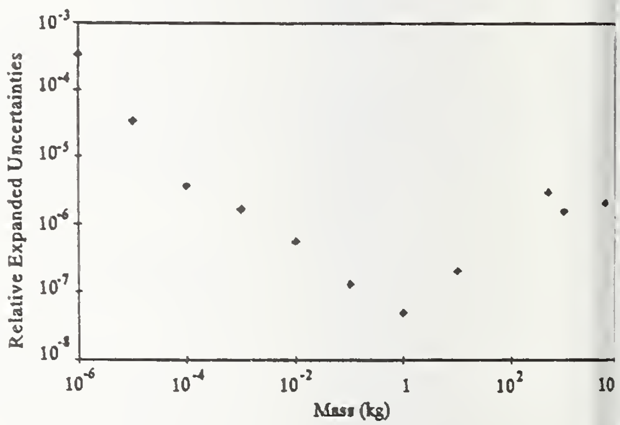

Figure 5.2. NIST's Relative Expanded Uncertainties for Normal Calibrations of Mass Standards.

Single Weights for Deadweight Pressure Testers (22130C–22150C)

Weights are compared to discrete standards by the method of double substitution weighing.

Special Mass Measurement Services (22170S)

For tests not covered by the previous descriptions, the NIST technical contact cited at the beginning of this section should be consulted to determine whether a test can be performed and to obtain an estimate of the price of the test.

Measurement Assurance Program for Mass (22180M)

This service is most appropriate for primary calibration laboratories. Total relative uncertainties ranging from a few parts in 10^7 to a few parts in 10^5 for 1 kg can be obtained. Unlike most other NIST MAP services, the Mass MAP service does not involve the use of a NIST-owned transport standard that is shipped to participants for measurement. The transfer standards in the Mass MAP are a set of mass standards owned by the participant and sent to NIST for calibration. These standards are referred to as the starting standards. In addition to the starting standards, the mass MAP participant must also furnish a set of much smaller weights called “sensitivity weights.” The choice of both the starting standards and the sensitivity weights will depend on the particular mass range of interest to the participant; NIST staff can provide advice regarding suitable starting standards and sensitivity weights for a particular range of mass weighings. In addition to the starting standards and the sensitivity weights, the participating facility should have a working set of weights known as the “test set” and a set of weights to be used as check standards. This set usually consists of weights in the range of 1 g to 1000 g. This service, like other NIST MAP services, samples the participant’s measurement process and establishes its uncertainty. Once the participant has become well-established in the Mass MAP, two options are possible:

(1) NIST personnel do all of the data analysis and record keeping for the participant and provide periodic reports on the uncertainty of the participant’s mass measurements.

(2) The participant keeps all records and calculates the uncertainties of his measurements using NIST methods and computer codes.

The implementation of the Mass MAP in its most complete form typically proceeds in four distinct phases, which may be abbreviated somewhat if the participant already has a suitable mass measurement quality control system.

Phase I: Each new participant completes a questionnaire on equipment and facilities and receives a written description of the NIST process, methods and procedure to be used, an introduction to the interpretation of results, and information on the use of these results in measurement decisions. At the participating laboratory, the suitability of the weighing equipment is verified, the starting standards selected or procured, and operators are trained, if the procedures are entirely new. The starting standards and sensitivity weights are sent to NIST for calibration. If the starting standards have a NIST calibration history, those data are reviewed and, if satisfactory, are considered, along with the data from the more recent determinations to arrive at assigned values for the starting standards. NIST will recommend a weighing design to be used for calibrating the test weight. This weighing design prescribes the set of observations for intercomparing the test weights with known weights. NIST will also supply data sheets to be used throughout the first three phases of the program for recording data taken using the design. The objective of the first phase is to ensure that the new participant is familiar with good laboratory practices for high precision weighing. If the participating laboratory has an established mass measurement capability and an existing quality control procedure for mass measurements, Phase I is abbreviated considerably.

Phase II: The starting standards and sensitivity weights are returned to the participant and, following the prescribed procedures, measurements are made by the participant over a period of time to verify that a state of statistical control exists. The data sheets are sent to NIST for review, comments, and processing after each measurement. If there are unanticipated problems, or if the procedure has not been followed exactly, more measurements may be required. After three or more successful calibrations in the user’s facility, NIST analyzes the data to determine the values of the check standards.

Phase III: A comprehensive report is issued by NIST containing a review of the actions and decisions in each of the phases, control charts for the check standards to be used in the participant's facility, and a comparison of the values assigned to the starting standards by NIST and by the participant. It is assumed at this point that the participating facility is now ready to extend the operation of the MAP to its regular workload.

Phase IV: Having thus established measurement comparability, the MAP user can then, in principle, operate independently of NIST. As long as there is no indication of a loss of statistical control of the process, no further checking with NIST should be necessary. Most participants request a recheck of the starting standards every few years to ensure that no undetected long-term drift has taken place.

For work that differs from the items normally calibrated by the participant, NIST can provide consulting help and assistance necessary to accommodate a greater range of weights, calibrate pound standards, and extend pound standards to large weights normally associated with force measurement. Although the usual Mass MAP service uses two one kilogram masses as the starting standards, the program is sufficiently flexible that the same methods can be used with other mass values.

References—Mass Standards

New Assignment of Mass Values and Uncertainties to NIST Working Standards, R. S. Davis, J. Res. Natl. Inst. Stand. Technol. **95** (1), 79 (Jan.-Feb. 1990).

NIST Measurement Services: Mass Calibrations, R. S. Davis, Natl. Inst. Stand. Technol. Spec. Publ. 250-31 (Jan. 1989).

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Direct Determination of Air Density in a Balance through Artifacts Characterized in an Evacuated Weighing Chamber, W. F. Koch, R. S. Davis, and V. E. Bower, J. Res. Natl. Bur. Stand. (U.S.), **83** (5), 407 (Sept.-Oct. 1978).

The Air Density Equation and the Transfer of the Mass Unit, F. E. Jones, J. Res. Natl. Bur. Stand. (U.S.) **83** (5), 419 (Sept.-Oct. 1978).

Designs for the Calibration of Standards of Mass, J. M. Cameron, M. C. Croarkin, and R. C. Raybold, Natl. Bur. Stand. (U.S.), Tech. Note 952 (June 1977).

The Air Density Equation and the Transfer of the Mass Unit, F. E. Jones, Natl. Bur. Stand. (U.S.), NBSIR 77-1278 (July 1977).

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Mass and Mass Values, P. E. Pontius, Natl. Bur. Stand. (U.S.), Monogr. 133 (Jan. 1974).

Weight Cleaning Procedures, H. E. Almer, Natl. Bur. Stand. (U.S.), NBSIR 74-443 (Nov. 1973).

On Uncertainty in Mass Measurement, J. R. Donaldson, Natl. Bur. Stand. (U.S.), NBSIR 73-151 (Mar. 1973).

Method of Calibrating Weights for Piston Gages, H. E. Almer, Natl. Bur. Stand. (U.S.), Tech. Note 577 (May 1971).

Realistic Uncertainties and the Mass Measurement Process, P. E. Pontius and J. M. Cameron, Natl. Bur. Stand. (U.S.), Monogr. 103 (Aug. 1967).

Introduction to Intercomparison Methods in Mass Measurement, H. E. Almer, Natl. Bur. Stand. (U.S.), Report 9487 (Feb. 1967).

Measurement Philosophy of the Pilot Program for Mass Calibration, P. E. Pontius, Natl. Bur. Stand. (U.S.), Tech. Note 288 (May 1966).

E. Force Measurements

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Service ID No.	Items
23010C	Force Transducers to 112 540 N (25 300 lbf), 1 mode
23020C	Extra observation
23030C	Additional bridges
23040C	Force Transducers to 112 540 N (25 300 lbf), 2 modes
23050C	Extra observation
23060C	Additional bridges
23070C	Force Transducers, 112 544 N to 498 201 N (25 301 lbf to 112 000 lbf), 1 mode
23080C	Extra observation
23090C	Additional bridges
23100C	Force Transducers, 112 544 N to 498 201 N (25 301 lbf to 112 000 lbf), 2 modes
23110C	Extra observation
23120C	Additional bridges
23130C	Force Transducers, 498 205 N to 1 334 467 N (112 001 lbf to 300 000 lbf), 1 mode
23140C	Extra observation
23150C	Additional bridges
23160C	Force Transducers, 498 205 N to 1 334 467 N (112 001 lbf to 300 000 lbf), 2 modes
23170C	Extra observation
23180C	Additional bridges
23190C	Force Transducers, 1 334 471 N to 4 448 222 N (300 001 lbf to 1 000 000 lbf), 1 mode
23200C	Extra observation
23210C	Additional bridges
23220C	Force Transducers, 1 334 471 N to 4 448 222 N (300 001 lbf to 1 000 000 lbf), 2 modes
23230C	Extra observation
23240C	Additional bridges
23250C	Force Transducers over 4 448 222 N (1 000 000 lbf) compression only
23260S	Special Tests of Force Transducers

Force Transducers (23010C–23250C)

NIST provides calibration services for force-measuring devices by applying known forces, either tension or compression, to the elastic device and recording the sensed deformation. Most calibrated devices are either proving rings or load cells. The deformation of proving rings is usually measured by means of a micrometer screw and vibrating reed, which are an integral part of the device. Load cells, which utilize strain gauge bridges, produce an electrical output that is related to the applied force.

The calibration report describes the relationship between the applied force and the measured deformation, either in electrical or mechanical units. A load cell can be calibrated using (1) a readout device furnished by the customer, in which case the load cell and the readout device are calibrated as a system, and the calibration is valid only when the load cell and the readout device are used together; or (2) instrumentation furnished by NIST, in which case data are reported in terms of the ratio of the output voltage to the DC excitation voltage (mV/V). In the latter case, the customer must possess the necessary electrical instrumentation and expertise to utilize the calibration results. The relative standard uncertainty* of the calibration of the voltage-ratio measurement instrumentation used at NIST is 0.0005 %.

Tension or compression calibrations in the range of 0.445 kN to 4.448 222 MN (100 lbf to 1 000 000 lbf) are performed using deadweight machines. NIST has six deadweight machines with maximum capacities of 2 226 N (505 lbf), 27 134 N (6 100 lbf), 112 540 N (25 300 lbf), 498 201 N (112 000 lbf), 1 334 467 N (300 000 lbf), and 4 448 222 N (1 000 000 lbf). The standard uncertainty of the applied forces incorporates the uncertainties associated with the determination of the mass of the deadweight, the acceleration due to gravity and the air density. The relative standard uncertainty* of applied force is 0.0005 %.

* See Chapter 1, Section H for more information about uncertainty.

Comparison calibrations in the range of 4 448 226 N to 53 378 659 N (1 000 001 lbf to 12 000 000 lbf) in compression only are performed in a universal testing machine. In this case, the system to be calibrated is loaded in series with load cells that have been previously calibrated in a deadweight machine. See Figure 5.3 for the relationship of force to S.I. units.

Special Tests of Force Transducers (23260S)

Temperature sensitivity, pressure sensitivity, and creep tests of force transducers are measured. The ranges of test parameters and environmental conditions may be limited by the characteristics of the force transducer and the availability of special test fixtures. These special tests should be discussed with the designated NIST technical contact before the work is scheduled.

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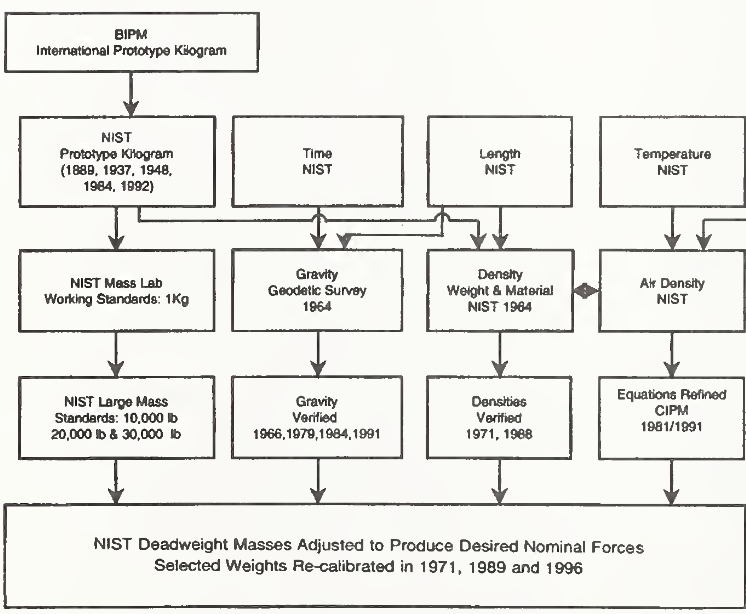

Figure 5.3. Relationship of Force to SI Units.

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F. Vibration Measurements

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Service ID No.	Items	Freq. Range	Peak Accel. (g_n)	Rel. Exp. Uncer*. in %
24010C	Pickup Sensitivity	2 Hz to 160 Hz	0.2 to 2	1 to 2
24020C	Pickup Sensitivity	10 Hz to 3500 Hz	2 to 10	1 to 2
24030C	Pickup	10 Hz to 10 kHz	2 to 10	1 to 2
24040S	Shock Measurement	250 Hz to 10 kHz	20 to 10000	3 to 5
24050S	Pickup Sensitivity	3 kHz to 20 kHz	4 to 200	1 to 3
24060S	Special Vibration Tests, by Prearrangement			

*See Chapter 1, Section H for more information about uncertainty.

Pickup Sensitivity (24010C–24030C)

NIST calibrations of vibration exciters and pickups are performed by comparison with the response characteristics of NIST standards or by absolute measurements. A calibration consists of measuring the transfer function of the instrument, usually referred to as the sensitivity. For a pickup, it is the ratio of the electrical output to a mechanical input. The magnitude of the latter is set in accordance with the calibration method, the type of vibration exciter, and the frequency of vibration. The magnitude of the output depends, of course, on the nature of the test device. In the case of an accelerometer with signal conditioner, the practice has been to express the output in millivolts, and the input in units of g_n, the standard acceleration of free fall:

$$g_n = 9.80665 \text{ ms}^{-2} .$$

The acceleration sensitivity is then given in mV/g_n. For charge-output devices without signal conditioners, the acceleration sensitivity is stated in picocoulombs per g_n (pC/g_n). All measurements are performed at 23 ± 3 °C. The calibration of an accelerometer is reported in tabular form as the sensitivity magnitude at a set of discrete frequencies; the phase component can be furnished at additional cost on request.

The NIST vibration standards are periodically calibrated by reciprocity and/or interferometric techniques, two independent and absolute methods. The use of these standards in the calibration of stable transducers furnishes calibration data with a typical relative expanded uncertainty* of 1 % to 2 % depending on the frequency range.

Special Shock Measurement Services (24040S)

The shock facility provides a comparison calibration of accelerometers by subjecting them to half-sinewave pulses with peak amplitudes of 20 g_n to 10 000 g_n and pulse widths from 0.1 ms to 40 ms. Both time and frequency domain measurements can be performed.

Special Tests of Pickup Sensitivity (24050S)

This test measures the pickup sensitivity by the fringe-disappearance method, using an automated Michelson interferometer. As presently configured, the system operates between 3 kHz and 20 kHz. The method requires precise setting of vibration amplitude to 121.10 nm; consequently, the acceleration amplitude in the stated frequency range increases from about 4 g_n to 200 g_n.

Special Vibration Tests (24060S)

Calibration of vibration and shock-measuring instruments to specifications other than those above, as well as other specified measurements, can be performed by prearrangement.

* See Chapter 1, Section H for more information about uncertainty.

For example, an interferometer calibration for frequencies less than 2 Hz or greater than 10 kHz can be performed on request. Consult with the technical contacts cited at the beginning of this section.

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G. Acoustic Measurements

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Service ID No.	Items
25010C	Pressure Response: WE Type 640AA microphones or equivalent (e.g., Tokyo Riko Type ECL MR103, Bruel & Kjaer Type 4160, Bruel & Kjaer Types 4144 or 4132 with DB0111 adapter). 50 Hz to 10 000 Hz
25020C	Pressure Response: WE Type 640AA microphones or equivalent (e.g., Tokyo Riko Type ECL MR103; Bruel & Kjaer Type 4160; Bruel & Kjaer Types 4144 or 4132 with DB0111 adapter). 50 Hz to 20 000 Hz
25030C	Pressure Response: Tokyo Riko Type ECL MR112, Bruel & Kjaer Type 4134, or equivalent half-inch microphones, 50 Hz to 10 000 Hz
25040C	Pressure Response: Tokyo Riko Type ECL MR112, Bruel & Kjaer Type 4134, or equivalent half-inch microphones, 50 Hz to 20 000 Hz
25050C	Free-Field Response: Tokyo Riko Type ECL MR112, Bruel & Kjaer Types 4133, 4134, 4165, 4166, 4180, or equivalent half-inch microphones, 2 500 Hz to 20 000 Hz
25060S	Special Tests of Acoustic Devices
25070S	Special Tests of Audiometers/Earphones

Pressure and Free-Field Responses of Microphones (25010C–25050C)

Pressure calibrations (Service ID Nos. 25010C and 25020C) are performed on Type-L one-inch microphones* satisfying the requirements of American National Standard S1.12-1967 (R1977), Specifications for Laboratory Standard Microphones and its impending revision. The microphones submitted for pressure calibration must be suitable for use with the calibrating couplers shown in Figures 6 and 10 of the applicable American National Standard S1.10-1966 (R1986).

*Type-L one-inch is a commercial designation for these microphones.

Table 5.3. Typical Expanded Uncertainties** for Pressure Calibrations of Type-L Microphones

Expanded Uncertainty** (dB)	Frequency Range
0.09	50 Hz to 7 kHz
0.26	7 kHz to 10 kHz
0.17	10 kHz to 17 kHz
0.32	17 kHz to 20 kHz

**See Chapter 1, Section H for more information about uncertainty.

Further information is contained in the references for acoustic measurements.

Since American National Standards Institute publications S1.10-1966 (R1986) and S1.12-1967 (R1977) were issued, certain types of half-inch diameter precision microphones have attained widespread use. Therefore, NIST has developed procedures (Service ID Numbers 25030C and 25040C) for determining the pressure response levels of half-inch microphones by comparison with NIST-owned Type-L standard microphones, which in turn are calibrated periodically by the reciprocity technique. The technique used, precautions to be observed, and uncertainties of measurement are essentially the same as those given above for one-inch microphones. Significantly different aspects of the procedures for half-inch microphones, such as ground shield configuration, are described in the test report. Since several half-inch laboratory standard microphones have been available for only a relatively short time, their long-term stability has yet to be determined.

The free-field response levels of certain Type-L microphones (e.g., Western Electric Type 640AA condenser microphones) can be computed from pressure response levels reported by NIST. However, certain precautions must be taken, and there is some degradation in accuracy.

Therefore, for the most demanding free-field measurement requirements, NIST offers a calibration service (Service ID No. 25050C) for determining the free-field response levels for half-inch microphones. The calibrations are made over the frequency range of 2.5 kHz to 20 kHz at normal incidence. Response levels (sensitivity levels) are reported in terms of open-circuit voltage per unit sound pressure (in the absence of the microphone) of a plane progressive wave whose direction of propagation is normal to the plane of the diaphragm. The calibrations are performed in a well-characterized anechoic chamber. A typical expanded uncertainty* in this calibration is approximately 0.21 dB or less at each frequency within the range of 2.5 kHz to 6.3 kHz and 0.15 dB or less at each frequency within the range of 6.3 kHz to 20 kHz. Calibrations can be performed with or without protective grids on the microphone. For the most precise free-field measurements, the customer should contact the NIST staff person cited at the beginning of this section for recommendations prior to submitting the microphone to NIST for calibration.

Special Tests of Acoustic Devices (25060S)

Acoustical measurement services are available by special arrangement. These services include extended frequency ranges of calibration, additional data points, measurements at very low sound pressure levels, and calibration of certain pistonphones and acoustic calibrators. NIST has a large general-purpose anechoic chamber available for special calibrations requiring such a facility. The frequency-dependent and position-dependent acoustical performance of this chamber, including extremely low background noise, was carefully controlled during design and construction and is documented in archival journal publications.

* See Chapter 1, Section H for more information about uncertainty.

Special Tests of Audiometers/ Earphones (25070S)

Earphones are tested on the NIST 9-A Coupler from 125 Hz to 8000 Hz. Measurements of audiometer/earphone response and linearity can be made at very low sound pressure levels.

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Service ID No.	Items
26030S	Special Tests of Area Amplitude Aluminum Reference Blocks—Set of Eight Blocks
26040S	Special Tests of Area Amplitude Titanium or Steel Ultrasonic Reference Blocks—Set of Eight Blocks
26050S	Special Tests of Distance Amplitude Aluminum Reference Blocks-Set of Fifteen Blocks
26060S	Special Tests of Distance Amplitude Titanium or Steel Ultrasonic Reference Blocks—Set of Fifteen Blocks
26070S	Special Tests of Distance and Area Amplitude Aluminum, Titanium or Steel Ultrasonic Reference Blocks—Miscellaneous Sets

Special Tests of Aluminum Reference Blocks (26030S, 26050S, and 26070S)

The ultrasonic response of 7075 aluminum alloy ASTM E127-type flat-bottom-hole (FBH) reference blocks of 12.7 mm (and greater) metal path distances is determined relative to a NIST reference block. The immersion, pulse-echo, longitudinal wave, 5 MHz quartz transducer testing system specified in ASTM E127-95 is used according to NIST-modified procedures (see publication NISTIR 5430) for improved measurement precision. Instrument gain settings are established using a selected 5-0050 block rather than the steel spheres stipulated in ASTM E127-95, and relative gain settings for different FBH sizes are determined from ratios of the respective FBH areas, rather than from the results of tests of various steel spheres. A specific set of NIST FBH check-standard blocks is tested along with the customer's block. The long-term precision and stability of the NIST testing system are monitored using a database reflecting the results of repeated tests of a set of check standard blocks. Standard deviation data representing the uncertainties associated with a particular test are reported for each block and hole size.

Relative expanded uncertainties* range from 3 % to 12 %. Upon request, block response can be determined using the procedures specified in the ASTM Recommended Practice E127-95. Turnaround is expedited by prearrangement with the technical contacts.

Special Tests of Titanium or Steel Reference Blocks (26040S, 26060S, and 26070S)

Steel and titanium ultrasonic reference blocks can be calibrated using procedures similar to those described in ASTM E428.

References—Ultrasonic Reference Block Measurements

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* See Chapter 1, Section H for more information about uncertainty.

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I. Ultrasonic Transducer Measurements

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Service ID No.	Items
26100C	Ultrasonic Power Output

Ultrasonic Power Output (26100C)

Measurements of total ultrasonic forward power radiated into a reflectionless water load are offered for the purpose of characterizing ultrasonic systems and transducers. Ultrasonic systems are characterized by measurement of output power under operating conditions specified by the customer. Transducers for which continuous-wave electrical input voltage can accurately and reproducibly be measured are characterized by a radiation conductance determined from measurements of input voltage and output power. A typical calibration report for an ultrasonic system provides the results of at least three measurements of output power for each operating condition specified. Calibration reports for transducers typically present a single value of radiation conductance derived from at least 15 measurements spanning an appropriate range of output power. Resonance frequencies of transducers are determined from the results of iterative spot-frequency relative measurements of radiation conductance.

Continuous-wave ultrasonic power is measured using a radiation force balance which allows power to be determined from the force required to arrest the motion of a conical target that diverts the output beam of the transducer under test into a bank of absorbers. Absolute power can be measured at spot frequencies between 0.5 MHz and 30 MHz. The relative expanded uncertainty* is dominated by frequency dependent effects and ambient vibration levels at the time of measurement, and ranges from 0.4 % to 7 % for power levels above a few mW. The best-case minimum detectable power is about 100 μW; high-power measurements are limited by the onset of cavitation in the water load itself. Transducers of diameter no greater than 45 mm can be tested in this apparatus.

Pulsed ultrasonic power is measured for the purpose of characterizing ultrasonic systems comprising a transducer and an electrical driver. Transducers by themselves cannot be independently characterized with nonsinusoidal drive waveforms since the electrical input signals cannot at present be adequately measured. Systems to be tested must be capable of generation of a sequence of at least 15 pulses in a 500 ms interval under external triggering.

References—Ultrasonic Transducer Measurements

Ultrasonic Power Output Measurement by Pulsed Radiation Pressure, S. E. Fick and F.R. Breckenridge, J. Res. Inst. Stand. Technol. **101**, 659 (1996).

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* See Chapter 1, Section H for more information about uncertainty.

J. Acoustic Emission Transducer Measurements

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Service ID No.	Items
26200C	Acoustic Emission Transducer Sensitivity

Acoustic Emission Transducer Sensitivity (26200C)

Acoustic emission transducer sensitivity is expressed as the voltage output of the transducer per unit of perpendicular surface motion (displacement or velocity) induced by an impulsive elastic wave traveling on the surface, or through the bulk, of a steel test block. Sensitivity is computed by comparing the output of the transducer under test (TUT) to an independently derived estimate of the surface motion that would occur if the transducer were not present. The magnitude and phase of the computed sensitivity are reported as a function of frequency for discrete frequencies separated by approximately 10 kHz in the interval 0.1 MHz to 1 MHz.

For surface-pulse tests, the TUT and a capacitive displacement transducer (CDT) are placed at symmetric locations 10 cm from the center of the circular upper end face of the test block, which is a cylinder 90 cm diameter and 43 cm long, positioned with its axis of rotation vertical. Elastic waves are induced in the block by rapid unloading due to breakage of a quasi-statically loaded glass capillary source located at the center of the upper surface of the block. The CDT output, corrected for aperture effects, provides a direct measurement of surface motion which, from independent measurements of the homogeneity of test block properties, bears a known similarity to the surface motion at the TUT location.

For through-pulse testing, the source is located on the lower end face of the block, directly opposite the TUT. Because phenomena intrinsic to bulk wave propagation would excessively complicate the task of correcting its output, the CDT output is not used. Instead, an estimate of upper surface motion at the TUT location is obtained from calculations based on the measured unloading force due to breakage of the glass capillary.

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Chapter 6

A Pressure Measurements

B Low Pressure, Vacuum, and Leak Measurements

C Laboratory and Industrial-Grade Thermometers

D Thermocouples, Thermocouple Materials, and Thermometer Indicators

E Resistance Thermometry

F Radiance Temperature Measurements

G Humidity Measurements

Thermodynamic Quantities*

A. Pressure Measurements

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Service ID No.	Items
29010C	Deadweight Piston Gages
29020C	Controlled Clearance Piston Gages
29030C	Pressure Gages and Transducers
29035C	Non-Mercurial Barometers and Manometers
29040S	Special Tests of Pressure Gages

Piston Gages and Pressure Transducers (29010C–29035C)

NIST provides measurement services for the calibration of piston gages (PG) and transducers operating with gas in the range of 7 kPa to 110 MPa and with oil in the range of 1 MPa to 280 MPa. Work is in process to extend the upper range for oil piston gage calibration services to 500 MPa. Calibrations of customer piston gages are done in the gage mode by the cross-floating technique using NIST working standard piston gages. NIST pneumatic working standards have been calibrated at the low end of the pressure range using the NIST mercury manometers and are modeled to extend their range to higher pressures. The NIST working standards for oil service have been calibrated using three controlled-clearance piston gages. Relative expanded uncertainties** associated with such calibrations are shown in Table 6.1.

*See Chapter 1, Section C for information available from the Standard Reference Materials Program on calibrating certain thermodynamic property measurement instruments.
** See Chapter 1, Section H for more information about uncertainty.

Table 6.1. Relative Expanded Uncertainties** of Piston Gage Standards in Gage Mode

Type of Instrument	Range	Relative Expanded Uncertainty** ($\times 10^{-6}$)
Gas-operated PG	7 kPa to 105 kPa	13
	105 kPa to 1.4 MPa	19
	1.4 kPa to 17.3 MPa	33
	17.3 kPa to 103 MPa	38
Oil-operated PG	1 MPa to 29 MPa	22
	29 MPa to 140 MPa	37
	140 MPa to 280 MPa	49

**These expanded uncertainties are based on recent evaluations of NIST "transfer" piston gage standards. Uncertainty estimates are continually being revised to reflect development of new primary pressure standards and improvements in measurement techniques.

Special Tests of Pressure Gages (29040S)

Special tests of pressure gages and other pressure measuring devices may be performed on request. This includes, special test 30040S for deadweight piston gages, an absolute mode test in the pressure range 7 kPa to 350 kPa that can provide relative expanded uncertainties that are smaller than those given in Table 6.1. A minimum piston gage test will require data at five or more pressures for each gas desired. Call Mr. Driver for further information about this service.

References—Pressure Measurements

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B. Low-Pressure, Vacuum, and Leak Calibrations

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Service ID No.	Items
30010C	One Low-Pressure Transducer (Absolute or Differential) Relative to Vacuum
30011C	Additional Transducers (cost per unit)
30020C	One Differential Low-Pressure Transducer Relative to Near Atmospheric Pressure
30021C	Additional Transducers (cost per unit)
30025C	Ball-Type Deadweight Tester
30029C	Spinning Rotor Gages, below 0.1 Pa, Nitrogen Gas With NIST Controller
30030C	Spinning Rotor Gages, below 0.1 Pa, Nitrogen Gas, Customer Controller with IEEE-488
30031C	Spinning Rotor Gages, below 0.1 Pa, Additional Gas
30032S	Special Tests of Spinning Rotor Gages, Transition Range (above 0.1 Pa)
30034C	Ionization Gages, 10^{-4} to 10^{-1} Pa, Nitrogen Gas
30035C	Ionization Gages, 10^{-5} to 10^{-1} Pa, Nitrogen Gas
30036C	Ionization Gages, 10^{-7} to 10^{-1} Pa, Nitrogen Gas
30037C	Ionization Gages, Additional Filament or Gas for Above Tests
30038C	Ionization Gages, NIST-Supplied Gage Tube for Above Tests
30040S	Special Tests of Low-Pressure Gages
30050S	Special Tests of Vacuum Gages
30060S	Special Tests of Leak Artifacts (10^{-13} mol/s to 10^{-6} mol/s)
30061C	Helium Leaks, Primary Calibration (10^{-13} mol/s to 10^{-6} mol/s)
30062C	Helium Leaks, Comparison Calibration (10^{-13} mol/s to 10^{-9} mol/s)
30063S	Special Tests of Low-Gas Flow Instruments

General Notes:

1 Torr = 133.322 Pa

Due to the time and effort required to prepare vacuum instrumentation for operation it is particularly important that these instruments be known to be in proper operating condition when they are submitted for calibration. Equipment will be inspected upon receipt and the customer notified of any obvious damage. If the schedule permits, we will cooperate with the customer's efforts to repair or replace damaged equipment so that calibration can proceed. However, concealed damage or operational deficiencies most likely will not be detected before the instrument is operating on the vacuum system or the calibration has started; in such cases, if the equipment cannot be calibrated, we will charge 20 % of the regular calibration fee for capacitance diaphragm gages and 30 % of the regular fee for spinning rotor and ionization gages.

Low-Pressure Calibrations (30010C–30025C and 30040S)

Low-pressure gages are calibrated by direct comparison to NIST UIM (Ultrasonic Interferometer Manometer) primary standards. Calibrations relative to vacuum are performed with either an oil UIM that has a range of 135 Pa (1 Torr), or one of two mercury UIMs that have ranges of 140 kPa (1100 Torr) and 360 kPa (2700 Torr). Calibrations relative to higher reference pressures (up to 200 kPa) are performed with either the 360 kPa UIM or a new low-differential-pressure standard based on a 13 kPa (100 Torr) mercury UIM. The expanded uncertainty* due to systematic effects of the mercury UIM standards is 5.2×10^{-6} of reading plus 18 mPa; the expanded uncertainty of the oil UIM standard is 100×10^{-6} of reading plus 2 mPa.

* See Chapter 1, Section H for more information about uncertainty.

Pressure measuring devices accepted for calibration generally fall into three categories. The first are absolute pressure transducers or differential pressure transducers that are operated relative to vacuum, such as capacitance diaphragm gages or quartz bourdon gages (Service ID Numbers 30010C and 30011C). The second category includes differential pressure transducers of a similar type intended for use with reference pressures near atmospheric pressure (Service ID Numbers 30020C and 30021C). The third category includes certain types of dead weight testers, such as ball gages (Service ID Number 30025C) and low range piston gages (Service ID Number 30040S). Calibrations of transducers relative to vacuum are performed in batches twice a year. Please call for deadline dates for the next calibration batch. Other calibrations are performed on request as NIST schedules and equipment availability permit.

Spinning Rotor Gages (30029C–30032S)

Spinning Rotor Gages (SRGs, also called Molecular Drag Gages) are calibrated on a new Transition Range Standard of the orifice-flow type with an extended range from 10^{-4} Pa to 30 Pa and a relative expanded uncertainty* between 0.3 % and 1.0 %. The routine calibrations, 30029C–30031C, cover molecular-flow pressures below 0.1 Pa, where the SRG can, for all practical purposes, be characterized by a constant effective accommodation coefficient without a viscosity correction. Calibrations in this range can be performed using either the customer's controller or a NIST controller. The vacuum flange for the thimble assembly must be bakeable (2.75 in "Conflat" type preferred) unless special arrangements have been made.

* See Chapter 1, Section H for more information about uncertainty.

These calibrations are performed with nitrogen, in batches, typically two or three times a year. Please call for the next scheduled calibration date, or to arrange for a gas other than nitrogen.

Viscosity effects become increasingly important above 0.1 Pa. As a special service (30032S), SRGs can be calibrated up to 30 Pa on the Transition Range standard, and up to 100 Pa using an ultrasonic interferometer manometer. This requires that the ball, thimble, suspension head, and controller be calibrated as unit. Please call for scheduling and costs.

Ionization Gages (30034C–30038C)

A standard of the orifice-flow type covers the pressure range from 10^{-1} Pa to 10^{-7} Pa (10^{-3} Torr to 10^{-9} Torr) for inert gases with a relative expanded uncertainty* of 0.7 % or less in the range 10^{-5} Pa to 10^{-3} Pa, increasing to 2 % at 10^{-7} Pa. To be acceptable for calibration all gages must be bakeable to 250 °C and should be welded to "Conflat" type flanges. Standard procedure is to calibrate the gage and its control electronics as a package, although gages may be calibrated using NIST electronics by special arrangement. Unless specifically requested by the customer, all hot-cathode gages will be calibrated with 1 mA electron emission current and the preset bias voltages supplied by the customer's controller. Note that ionization gage controllers that do not regulate the emission current or deliberately change it are not considered suitable as transfer standards. After a gage has been calibrated via any of the Service ID Numbers 30034–30036C, calibration of the gage for additional gases or additional filaments (30037C) may be done for a reduced fee. Cold-cathode gages can be calibrated by special arrangement at the same fees. Ionization gage calibrations are generally performed twice a year; please call for scheduled dates.

For an additional fee, NIST will provide glass-envelope Bayard-Alpert ionization gages with tungsten filaments and mounted on non-rotatable 2.75 in "Conflat" type flanges* (30038C). These will be calibrated with the user's electronics.

Special Tests of Low-Pressure Gages (30040S)

Instruments requiring special calibration procedures or prolonged testing can often be accommodated as a special test. This includes, as a complement to the 29000 Service ID Numbers, the determination of deadweight piston gage effective area using the NIST ultrasonic interferometer manometer as the reference standard. This test can be done in either the gage or absolute mode for a variety of gases. Please call for additional information.

Special Tests of Vacuum Gages (30050S)

Instruments requiring special calibration procedures or prolonged testing can often be accommodated as a special test. Please call for additional information.

Leaks (30060S–30062C)

Leak artifacts are calibrated in the range 1×10^{-6} mol/s to 1×10^{-13} mol/s (2×10^{-2} std. cm^3/s to 2×10^{-9} std. cm^3/s at 0 °C). Flow rates are quoted at standard conditions for leak measurements of P = 101 325 Pa and T = 0 °C. When referenced to the specific temperature, std. cm^3/s can be converted to mol/s by multiplying by 4.45×10^{-5}. The calibration can be performed directly by the NIST primary leak standard (30061C) which has a range-dependent relative expanded uncertainty** between 0.2 % and 4.5 %. For a lower fee, helium leak artifacts in the range 1×10^{-9} mol/s to 1×10^{-13} mol/s may be calibrated (2×10^{-5} std. cm^3/s to 2×10^{-9} std. cm^3/s at 0 °C) on a comparison system with respect to NIST-calibrated reference leaks (30062C). In both cases, the temperature dependence of the leak is measured and the Report of Calibration will include tabulated leak rates at 1 °C intervals from 0 °C to 50 °C. All leak artifacts submitted for measurement must be ultrahigh vacuum compatible and clean. The vacuum connection must have a standard 2.75 in "Conflat" type flange or 1/4 in VCR type fitting (30061C). An easily observable customer identification number or code must be engraved on the circumference of the vacuum flange or reservoir. By special arrangement (30060S), leaks can be calibrated with gases other than helium, such as argon and common refrigerants. Leaks can also be calibrated as a function of reservoir pressure. Calibrations using the NIST primary leak standard are performed once a year, usually in January. Comparison calibrations are performed throughout the year. Please call for further information.

Special Tests of Low-Gas-Flow Instruments (30063S)

High precision low-gas-flow instruments are calibrated in the range of (10^{-8} to 10^{-3}) mol/s with inert gases and other gases by special arrangement. The calibration is performed by direct comparison to a NIST primary flow standard and can be accomplished with down stream pressures ranging from 10 Pa (vacuum) to 300 kPa. The relative expanded uncertainties* in the measured flow are range dependent and vary from 0.05 % at a flow of 10^{-3} mol/s to 0.1 % at a flow of 10^{-8} mol/s. Gas flows higher than 10^{-3} mol/s are described under Service ID Numbers 18010C and 18050S. On-site proficiency tests may also be accomplished by special arrangement.

* 2.75 in Conflat flange is an industrial designation for connectors.

** See Chapter 1, Section H for more information about uncertainty.

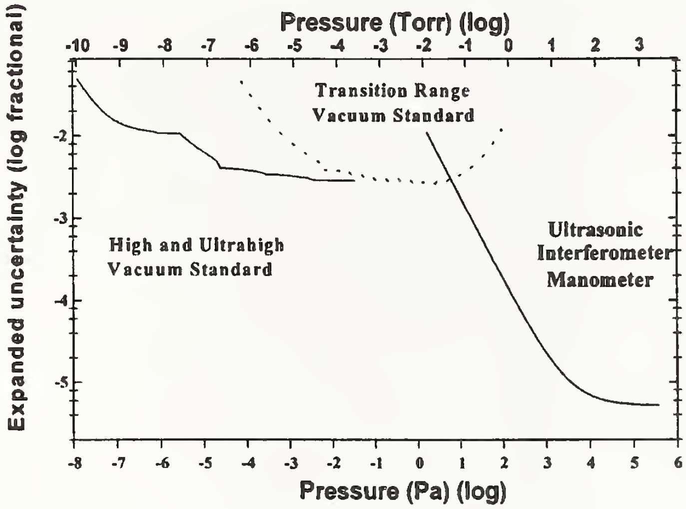

Figure 6.1. Uncertainties of the NIST Low-Pressure and Vacuum Standards.

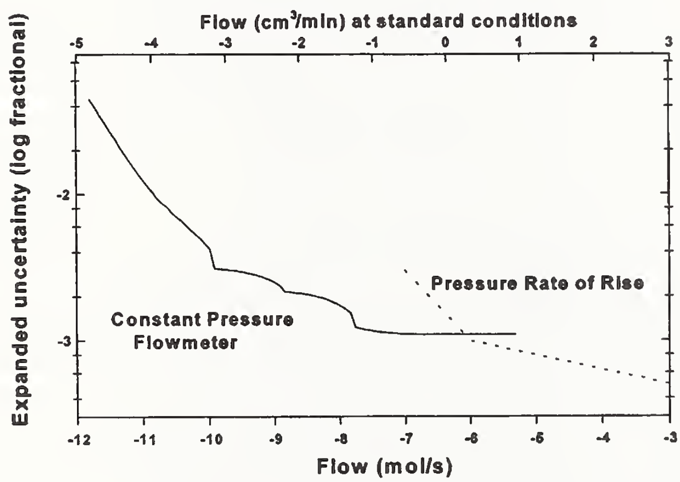

Figure 6.2. Uncertainties of the NIST Leak and Low-Gas- Flow Standards.

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C. Laboratory and Industrial-Grade Thermometers*

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Note: The minimum number of test points per thermometer is two. Fahrenheit ranges are not direct conversions of the Celsius ranges.

Service ID No.	Items
31010C	Laboratory Thermometers (0 °C to 150 °C) (32 °F to 300 °F)
31020C	Laboratory Thermometers (151 °C to 315 °C) (300 °F to 600 °F)
31030C	Laboratory Thermometers (316 °C to 550 °C) (600 °F to 1022 °F)
31040C	Laboratory Thermometers (–1 °C to –110 °C) (31 °F to –166 °F)
31050C	Laboratory Thermometers (Liquid N_2) (–196 °C or –321 °F)
31100C	Quantity Tests of Liquid-in-Glass Thermometers
31110S	Special Tests of Industrial Platinum Resistance Thermometers, Thermistor Thermometers, Digital Thermometers, and Other Types of Thermometers (0 °C to 150 °C) (32 °F to 300 °F)
31120S	Special Tests of Industrial Platinum Resistance Thermometers, Thermistor Thermometers, Digital Thermometers, and Other Types of Thermometers (151 °C to 315 °C) (301 °F to 600 °F)
31130S	Special Tests of Industrial Platinum Resistance Thermometers, Thermistor Thermometers, Digital Thermometers, and Other Types of Thermometers (316 °C to 550 °C) (601 °F to 1022 °F)
31140S	Special Tests of Industrial Platinum Resistance Thermometers, Thermistor Thermometers, Digital Thermometers, and Other Types of Thermometers (–1 °C to –110 °C) (31 °F to –166 °F)
31150S	Special Tests of Industrial Platinum Resistance Thermometers, Thermistor Thermometers, Digital Thermometers, and Other Types of Thermometers (Liquid N_2) (–196 °C or –321 °F)
31170S	Special Tests of Calorimetric Thermometers
31180S	Special Tests of Beckmann Thermometers
31200S	Preliminary Examination of Ineligible Thermometer
31250S	Additional Copy of Report
31260S	Special Thermometry Services, by Prearrangement

* See Chapter 1, Section C for information on other thermodynamic property measurement standards available from the Standard Reference Materials Program.

Laboratory Thermometers (31010C–31100C)

This service provides for the calibration of a variety of thermometers covering the range from –196 °C to +550 °C (–321 °F to +1022 °F).

Thermometers belonging to the large and varied group which may be classified as laboratory, or "chemical," thermometers are regularly accepted. These are of the liquid-in-glass type with either solid-stem or enclosed scale. 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 liquid 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 the 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.

The thermometers to be calibrated are placed in a constant temperature bath along with a NIST-calibrated standard platinum resistance thermometer (SPRT). The SPRT maintains calibrations traceable to the International Temperature Scale of 1990 (ITS-90), with a maximum expanded uncertainty** of 0.7 mK. (See Table 6.2)

** See Chapter 1, Section H for more information about uncertainty.

Table 6.2. Calibration Uncertainties for Total Immersion Thermometers

Type of Thermometer	Range (°C)	Expanded Uncertainty* (°C)
Mercury-in-glass (graduations: 0.1 °C or 0.2 °C)	0 to 100	0.024
Mercury-in-glass (graduations: 1 °C or 2 °C)	0 to 300 300 to 550	0.5 to 0.1 0.16 to 0.3
Organic liquid-in-glass	– 200 to 0	0.2 to 0.5

* See Chapter 1, Section H for more information about uncertainty.

Special Tests of Thermometers (31110S–31150S)

Special tests may be conducted on temperature-measuring devices such as industrial grade platinum resistance thermometers, digital thermometers, and thermistors. Laboratory personnel should be consulted before submitting items.

References—Laboratory and Industrial-Grade Thermometers

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National Institute of Standards and Technology,
I-270 at Quince Orchard Road,
[**For:** 32010C–32101C, 32150S; **Attn:** D. C. Ripple or K. Garrity, Bldg. 221, Room B229]
[**For:** 32110C–32147C; **Attn:** C. D. Vaughn or D. C. Ripple, Bldg. 221, Room B241]
Gaithersburg, MD 20899-0001

Comparison Calibrations, Temperature Measured with Thermocouple (TC):

Service ID No.	TC Type	Temp. Range (°C)	Points	Min. Length (mm)	Temp. (°C)	Expanded Uncert.* (°C)
32010C	S	0 to 1450	1 ° or 1 °F Interv. Table	700	0 to 1100 1450	0.3 1.6
32020C	R	0 to 1450	" " "	700	0 to 600 1450	0.5 1.6
32030C	B	0 to 1750	" " "	1000	0 to 800 800 to 1100 1450 1750	(3 μV) 0.3 1.6 2.4
32031C	B	800 to 1750	" " "	1000	800 to 1100 1450 1750	0.6 1.6 2.4
32040C	E	0 to 1000	4 to 15	700	0 to 1000	0.9
32041C	J	0 to 760	4 to 15	700	0 to 760	0.7

* See Chapter 1, Section H for more information about uncertainty.

** See Chapter 1, Section C for contact information on the Standard Reference Materials Program, which has thermocouple materials and other temperature standards available for sale.

Comparison Calibrations, Temperature Measured with Thermocouple—Continued:

Service ID No.	TC Type	Temp. Range (°C)	Points	Min. Length (mm)	Temp. (°C)	Expanded Uncert.* (°C)
32042C	K	0 to 1100	4 to 15	700	0 to 1100	1
32043C	N	0 to 1100	4 to 15	700	0 to 1100	1
32044C	T	0 to 400	4 to 15	700	0 to 400	0.4
32050C	Comparison calibration, 2 point minimum, per point, for all items above					
32060C	Each additional table of results at 1 °C or 1 °F intervals, for Type S, R, or B at later date					
32061C	Each additional table of results at 1 °C or 1 °F intervals, for Type S, R, or B at time of test					
32070C	Thermocouple materials tested against Pt thermoelectric standard, 4 to 15 points, 700 mm minimum lengths					

* See Chapter 1, Section H for more information about uncertainty.

Calibration at Metal Freezing Points, Minimum TC Wire Diameter 0.4 mm, Freezing Point Determination at Au, Ag, Al and Zn

Service ID No.	TC Type	Temp. Range (°C)	Points	Length (mm)	Temp. (°C)	Expanded Uncert.* (°C)
32090C	S or R	0 to 1450	Table, 1 °C or 1 °F interv. and equations to generate table	1000	at freezing points 0 to 1100 1450	0.1 0.1 1.6
32091C	Type S or T, freezing point determination, per point, 2 point minimum					

* See Chapter 1, Section H for more information about uncertainty.

Calibration of Digital Thermometer Indicator or Portable Potentiometer

Service ID No.	Items
32100C	Indicator or Potentiometer, first dial or range
32101C	Indicator or Potentiometer, each additional dial or range

Service ID No.	Items
	Comparison Calibration of Thermocouples or Thermocouple Materials Tested against Pt Thermoelectric Standard, Temperature Measured with Platinum Resistance Thermometer, Minimum TC Wire Length 1.0 m, 2 Point Minimum
32110C	Range −110 °C to +315 °C and Liquid N_2 (−196 °C) or −166 °F to 600 °F and Liquid N_2 (−321 °F), Expanded Uncertainty* 0.4 °C
32120C	316 °C to 550 °C or 601 °F to 1022 °F, Expanded Uncertainty* 0.5 °C
	Table at one degree intervals for Type T thermocouple for any of the following options: (The cost of the table will be in addition to the calibration per point covered under fee schedule service ID numbers 32110C–32120C.)
32141C	Option 1: Table from −190 °C to +300 °C (−321 °F to +572 °F), calibration points at (−196, −110, −50, +100, +200, +300) °C
32142C	Option 2: Table from −190 °C to +100 °C (−321 °F to +212 °F), calibration points at (−196, −110, −50, +50, +100) °C
32143C	Option 3: Table from −110 °C to +300 °C (−166 °F to +572 °F), calibration points at (−110, −50, +100, +200, +300) °C
32144C	Option 4: Table from −110 °C to +100 °C (−166 °F to +212 °F), calibration points at (−110, −50, +50, +100) °C
32145C	Option 5: Table from 0 °C to 300 °C (32 °F to 572 °F), calibration points at (+100, +200, +300) °C
32146C	Option 6: Table from −110 °C to 0 °C (−166 °F to +32 °F), calibration points at (−110, −50) °C.
32147C	Option 7: Table from −196 °C to 0 °C (−321 °F to +32 °F), calibration points at (−196, −110, −50) °C
32150S	Special Tests of Thermocouples and Thermocouple Materials
Note:	Due to the extra time involved in calibrating sheathed thermocouples, a surcharge of 20 % of the cost of calibrating bare-wire thermocouples will be added to the relevant fees listed for the above.

* See Chapter 1, Section H for more information about uncertainty.

Thermocouples, Thermocouple Materials and Thermometer Indicators (32010C–32147C)

Calibration services for all commonly used types of thermocouples are provided by NIST from −196 °C to 1750 °C depending upon the wire or thermocouple type. The thermocouples are calibrated by one or a combination of three general methods, depending on the thermocouple type, the temperature range, and the uncertainty required. All three methods provide traceability to the ITS-90. In the first method, thermocouples are calibrated by comparison with a reference thermocouple maintained at NIST. In the second method, thermocouples are calibrated by comparison with a standard platinum resistance thermometer. In the third method, thermocouples are calibrated at four defining fixed-point temperatures on the ITS-90: the freezing points of Zn, Al, Ag, and Au. Below 0 °C, the thermocouple calibration is performed in a cryostat; above 0 °C, stirred liquid baths, metal freezing-point cells, and electric tube-type furnaces are employed for the calibrations. Vacuum or inert gas furnaces are also available for testing thermocouples.

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. Minimum thermocouple length requirements listed in the Service ID Number tables are exclusive of lead wire. Lead wires (for connections) should 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 (32 °F). The calibration results will be given in °C or °F, as requested by the customer.

The calibration of a thermocouple will not be undertaken if it will likely not yield the specified expanded uncertainty* or if it possesses unusual characteristics that would prevent the performance of the calibration or test at a reasonable cost. Only unused base-metal thermocouples and thermocouple materials will be accepted for test.

All uncertainties are expressed as expanded uncertainties* and vary with test temperature. In cases where a range of temperatures is given, the stated expanded uncertainty is the maximum of the expanded uncertainties over this range of temperatures.

Special Tests of Thermocouples and Thermocouple Materials (32150S)

For requirements not covered by calibrations described above, special arrangements may be made by consulting one of the specified staff members.

References—Thermocouples

ASTM Standard E 220-86(96), Standard Method for Calibration of Thermocouples by Comparison Techniques, Annual Book of ASTM Standards **14.03**, 94, Amer. Soc. for Test. and Matls., Philadelphia, PA (1997).

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*See Chapter 1, Section H for more information about uncertainty.

E. Resistance Thermometry

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I-270 at Quince Orchard Road,
Building 221, Room B04,
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Gaithersburg, MD 20899-0001

Service ID No.	Items
33010C	Capsule SPRT (13.8 K to 30 °C) H_2 to Ga
33020C	Capsule SPRT (13.8 K to 157 °C) H_2 to In
33030C	Capsule SPRT (13.8 K to 232 °C) H_2 to S_n
33031C	Capsule SPRT (24.5 K to 30 °C) Ne to Ga
33032C	Capsule SPRT (24.5 K to 157 °C) Ne to In
33033C	Capsule SPRT (24.5 K to 232 °C) Ne to Sn
33040C	Capsule SPRT (54 K to 30 °C) O_2 to Ga
33050C	Capsule SPRT (54 K to 157 °C) O_2 to In
33060C	Capsule SPRT (54 K to 232 °C) O_2 to Sn
33065S	Capsule SPRT (83 K to 0.01 °C) Ar to TPW
33070C	Capsule SPRT (83 K to 30 °C) Ar to Ga
33080C	Capsule SPRT (83 K to 157 °C) Ar to In
33090C	Capsule SPRT (83 K to 232 °C) Ar to Sn
33100C	Capsule SPRT (0 °C to 30 °C) TPW to Ga
33110C	Capsule SPRT (0 °C to 157 °C) TPW to In
33120C	Capsule SPRT (0 °C to 232 °C) TPW to Sn
33130C	Capsule SPRT (234 K to 30 °C) Hg to Ga
33140C	Rhodium-Iron or Germanium Resistance Thermometers (0.65 K to 24.6 K)
33141C	Rhodium-Iron or Germanium Resistance Thermometers (0.65 K to 84 K)
33150C	Long Stem SPRT (83 K to 0.01 °C) Ar to TPW
33160C	Long Stem SPRT (83 K to 30 °C) Ar to Ga
33170C	Long Stem SPRT (83 K to 157 °C) Ar to In
33180C	Long Stem SPRT (83 K to 232 °C) Ar to Sn
33190C	Long Stem SPRT (83 K to 420 °C) Ar to Zn

TPW = triple point of water

Test No.	Items
33200C	Long Stem SPRT (83 K to 661 °C) Ar to Al
33210C	Long Stem SPRT (234 K to 30 °C) Hg to Ga
33220C	Long Stem SPRT (234 K to 157 °C) Hg to In
33230C	Long Stem SPRT (234 K to 232 °C) Hg to Sn
33240C	Long Stem SPRT (234 K to 420 °C) Hg to Zn
33250C	Long Stem SPRT (234 K to 661 °C) Hg to Al
33260C	Long Stem SPRT (0 °C to 30 °C) TPW to Ga
33270C	Long Stem SPRT (0 °C to 157 °C) TPW to In
33280C	Long Stem SPRT (0 °C to 232 °C) TPW to Sn
33290C	Long Stem SPRT (0 °C to 420 °C) TPW to Zn
33300C	Long Stem SPRT (0 °C to 661 °C) TPW to Al
33310C	Long Stem SPRT (0 °C to 962 °C) TPW to Ag
33320C	Additional Copy of Table from Results of 33010C–33310C at Time of Test
33330C	Additional Copy of Table from Results of 33010C–33310C at a Later Date
33340C	Minimum Charge for Unsuitable Thermometer
33350S	Special Tests of Resistance Thermometers
33360S	Special Tests of Thermometric Fixed-Point Devices
33370M	Measurement Assurance Program for Temperature 83 K to 420 °C (Ar to Zn)
33380M	Measurement Assurance Program for Temperature 83 K to 661 °C (Ar to Al)

Resistance Thermometers (33010C-33310C)

NIST provides calibration services for standard platinum resistance thermometers (SPRTs) from 13.8 K to 1235 K. Both long-stem and capsule-type SPRTs are calibrated, providing direct access to the International Temperature Scale of 1990 (ITS-90). There are eleven temperature subranges over which an SPRT may be calibrated according to the ITS-90 definitions. From 13.8 K to 83.8 K, SPRT calibrations are performed by comparison with a set of NIST reference thermometers. From 83.8 K to 962 °C, calibrations are performed using the ITS-90 defining fixed points as described in NIST Technical Note 1265. Expanded uncertainties*, as described in NISTIR 5319, for SPRT calibrations are given in Table 6.3. The comparison calibration of rhodium-iron resistance thermometers (RIRTs) in the temperature range from

*See Chapter 1, Section H for more information about uncertainty.

0.65 K to 26 K, using the NIST-maintained ITS-90, is based on a set of reference capsule-type RIRTs. The expanded uncertainty of those calibrations is given in Table 6.4. Extended range RIRT calibrations, for temperatures greater than 26 K and up to 83.8 K, are accomplished by comparison with reference capsule SPRTs in the range 26 K to 83.8 K.

Table 6.3. Maximum Expanded Uncertainties of SPRTs at NIST

Temperature Subrange (K)	Maximum Expanded Uncertainty* (mK)
13.8033 to 273.16	0.54[a]
24.5561 to 273.16	0.40[a]
54.3584 to 273.16	0.29[a]
83.8058 to 273.16	0.39
234.3156 to 302.9146	0.20
273.15 to 302.9146	0.04
273.15 to 429.7485	0.32
273.15 to 505.078	0.37
273.15 to 692.677	0.54
273.15 to 933.473	0.68
273.15 to 1234.93	1.1

[a] The uncertainty used at the Ar, Hg, and H_2O triple points are based on the fixed-point realization.
*See Chapter 1, Section H for more information about uncertainty.

Table 6.4. NIST Expanded Uncertainties for Comparison Measurements of RIRTs

Range (K)	Expanded Uncertainty* (mK)
0.65 to 2.0	0.5
2.0 to 5.0	0.08
5.0 to 8.8	0.17
8.8 to 13.8	0.21
13.8 to 17.0	0.34
17.0 to 20.3	0.18
20.3 to 24.5561	0.24
24.5561 to 54.3584	0.27
54.3584 to 83.8058	0.22

*See Chapter 1, Section H for more information about uncertainty.

To qualify for testing, either long-stem or capsule SPRTs must meet two conditions. They must meet the ITS-90 criteria** of W(Hg) ≤ 0.844 235 or W(Ga) ≥ 1.118 07, and for use above 660 °C the criterion of W(Ag) ≥ 4.284 4. Second, they must be compatible with the NIST calibration equipment. It is important that, insofar as possible, resistance thermometers be protected from any mechanical shock that could alter their calibration. For shipment, the thermometer should 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 be softly packed inside a shipping container. The shipping container must be sufficiently rigid and strong that it will not appreciably deform under the treatment usually given by common carriers. Styrofoam is not sufficiently rigid to be used as an outside container. Similarly, mailing tubes are unacceptable. Thermometers will not be returned in containers that are obviously unsuitable, such as those closed by nailing. Suitable containers will be provided when a thermometer shipping container is not satisfactory for re-use.

Special Tests of Resistance Thermometers and Special Tests of Thermometric Fixed-Point Devices (33350S and 33360S)

Special tests (e.g., certification, prototype testing) of various resistance thermometers and thermometric fixed-point devices may be made by prior arrangement with the specified technical contacts. Fixed-point cells may be sent to NIST for certification by the method of direct comparison with the applicable NIST laboratory standard fixed-point cell.

**See 1990 publication "The International Temperature Scale of 1990 (ITS-90)" reference at end of the section.

Measurement Assurance Program for Temperature (33370M and 33380M)

The purpose of this Measurement Assurance Program (MAP) is to assure the accuracy of the calibration of temperature standards (83 K to either 420 °C or 661 °C) conducted by participating laboratories when using platinum resistance thermometry. Other temperature ranges are available upon request.

The MAP transport standard consists of sets of three commercial SPRTs packaged in a special shock-proof shipping container (mechanical shock may shift calibration values). These SPRTs are used to assess both the reproducibility and the uncertainty of calibrations performed by the participating laboratory.

MAP participants should use the techniques described in NIST Technical Note 1265 and ITS-90 fixed-point cells, or use an SPRT previously calibrated by NIST. In order to achieve high accuracy, SPRTs used as standards should be either metal sheathed or of the matte-finish glass-sheathed type to avoid systematic errors arising from light-pipe effects in the glass sheath. The participant must have a triple point of water cell and an appropriate resistance bridge.

NIST provides worksheets on which the participant records data. The participant calculates the thermometer constants from experimental data, records them, and prepares tables of either resistance ratio or resistance versus temperature. These completed worksheets and the participant's calibration reports are sent to NIST with the return of the MAP SPRTs.

The SPRTs are recalibrated upon return to NIST and the participant's data are compared with NIST's calibration results. NIST provides a plot of the participating laboratory's temperature deviation from NIST values and a written analysis of the data, including any pertinent observations. In a typical MAP transfer, the participant makes measurements over a period of 1 to 2 months. A typical turnaround time from the date NIST receives the participant's data until a test report is sent to the participant is 4 to 6 weeks. Former participants in the MAP have had expanded uncertainties* that ranged from about 1 mK to several tens of millikelvins.

No rigid recommendations can be given concerning how often a participant should utilize the temperature MAP service. Experience has indicated that when temperature measurements are in a state of statistical control, as evidenced by in-house check standards and control charts used to monitor the measurement process, the participant should be able to go at least 3 years between transfers from NIST without significantly degrading the confidence in the correctness of the measurements.

Among other NIST Services for Temperature Calibration Laboratories, NIST provides Standard Reference Materials for use as defining fixed points of the ITS-90 and as secondary reference points.**

References—Resistance Thermometry

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*See Chapter 1, Section H for more information about uncertainty.

** See Chapter 1, Section C for information on the Standard Reference Materials Program.

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F. Radiance Temperature Measurements

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Mailing Address: Building 221, Room B208, National Institute of Standards and Technology, Gaithersburg, MD 20899-0001

Service ID No.	Items
	Calibration reports are issued giving the radiance temperature of the blackbody at 655.3 nm versus the scale reading, output current, or output voltage.
35010C	Radiance Temperature Standard, Disappearing Filament Optical Pyrometer (800 °C to 2400 °C, 4 to 12 points, 1 range)
35020C	Radiance Temperature Standard, Disappearing Filament Optical Pyrometer (each additional range up to 4200 °C, only available with 35010C)
35030C	Additional Interpolated Values
35040C	Radiance Temperature Standard, Disappearing Filament Optical Pyrometer (800 °C to 4200 °C, 3 or fewer points, 1 range)
	Calibration reports are issued giving the radiance temperature of the lamp at 655.3 nm versus the lamp current.
35050C	Radiance Temperature Standard, Ribbon Filament Lamp (800 °C to 2300 °C, 6 to 16 points)
35060C	Radiance Temperature Standard, Ribbon Filament Lamp (800 °C to 2300 °C, 5 or fewer points)
	Test reports are issued giving the radiance temperature of the blackbody at 655.3 nm, 900 nm, or 1000 nm versus the indicator reading, output current, or output voltage.
35070S	Special Tests of Radiation Thermometers

Standard	Temperature Range (°C)	Expanded Uncertainty* (°C)
Ribbon filament lamp	800 to 1600	0.7
	1600 to 1900	1.0
	1900 to 2300	1.5
Leeds & Northrup	800 to 1600	4
Model 8000 series	1600 to 2100	5
	1900 to 2300	7
Disappearing filament	2400 to 2700	8
optical pyrometer	2700 to 3200	17
	3200 to 4200	25
Pyrometer Instrument	800 to 1400	3
Model 95	1400 to 1800	4
Disappearing filament	1800 to 2400	5
optical pyrometer	2400 to 2700	8
	2700 to 3200	12
Infrared radiation	800 to 2000	2
thermometer	2000 to 2700	3

* See Chapter 1, Section H for more information about uncertainty.

This laboratory's quality system is based on the ANSI/NCSL Z540-1-1994 standard and the ISO/IEC Guide 25.

Disappearing Filament Optical Pyrometers and Ribbon Filament Lamps (35010C–35060C)

These calibration services provide access to the International Temperature Scale of 1990 (ITS-90) as realized by NIST for the temperature range 800 °C to 4200 °C. NIST disseminates the radiance temperature scale by issuing ribbon filament lamp standards of radiance temperature and by calibrating customer supplied pyrometers and radiation thermometers.

High-accuracy monochromatic disappearing filament optical pyrometers are calibrated in the full temperature range. Calibration reports are issued giving the radiance temperature of the NIST blackbody versus the test pyrometer scale reading, output current, or output voltage.

Ribbon filament lamps are calibrated using the NIST photoelectric pyrometer. Calibration reports are issued giving the radiance temperature of the test lamp at 655.3 nm versus direct current for the temperature range 800 °C to 2300 °C. The radiation thermometry portion of ITS-90 is defined in terms of the fixed temperature of the freezing point of gold (1064.18 °C) and the Planck equation for the radiation of a blackbody source. In practice, the temperature scale is realized by constructing a gold-point blackbody and a variable temperature blackbody, and then measuring the spectral radiance ratio at a red wavelength (approximately 650 nm) in terms of the Planck equation. Gold-point blackbodies are reproducible to 0.02 °C, but the temperature assignment of the freezing point of gold is uncertain by about 0.23 °C. The spectral radiance ratio measurements can be performed with a relative expanded uncertainty* of 0.2 % to 0.3 %. Smaller uncertainties than available in the routine services described above can be provided as special tests subject to the ITS-90 uncertainties noted. Calibrations at wavelengths other than 655.3 nm can be provided in the wavelength range 250 nm to 2500 nm subject to an additional uncertainty due to the quality of the variable temperature blackbody.

Special Tests of Radiation Thermometers (35070S)

Infrared thermometers are calibrated at 655.3 nm, 900 nm, and 1000 nm as special tests. Absorbing glass filters used for range changing in disappearing filament optical pyrometers can also be calibrated as special tests.

Calibration Schedule

Radiance temperature calibrations are performed in February, May, August, and November. Requests for calibration services are scheduled after the receipt of a purchase order.

* See Chapter 1, Section H for more information about uncertainty.

References—Radiation Thermometry

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G. Humidity Measurements

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Service ID No.	Items
36010C	Dew-Point Hygrometers (+25 °C to − 15 °C)
36020C	Dew-Point Hygrometers (−70 °C to − 15 °C)
36030C	Electric Hygrometers
36040C	Electrolytic Hygrometers
36050C	Aspirated Hygrometers
36060C	Pneumatic Bridge Hygrometers
36070S	Special Tests of Humidity

Hygrometers (36010C–36060C)

NIST 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 NIST two-pressure humidity generator. The instruments and ranges of calibration are listed below:

A. Dew-Point Hygrometers calibrated over the dew/frost range of −70 °C to + 60 °C.

B. Electric Hygrometers classified under this category are sensors which sorb water vapor as a function of relative humidity; associated with this sorption is a corresponding change in an electric parameter (that is, resistance, capacitance). The range of calibration is 3 % to 98 % relative humidity over the temperature range −55 °C to + 40 °C.

C. Psychrometers are wet-dry bulb hygrometers (aspirated psychrometers). The contact person should be consulted for the special features of the psychrometer which are necessary in order that the instrument can be calibrated at NIST.

D. Electrolytic Hygrometers are devices which electrolyze water into gaseous oxygen and hydrogen by the application of a voltage in excess of the thermodynamic decomposition voltage for water, and then measure the electrolysis current. The range of calibration in volume ratio is 10^{-6} to 3×10^{-2}.

E. Pneumatic Bridge Hygrometers are instruments that measure the variation of the 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 ratio (grams of water vapor/grams of dry air) is 0.0005 to 0.015.

Table 6.5 illustrates typical NIST uncertainties for measurement of humidity standards with atmospheric air at atmospheric pressures.

Special Tests of Humidity (36070S)

Tests for response time, hysteresis, and stability can be provided upon request.

Table 6.5. NIST Two-Pressure Humidity Generator, Mark 2, Range and Uncertainty

Humidity Parameter	Range	Expanded Uncertainty*
Mixing ratio, r_W (g water vapor/ kg dry air)	$0.0015 \le r_w < 0.005$	1.5 % of value
	$0.005 \le r_w < 0.1$	1.0 % of value
	$0.1 \le r_w < 0.3$	0.5 % of value
	$0.3 \le r_w < 515$	0.3 % of value
Volume ratio, V (× 10^{-6})	$3 \le V < 10$	1.5 % of value
	$10 \le V < 170$	1.0 % of value
	$170 \le V < 500$	0.5 % of value
	$500 \le V < 820\,000$	0.3 % of value
Dew point temperature, T_d (°C)	$-70 \le T_d < -35$	0.1 °C
	$-35 \le T_d < +40$	0.04°C
Relative humidity, RH (%) at test chamber temperature, T_c (°C) of:	$-55 \le T_c < -40$	3–98 1.5 %
	$-40 \le T_c < -20$	3–98 0.8 %
	$-20 \le T_c < 0$	3–98 0.2 %
	$0 \le T_c < +40$	3–98 0.2 %

* See Chapter 1, Section H for more information about uncertainty.

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Chapter 7

A. Photometric Measurements*

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Service ID No.	Items
37010C	Luminous Intensity and Color Temperature Standard Lamps
37020S	Special Tests for Luminous Intensity and Color Temperature of Submitted Lamps
37030C	Color Temperature Standard Lamps
37040C	Each Additional Color Temperature for 37030C
37050S	Special Tests for Color Temperature of Submitted Lamps
37060S	Special Tests for Total Luminous Flux of Submitted Incandescent Lamps and Fluorescent Lamps
37070C	Opal Glass Luminance Coefficient Standards
37080S	Special Tests for Submitted Luminance Sources and Transmitting Diffusers
37090S	Special Tests for Photometers, Illuminance Meters, and Luminance Meters
37100S	Special Photometric Tests
37110S	Special Tests for Submitted Flashing-Light Photometers

General Information

Calibration services in this area provide access to the photometric scales that are realized and maintained at NIST. Lamp standards of luminous intensity, luminous flux, and color temperature, as well as reference photometers and materials as described below, are issued or calibrated on a routine basis.

This laboratory's quality system is based on the ANSI/NCSL Z540-1-1994 standard and the ISO/IEC Guide 25.

*See Chapter 1, Section C for information on spectrophotometry standards available from the Standard Reference Materials Program.

Luminous Intensity and Color Temperature Standard Lamps (37010C)

NIST will issue to the customer 1000 W modified FEL (free electron laser) quartz halogen lamps calibrated for luminous intensity (candela) and color temperature (kelvin). These lamps have a double coil filament and a clear bulb, and are potted on a medium bipost base. The lamps are operated at approximately 7 A/85 V dc, at a color temperature of 2856 K. The relative expanded uncertainty** of the luminous intensity of these lamps is 0.6 % and the expanded uncertainty of the color temperature is 8 K at 2856 K.

Special Tests for Luminous Intensity and Color Temperature of Submitted Lamps (37020S)

NIST will calibrate the luminous intensity and color temperature of incandescent lamps with a medium bipost base submitted by customers. The inside frosted lamps, the airway beacon lamps, and the 1000 W FEL lamps previously issued by NIST can be submitted for recalibration. Customers can specify either the lamp current or the color temperature of the lamp (normally 2856 K) for calibration. The uncertainty of calibration is described above.

Color Temperature Standard Lamps (37030C)

NIST will issue to the customer 1000 W modified FEL quartz halogen lamps as described in 37010C calibrated for color temperature. The lamps are usually calibrated for a color temperature of 2856 K. The expanded uncertainty** of the color temperature of these lamps is 8 K at 2856 K.

Each Additional Color Temperature for 37030C (37040C)

The color temperature standard lamps issued for 37030C can be calibrated for additional color temperature points in a

**See Chapter 1, Section H for more information about uncertainty.

range from 2000 K to 3200 K. The expanded uncertainty* of this calibration is 4 K to 11 K in the range from 2000 K to 3200 K.

Special Tests for Color Temperature of Submitted Lamps (37050S)

NIST will calibrate the color temperature of incandescent lamps with a medium bipost base submitted by customers. The inside frosted lamps, the airway beacon lamps, and the 1000 W FEL lamps previously issued by NIST can be submitted for recalibration.

Special Tests for Total Luminous Flux of Submitted Incandescent Lamps and Fluorescent Lamps (37060S)

NIST will calibrate the total luminous flux (lumen) of incandescent lamps and fluorescent lamps submitted by customers. The standard lamps previously issued by NIST can be submitted for recalibration. Miniature lamps may also be accepted. Customers should contact NIST before submitting lamps. The relative expanded uncertainty* of this calibration is typically 1.0 % for incandescent lamps and 2.0 % for fluorescent lamps, depending upon the reproducibility of test lamps.

Opal Glass Luminance Coefficient Standards (37070C)

NIST will issue flashed opal glass plates, 51 mm × 51 mm, calibrated for luminance coefficient (ratio of luminance/illuminance, unit: sr^{-1}) for International Commission on Illumination (CIE) Illuminant A (2856 K source). The glass plates, masked with a circular aperture 25 mm in diameter, are calibrated for the luminance within a circular area of 1 cm in diameter in the center of the aperture. The relative expanded uncertainty* of this calibration is 0.8 %.

*See Chapter 1, Section H for more information about uncertainty.

Special Tests for Submitted Luminance Sources and Transmitting Diffusers (37080S)

NIST will calibrate luminance (cd/m^2) of submitted sources or the luminance coefficient (sr^{-1}) of submitted transmitting diffusers, including opal glass previously issued by NIST. Customers should contact NIST before sending sources or diffusers. The relative expanded uncertainty* of luminance calibration is 0.8 %.

Special Tests for Submitted Photometers, Illuminance Meters, and Luminance Meters (37090S)

NIST will calibrate photometers, illuminance meters, and luminance meters submitted by customers. Calibration is usually made with the CIE Illuminant A (2856 K incandescent source) in a range of 0.1 lx to 3000 lx for illuminance and 0.1 cd/m^2 to 4000 cd/m^2 for luminance. The relative expanded uncertainty* of calibration is 0.5 % for illuminance and 0.7 % for luminance at normal levels, which will increase at low levels. As an option, NIST can measure the relative spectral responsivity of submitted instruments and calculate spectral mismatch correction factors for a source of known spectral power distribution. Illuminance calibrations at a level up to 100 klx can also be made under a special arrangement.

Special Photometric Tests (37100S)

NIST can provide special tests for sources, detectors, and photometric instruments other than those stated above under limited conditions by special arrangements with NIST. Customers should contact NIST for consultation.

Special Tests for Submitted Flashing-Light Photometers (37110S)

NIST will calibrate submitted flashing-light photometers to measure integrated illuminance [lx · s] or effective intensity [cd]. Calibration is normally

* See Chapter 1, Section H for more information about uncertainty.

performed with white light (≈ 6500 K) from a xenon strobe light in the range of 1 lx · s to 100 lx · s and with red light using an Aviation Red filter. The relative expanded uncertainty* of calibration is ≈ 1 % or larger depending on the performance of the instrument under test.

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* See Chapter 1, Section H for more information about uncertainty.

B. Optical Properties of Materials Measurements*

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Service ID No.	Items
38010C	Spectral Transmittance Filters (Cobalt Blue Glass)
38020C	Spectral Transmittance Filters (Copper Green Glass)
38030C	Spectral Transmittance Filters (Carbon Yellow Glass)
38040C	Spectral Transmittance Filters (Selenium Orange Glass)
38050C	Wavelength Standards (Holmium Oxide Glass)
38060S	Special Tests of Spectral Transmittance or Spectral Reflectance (Directional-Hemispherical or Bidirectional Geometry) and Appearance
38070M	Measurement Assurance Program for Retroreflectance—Complete Package
38071M	Retroreflectance MAP—Sheeting Standards or Prismatic Standard with Colored Filters
38072M	Retroreflectance MAP—Sheeting Standards and Prismatic Standard without Colored Filters
38073M	Retroreflectance MAP—Sheeting Standards or Prismatic Standard without Colored Filters
38074M	Retroreflectance MAP—Colored Filters Only
38080M	Measurement Assurance Program for Transmittance

This laboratory's quality system is based on the ANSI/NCSL Z540-1-1994 standard and the ISO/IEC Guide 25.

Spectral Transmittance Filters (38010C–38040C)

NIST supplies to the customer 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. The relative expanded uncertainty** ranges from approximately 0.2 % to 0.3 % of the value. Information provided to the user includes values of transmittance at 25 °C at 10 nm intervals from 380 nm to 770 nm, the estimated uncertainty of each value, and data as to the effect of temperature change on transmittance at each wavelength.

Wavelength Standards (38050C)

NIST supplies to the customer holmium oxide glass standards 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 mm × 51 mm, or cuvette size [11 mm × 15 mm], approximately 2.5 mm thick. A table of wavelengths of minimum transmittance is provided in the report to the user. The expanded uncertainty** is 0.2 nm.

Special Tests of Spectral Transmittance or Spectral Reflectance (38060S)

Measurements of spectral transmittance can be made for the wavelength region 190 nm to 2500 nm. Measurements of absolute spectral reflectance factors (using either bidirectional or directional-hemispherical geometry) and of spectral specular reflectance (using bidirectional geometry) can be made for the wavelength region 250 nm to 2500 nm. Color and appearance attributes of materials are provided using bidirectional or directional-hemispherical geometry over the visible spectral region and can be extended depending on available instrumentation. However, arrangements for these measurements on submitted specimens must be made before shipment. The decision as to whether or not to perform the measurements and selection of the instruments to be used will rest with NIST. Specimens not accepted for measurement will be returned. Uncertainty estimates

*See Chapter 1, Section C for information on spectral reflectance standard artifacts available through the Standard Reference Materials Program.

** See Chapter 1, Section H for more information about uncertainty.

will be given and will depend on the optical characteristics of the submitted specimens and whether a primary or transfer instrument is used to perform the measurement.

Measurement Assurance Programs for Retroreflectance (38070M–38074M)

These Measurement Assurance Programs (MAPs) verify, within certain limits, how well a laboratory can measure the coefficient of luminous intensity. The verification is accomplished by means of a MAP package. The MAP package contains two white bead sheeting retroreflectors, one colorless prismatic retroreflector, and seven colored glass filters. The elements in this package are measured by NIST, then by the participating laboratory, and finally by NIST. Quality control procedures are maintained by using NIST master standards.

The use of three retroreflectors enables the determination of how well the participant can measure coefficient of luminous intensity for white or colorless samples of three kinds of geometries. The luminous transmittance of the seven colored glass filters can be used as a diagnostic tool to check measurements of coefficient of luminous intensity of colored retroreflectors. This is accomplished by checking the conformance of the source-receiver combination to CIE Illuminant A and CIE 2° standard observer respectively.

The coefficient of luminous intensity of each of the bead sheeting standards is measured at six combinations of observation and entrance angles. The coefficient of luminous intensity of the prismatic retroreflector is measured at 18 combinations of entrance and observation angles. The luminous transmittance of the filters is provided only for the spectral conditions of source and receiver specified above.

A general testing laboratory will probably need the service that utilizes the complete MAP package. However, some laboratories may be specialized. For this reason, we list five options that offer not only the complete package, but also some selected components. These options are:

A. Complete MAP package;
B. Sheeting standards or prismatic standard with colored filters;
C. Sheeting standards or prismatic standard without colored filters;
D. Sheeting standards and prismatic standard without colored filters; and
E. Colored filters only.

Even measurement of the complete MAP package achieves only part of the goal of a MAP service. To fully benefit from the MAP procedure, we suggest that the participant have on hand several check standards to be measured while also measuring the MAP package. These check standards can then be measured periodically to determine any gross error in measurement procedure, and a control chart can be constructed. A control chart is a plot of measurement result versus time, and the measurement process is normally considered to be under control if measurements fall within ± 2 standard deviations of the mean. For retroreflectance measurements where geometric errors are large, the standard deviation obtained after changing geometrical parameters may be large compared with that obtained from repeated measurements without changing the apparatus. Thus, the total variation for a given instrument can be obtained only by repetition over a period of time and realignment of the experimental apparatus.

The uncertainties of retroreflectometer measurements have three sources: uncertainties associated with values assigned by NIST to the MAP package, participant uncertainties, and uncertainties due to environment and sample interaction. Repeated measurements without changing the apparatus show that the NIST random error is small relative to the systematic errors. A large fraction of the latter arise when the retroreflector is rearranged and realigned for making measurements with different measurement parameters. The NIST relative expanded uncertainty* for retroreflectance measurement ranges from 2.7 % to 10 % of the value depending on the

*See Chapter 1, Section H for more information about uncertainty.

geometry and the type of retroreflectors. The NIST expanded uncertainty for luminous transmittance of the colored glass filters varies up to 0.002.

Measurement Assurance Program for Transmittance (38080M)

The Transmittance Measurement Assurance Program (MAP) provides a means for a laboratory to assess the uncertainty of its spectral transmittance measurement capabilities. A laboratory that participates in this program will be sent a package of transmittance filters that have been measured at NIST. These are to be measured by the laboratory on its spectrophotometer(s) and returned, together with the measurement results, to NIST. NIST will then remeasure the filters and send a final analysis of the results to the participating laboratory. The range of filter measurements provided in the MAP package permits an evaluation of the uncertainty of a laboratory's spectral transmission measurements and will often reveal the cause of any systematic errors that exist. The NIST expanded uncertainty* ranges from approximately 0.03 % to 0.3 % of the value for filters with nominal transmittance from 0.92 to 0.001.

The MAP package includes seven neutral density filters with nominal transmittances ranging from 0.92 to 0.001. The filters are available in three sizes. The filter holders are 51 mm × 51 mm, 51 mm × 38 mm, or standard cuvette. In addition, the package contains one didymium glass filter or cuvette-sized holmium oxide solution that is to be used for wavelength scale calibration. Several wavelengths of transmittance minima and points of inflection have been measured by NIST for the didymium filter. These wavelengths have been shown to be stable over long periods of time; therefore, these didymium filters are not normally measured by NIST with every use of the MAP package. The didymium filter is useful for triangular bandpasses between 1.5 nm and 10.5 nm with an expanded uncertainty* up to 0.2 nm. The holmium oxide solution has been certified at several wavelengths for bandpasses up to 3.0 nm with an expanded uncertainty* of 0.1 nm. It is strongly suggested that the participating laboratory acquire a set of check standards similar to the NIST filters for maintaining a control chart and measurement assurance.

*See Chapter 1, Section H for more information about uncertainty.

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C. Spectroradiometric Measurements

C.1 Spectroradiometric Source Measurements

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Service ID No.	Items
	NIST calibrates and issues a type 30A/T24/13 ribbon filament lamp with a mogul bi-post base.
39010C	Spectral Radiance Standard, Ribbon Filament Lamp (225 nm to 2400 nm)
39020C	Spectral Radiance Standard, Ribbon Filament Lamp (225 nm to 800 nm)
39030C	Spectral Radiance Standard, Ribbon Filament Lamp (650 nm to 2400 nm)
	NIST calibrates and issues a 1000 W, quartz halogen lamp mounted in a medium bi-post base. The calibrations are performed at 50 cm
39040C	Spectral Irradiance Standard, 1000 W Quartz-Halogen Lamp (250 nm to 1600 nm)
39045C	Spectral Irradiance Standard, 1000 W Quartz-Halogen Lamp (250 nm to 2400 nm)
	NIST calibrates and issues a 30 W deuterium arc lamp mounted in a medium bi-post base.
39050C	Spectral Irradiance Standard, 30 W Deuterium Lamp (200 nm to 400 nm)
39060S	Special Tests of Radiometric Sources

Calibration Schedule: Spectroradiometric source calibrations are performed in March, June, September, and December. Requests for calibration services are scheduled after receipt of a purchase order.

C.1. Spectroradiometric Source Measurements (39010C–39060S)

This laboratory's quality system is based on the ANSI/NCSL Z540-1-1994 standard and the ISO/IEC Guide 25.

Spectral Radiance Lamps (39010C–39030C)

Tungsten ribbon filament lamps (30A/T24/13) are supplied by NIST as lamp standards of spectral radiance. The lamps are calibrated at 34 wavelengths from 225 nm to 2400 nm, with a target area 0.6 mm wide by 0.8 mm high. The irradiance temperature ranges from about 2650 K at 225 nm, and 2475 K at 654.6 nm, to 1610 K at 2400 nm. Also see related services 40010C–40040S in next section.

Table 7.1. Calibration Uncertainties for Spectroradiometer Source Measurement

Standard	Wavelength (nm)	Typical values (W cm^{-3} sr^{-1})	Relative Expanded Uncertainty* (%)
Ribbon filament lamp	225	5.5	1.5
	250	36	1.3
	350	3.0×10^3	1.0
	655	1.3×10^5	0.6
	900	2.2×10^5	0.6
	1700	1.1×10^5	0.5
	2400	4.0×10^4	0.4
Quartz halogen lamp	250	0.2	1.8
	350	85	1.1
	655	170	0.9
	900	230	1.1
	1600	120	1.4
	2400	40	4.4
Deuterium arc lamp	200	0.5	5.0
	250	0.3	3.2
	400	0.05	3.2

*See Chapter 1, Section H for more information about uncertainty.

Spectral Irradiance Lamps (39040C–39050C)

These spectral irradiance standards are supplied by NIST. Lamp standards of spectral irradiance are provided in two forms. For general use, tungsten filament, 1000 W quartz halogen type FEL lamps are calibrated at 31 wavelengths in the range 250 nm to 2400 nm. The working distance is 50 cm. For use in the ultraviolet region, deuterium arc lamps are calibrated at 21 wavelengths from 200 nm to 400 nm. The deuterium lamps are intended

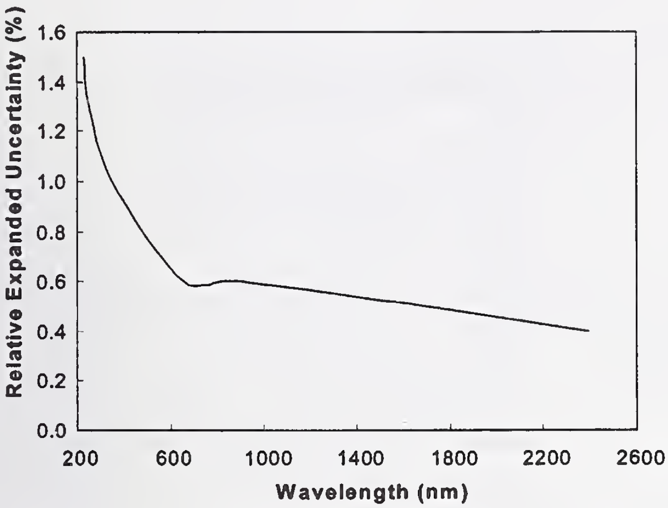

Figure 7.1. Measurement Uncertainty for NIST Spectral Radiance Calibrations.

primarily for the spectral region 200 nm to 250 nm. The relative expanded uncertainty* in relative spectral distribution is 3 %. It is strongly recommended that the deuterium standards be compared to an FEL tungsten standard over the range 250 nm to 300 nm each time the deuterium lamp is operated to take advantage of the accuracy of the relative spectral distribution.

Special Tests of Radiometric Sources (39060S)

Spectroradiometric source calibrations are performed in the Facility for Automatic Spectral Calibrations (FASCAL). This instrument has the capability of performing spectral radiance measurements from 200 nm to 2500 nm and measuring radiance temperatures from 1050 K to 2700 K with an adjustable spectral bandwidth down to 0.1 nm. Spectral irrdiance measurement capability from 200 nm to 2400 nm at flux levels down to 0.1 W/cm^3 is also available. For both spectral radiance and irradiance measurements a wide variety of sources and measurement geometries are possible. Special tests utilizing the capabilities of FASCAL are occasionally performed depending on the availability of the equipment and associated personnel.

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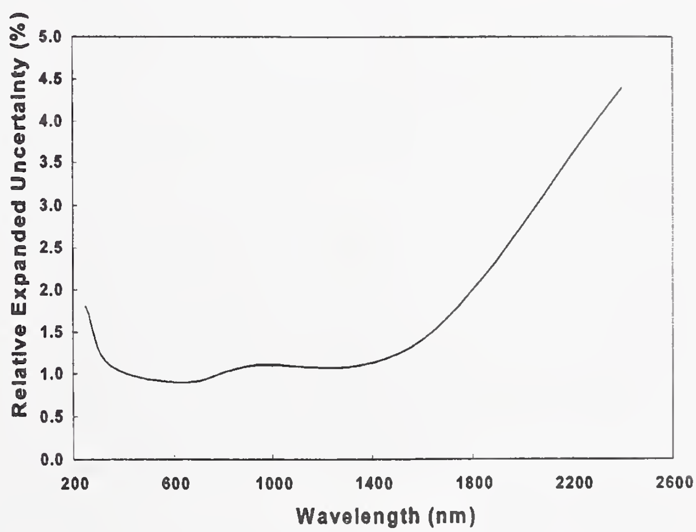

Figure 7.2. Measurement Uncertainty for NIST Spectral Irradiation Calibrations.

*See Chapter 1, Section H for more information about uncertainty.

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C. Spectroradiometric Measurements
C.2 Spectroradiometric Detector Measurements

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Service ID No.	Items
39071S	UV Silicon Photodiodes
39072S	Retest of UV Silicon Photodiodes
39073S	Visible to NIR Silicon Photodiodes
39074S	Retest of Visible to NIR Silicon Photodiodes
39075S	Special Tests of NIR Photodiodes
39080S	Special Tests of Radiometric Detectors
39081S	Special Tests of Photodetector Responsivity Spatial Uniformity
39090S	Special Tests of IR Detectors

This laboratory's quality system is based on the ANSI/NCSL Z540-1-1994 standard and the ISO/IEC Guide 25.

UV Silicon Photodiodes (39071S)

NIST will supply the customer with a 1 cm^2 UDT Sensors, Inc. model UV100 silicon photodiode characterized in the ultraviolet (UV) spectral region. The UV silicon photodiode includes the measured spectral responsivity (in the unit A/W) from 200 nm to 500 nm in 5 nm steps and the relative changes in responsivity over the photosensitive area at 350 nm. The photosensitive area of the photodiodes is under filled for the measurements with a 1.5 mm diameter beam. The spectral responsivity is measured at radiant power levels of less than 20 μW. The bandpass of the measurement is 4 nm. The relative expanded uncertainty* ranges from 0.4 % to 13 %, depending on the wavelength.

Retest of UV Silicon Photodiodes (39072S)

Special tests of previously supplied (39071S) NIST (UV) silicon photodiodes are performed by measuring spectral responsivitiy (in the unit A/W) from 200 nm to 500 nm.

Visible to Near Infrared (NIR) Silicon Photodiodes (39073S)

NIST will supply the customer with a 1 cm^2 Hamamatsu model S2281 silicon photodiode characterized in the visible to near infrared (NIR) spectral region. The spectral response (in the unit A/W) photodiode is measured from 350 nm to 1100 nm in 5 nm increments. The relative change in responsivity over the photosensitive area is also measured at 500 nm. The photosensitive area of the photodiodes is underfilled for the measurements with a 1.1 mm diameter beam. The spectral responsivity is measured at radiant power levels of less than 1 μW. The bandpass of the measurement is 4 nm. The relative expanded uncertainty* ranges from 0.2 % to 6 %, depending on the wavelength. The spectral range can be extended to 200 nm with a relative expanded uncertainty* from 0.2 % to 13 % for an additional fee.

Retest of Visible to NIR Silicon Photodiodes (39074S)

Special tests of previously supplied (39073S) NIST visible to NIR silicon photodiodes are performed by measuring responsivity (in the unit A/W) from 350 nm to 110 nm. The spectral range can be extended to 200 nm for an additional fee.

Special Tests of NIR Photodiodes (39075S)

Special tests of customer-supplied NIR photodiodes are performed by measuring spectral responsivity (in the unit A/W) from 700 nm to 1800 nm. A 1.1 mm diameter beam is centered on and underfills the photosensitive area.

*See Chapter 1, Section H for more information about uncertainty.

The spectral responsivity is measured at radiant power levels of less than 1 μW. The bandpass of the measurement is 4 nm. The relative expanded uncertainty* ranges from 0.7 % to 7 % or greater, depending on the wavelength and the individual item measured. Customers should contact Thomas Larason or Sally Bruce to discuss details before submitting a formal request.

Special Tests of Radiometric Detectors (39080S)

Special tests of radiometric detectors generally used in the ultraviolet, visible, and infrared regions of the spectrum can be performed. Responsivity of detectors can be measured between 200 nm and 1800 nm at power levels less than 4.0 μW. Examples of detector characteristics that can be determined in a special test include spectral responsivity (expressed in the unit A/W) and quantum efficiency (electrons per photon). The relative expanded uncertainty* ranges from 0.2 % to 13 % or greater, depending on the wavelength and the individual item measured. Measurements of the relative change in responsivity over the photosensitive area (responsivity spatial uniformity) are conducted under Service ID Number 39081S. Since special tests of this type are unique, details of the tests should be discussed with Thomas Larason or Sally Bruce before submitting a formal request.

Special Tests of Photodetector Responsivity Spatial Uniformity (39081S)

Special tests of measuring the relative changes in responsivity across the photosensitive area (responsivity spatial uniformity) can be performed for customer-supplied photodetectors. The uniformity is typically measured at a single wavelength in 0.5 mm spatial increments with a beam diameter of 1.5 mm in the 200 nm to 400 nm spectral region at power levels less than 20 μW, and a beam of diameter 1.1 mm in the 400 nm to 1800 nm spectral region at power levels less than 1 μW. The relative expanded uncertainty* ranges from 0.0024 % to 0.5 % or greater, depending on the wavelength and the individual item measured. Customers should contact Thomas Larason or Sally Bruce to discuss details before submitting a formal request.

Special Tests of IR Detectors (39090S)

Special tests of customer-supplied ambient temperature infrared detectors can be performed in the 2 μm to 20 μm wavelength range. Measurements at longer wavelength are possible, and may be provided to customers having special requirements. The special tests include spectral power responsivity and spatial response measurements. The standard configuration uses a 1.3 mm diameter monochromatic beam to under fill the active area of the detector with an f/# between f/4 and f/8. The monochromator output beam is chopped (≈39 Hz) and has a radiant power ranging from 1 μW at a wavelength of 4 μm to ≈10 nW at 18 μm. The optical bandpass of the measurement is ≈1 % of the test wavelength. The relative expanded uncertainty* is typically ≈5 %. Customers should contact George Eppeldauer to discuss details before submitting a formal request or to get information on extended measurement capability.

*See Chapter 1, Section H for more information about uncertainty.

Table 7.2. Detector Measurement Services Uncertainties*

Wavelength [nm]	UV 100 (UV)	S1337 (Visible)	GE (NIR)	InGaAs (NIR)
	Expanded Uncertainty Relative Estimated Uncertainty* $\delta S_{TEST}/S_{TEST}$ [%]			
200	13.10			
250	1.42			
300	2.56			
350	1.88	2.96		
400	1.50	1.56		
450	0.38	0.24		
500	0.38	0.22		
550		0.20		
600		0.20		
650		0.20		
700		0.20	2.48	2.50
750		0.22	1.98	2.02
800		0.22	1.86	1.88
850		0.24	1.54	1.58
900		0.22	1.28	1.30
950		2.62	1.88	1.90
1000		1.74	1.66	1.66
1050		3.16	1.80	1.82
1100		5.58	1.58	1.58
1150			1.94	1.94
1200			2.30	2.30
1250			2.60	2.60
1300			2.60	2.60
1350			3.46	3.46
1400			4.80	4.80
1450			4.64	4.64
1500			5.66	5.66
1550			5.06	5.08
1600			5.20	5.24
1650			6.10	6.14
1700			5.98	6.08
1750			5.98	6.10
1800			5.52	5.82

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* See Chapter 1, Section H for more information about uncertainty.

Table 7.3. NIST Spectroradiometric Detector Measurement Services

Service ID No.	Item of Test	Range (nm)	Relative Expanded Uncertainty* (%)
39071S	UV Silicon Photodiodes (UDT UV 100)	200 to 500	0.4 to 13
39072S	Retest of UV Silicon Photodiodes	200 to 500	0.4 to 13
39073S	Visible to NIR Silicon Photodiodes (Hamamatsu S2281)	400 to 1100	0.2 to 6
39074S	Retest of Visible to NIR Silicon Photodiodes (Hamamatsu S1337–1010BQ or S2281)	400 to 1100	0.2 to 6
39075S	Special Tests of NIR Photodiodes	700 to 1800	0.7 to 7
39080S	Special Tests of Radiometric Detectors	200 to 1800	0.2 to 13
39081S	Special Tests of Photodetector Responsivity Spatial Uniformity	200 to 1800	0.0024 to 0.5

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D. Radiometric Standards in the Far Ultraviolet
D.1 Standard Sources

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Service ID No.	Items
40010C	Spectral Irradiance Standard, Argon Mini-Arc (140 nm to 330 nm)
40020C	Spectral Radiance Standard, Argon Mini-Arc (115 nm to 330 nm)
40030C	Spectral Irradiance Standard, Deuterium Arc Lamp (165 nm to 200 nm)
40040S	Special Tests of Radiometric Devices in the Near and Vacuum Ultraviolet

This laboratory's quality system is based on the ANSI/NCSL Z540-1-1994 standard and the ISO/IEC Guide 25.

Source Calibrations in the Ultraviolet (40010C–40040S)

NIST maintains a collection of secondary standard sources such as argon maxi-arcs, argon mini-arcs, and deuterium arc lamps in the near and vacuum ultraviolet radiometric standards program to provide calibrations for user-supplied sources. The calibrations of these sources are traceable to a hydrogen arc whose radiance is calculable and which NIST maintains as a primary standard. Irradiance calibrations are now also traceable to the NIST electron storage ring, SURF II, against which working standard irradiance sources are periodically calibrated. The collection also includes tungsten strip lamps and tungsten halogen lamps whose calibrations are based on a blackbody rather than a hydrogen arc. Customer-supplied sources are calibrated in both radiance and irradiance by comparing them with NIST secondary standards.

Argon arcs are used to calibrate other sources in the wavelength range 115 nm to 330 nm for radiance and 140 nm to 330 nm for irradiance. The lower wavelength limit is determined in radiance by the cutoff of the magnesium fluoride windows used in the arcs and in irradiance by the decrease in signal produced by the addition of a diffuser. Deuterium arc lamps are used in the range 165 nm to 200 nm, with the low wavelength cutoff due to the onset of blended molecular lines. The high wavelength limit is the starting point of the range of another calibration group at NIST. (See Service ID Numbers 39010C–39050C, previous section.) The tungsten lamps are used at 250 nm and above, since their signals are too weak at shorter wavelengths. It should be noted that the wavelength range of the NIST arcs partially overlaps the range of tungsten lamps, thus providing an independent check on calibrations.

An argon mini-arc lamp supplied by the customer is calibrated for spectral irradiance at 10 nm intervals in the wavelength region 140 nm to 300 nm. Absolute values are obtained by comparison of the radiative output with laboratory standards of both spectral irradiance and spectral radiance. The spectral irradiance measurement is made at a distance of 50 cm from the field stop. Relative expanded uncertainties* are 10 % in the wavelength region 140 nm to 200 nm and 5 % in the wavelength region 200 nm to 330 nm. A measurement of the spectral transmission of the lamp window is included in order that the calibration be independent of possible window deterioration or damage. The spectral radiance of argon mini-arc radiation sources is determined with a relative expanded uncertainty* of 7 % over the wavelength range 140 nm to 330 nm and 20 % over the wavelength range 115 nm to 140 nm. The calibrated area of the 4 mm diameter radiation source is the central 0.3 mm diameter

*See Chapter 1, Section H for more information about uncertainty.

region. Typical values of the spectral radiance are as follows: at 250 nm, $L_\lambda = 30$ mW cm^{-2} nm^{-1} sr^{-1}; and at 150 nm, $L_\lambda = 3$ mW cm^{-2} nm^{-1} sr^{-1}. The transmission of the demountable lamp window and that of an additional MgF_2 window are determined individually so that the user may check periodically for possible long-term variations.

The deuterium arc lamp is calibrated at 10 wavelengths from 165 nm to 200 nm, at a distance of 50 cm. Typical values of spectral irradiance are 0.5 W/cm^3 at 165 nm, 0.3 W/cm^3 at 170 nm, and 0.5 W/cm^3 at 200 nm. The relative expanded uncertainty* is 10 %. The lamp is normally supplied by NIST and requires 300 mA at about 100 V.

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*See Chapter 1, Section H for more information about uncertainty.

D. Radiometric Standards in the Far Ultraviolet

D.2 Standard Detectors in the Far Ultraviolet

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Service ID No.	Items
40510C	Detector Standard, Windowless Photodiode (5 nm to 122 nm)
40511C	Recalibration of Detector Standard (5 nm to 122 nm)
40520C	Detector Standard, Windowless Photodiode (18 nm to 122 nm)
40521C	Recalibration of Detector Standard (18 nm to 122 nm)
40530C	Detector Standard, Windowless Photodiode (52 nm to 122 nm)
40531C	Recalibration of Detector Standard (52 nm to 122 nm)
40540C	Uncalibrated Windowless Photodiode
40560C	Detector Standard, Windowed Photodiode (116 nm to 254 nm)
40561C	Recalibration of Detector Standard (116 nm to 254 nm)
40599S	Special Tests on Detectors from the Ultraviolet (254 nm) to the Soft X-Ray Region (5 nm)

This laboratory's quality system is based on the ANSI/NCSL Z540-1-1994 standard and the ISO/IEC Guide 25.

Detector Calibrations in the Ultraviolet (40510C–40599S)

Calibrated transfer standard detectors for the far ultraviolet are available from NIST to cover the spectral region 5 nm to 254 nm. Users are furnished with the quantum efficiency as a function of wavelength; quantum efficiency is defined as the number of photoelectrons per incident photon. Three detector types are available to cover this range: (1) a windowless silicon semiconductor photodiode for the wavelength region 5 nm to 254 nm (available under Service ID No. 40599S); (2) a windowless photoemissive diode with an Al_2O_3 photocathode for the wavelength region 5 nm ro 122 nm; and (3) a MgF_2-windowed photodiode with a semi-transparent CsTe photocathode for the wavelength region 116 nm to 254 nm. The detectors have been extensively studied regarding radiometrically important parameters such as photocathode spatial uniformity and temporal stability of conversion efficiency. It should be noted that the silicon photodiode is not solar blind, while the windowless photoemissive diode is. Stray light considerations should be evaluated before making a choice for the 5 nm to 122 nm region.

The relative expanded uncertainties* in the measured quantum efficiencies are 7 % to 22 % in the 5 nm to 122 nm windowless photodiode region, and 9 % to 10 % in the 116 nm to 254 nm windowed photodiode region.

NIST working standard calbrations are based on the rare gas ionization chamber in the 5 nm to 92 nm region, and on the calculable synchrotron flux from the NIST electron storage ring, SURF II, at wavelengths longer than 110 nm. Two facilities at SURF II are used in these calibrations, one in the 5 nm to 50 nm region and a second in the 116 nm to 254 nm region. A separate laboratory facility is used for the 50 nm to 92 nm calibration of working standards.

Outgoing detectors are calibrated by direct intercomparison with precalibrated working standards that are periodically recalibrated. Windowless Al_2O_3 photodiodes are fabricated in-house; the windowless Si photodiodes and the windowed CsTe photodiodes are procured commercially and tested for stability and spatial homogeneity. Only those photodiodes meeting stringent NIST quality specifications are selected as transfer standards. The calibration costs include the cost of the detector and screening services unless a recalibration of previously used detectors is requested.

*See Chapter 1, Section H for more information about uncertainty.

Special detectors that do not lend themselves to convenient on-site cross-calibration may also be calibrated at NIST if the detectors merit radiometric application and if the NIST calibration facilities are suitable and available for the particular device.

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National Institute of Standards and Technology,
325 Broadway,
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Service ID No.	Items
42110C	Laser Power and Energy Meter (or Detectors Used with Lasers) Calibrations (single wavelength and power)
42111C	Same as 42110C, Additional Wavelengths or Powers
42120M	Laser Power and Energy Measurement Assurance Program (MAP)
42130C	Optical Fiber Power Meter (or Detectors Used with Lasers) Calibrations (single wavelength and connector type)
42131C	Same as 42130C, Additional Wavelengths or Connector Types
42140M	Optical Fiber Power Meter Measurement Assurance Program (MAP)
42150M	Low-Level Laser Measurement Assurance Program (MAP)
42151C	Low-Level Laser Radiometer Calibration
42160S	Special Test for Frequency Response Measurements of Detectors Used with Lasers
42161S	Special Test for Impulse Response Measurements of Detectors Used with Lasers
42162S	Special Tests for High Accuracy Laser and Optical Fiber Power Measurements
42163S	Special Test for Linearity Measurements of Laser and Optical Fiber Power Meters (or Detectors Used with Lasers)
42164S	Special Test for Spectral Responsivity Measurements of Laser and Optical Fiber Power Meters (or Detectors Used with Lasers)
42165S	Special Test for Spatial Uniformity of Laser and Optical Fiber Power Meters and Detectors Used with Lasers
42170S	Special Test for General Laser Measurements, by Prearrangement
42180S	Special Test for General Optical Fiber Power Measurements, by Prearrangement

General Information

The NIST Optoelectronics Division develops and maintains the U.S. national standards for the characterization of lasers, along with detectors and other optical and optoelectronic components used with lasers and in laser-based systems. These standards support applications of lasers in manufacturing, electronics, medicine, communications, and the military, among other fields, and are generally used to provide calibrations of instruments used in these areas.

For calibrating instruments used to measure the power or energy emitted by a laser, specially designed standards consisting of several types of isoperibol (constant temperature environment) calorimeters have been developed and used for many years. Low-level laboratory standards are realized using solid-state photodetectors and other thermal detectors. Well-characterized transfer standards (calibrated against the primary standards) are also maintained as laboratory standards for calibrations and for use in Measurement Assurance Program (MAP) intercomparisons. As part of a continuing process, new standards are being developed and implemented to improve accuracy and dynamic range. For example, the Division is developing ultra-high accuracy laser power measurement capability using a new cryogenically cooled electrical substitution laser power meter. The laboratory standards and secondary transfer standards are used in specially designed, beamsplitter-based calibration systems that allow various power and energy detectors to be compared to the standards.

The Optoelectronics Division maintains the capability of measuring other laser parameters, for example, beam profile and relative intensity noise. Because these measurements are generally less well defined than power and energy measurements, they are undertaken as Special Tests, after consultation with the customer. Instruments used in optical communications generally accept or receive optical power through a connectorized optical fiber.

Wavelength ranges of interest are generally centered on 850 nm, 1300 nm, and 1550 nm. In addition to power measurements in these ranges, calibrations of the frequency response (or impulse response) of detectors and analog and digital receivers used in optical communications can be provided. NIST also provides several Standard Reference Materials* for calibrating instruments used in optical communications.

The Optoelectronics Division can also characterize many other optical and optoelectronic components used with lasers. Within existing capabilities, Special Test measurements can be provided. Those needing such measurements are invited to contact the Division.

Laser Power and Energy Meter (or Detectors Used with Lasers) Calibrations (42110C–42111C)

Within the ranges listed in Table 7.4, NIST can perform calibrations at the power (or energy) and wavelength specified by the customer. These ranges are determined by the combined limits of our standards and available laser sources. For these measurements, the instrument to be measured is sent to NIST, where it is then compared to the appropriate laboratory reference standard using a calibrated beamsplitter measurement system. Normally, the response of the detector is characterized but no physical adjustments are made to the test instrument. At the completion of the calibration measurements, the instrument and a calibration report are sent to the customer. The calibration report summarizes the results of the measurements and provides a detailed listing of the associated measurement uncertainties.

The laboratory standard isoperibol calorimeters used as references for these measurements were designed and built at NIST and all their critical parameters (electrical calibration coefficient, absorptivity, window transmittance, etc.) have been evaluated for the laser wavelengths and energies for which they are used. The characteristic voltage response of the standard isoperibol calorimeters is described by first principles of thermodynamics and linear system analysis. Accurate quantitative responsivity characterization (including linearity and stability) of the calorimeters is accomplished by periodically performed, electrical heater calibrations.

The laser power and energy measurements are accomplished using a calibrated beamsplitter arrangement in which both the standard and the test meter are exposed to the laser beam simultaneously. In addition to the isoperibol calorimeters, solid-state photodiodes and trap detectors are used as laboratory standards, especially at powers below 1 mW. The beamsplitters used in these systems have been characterized for all specific wavelengths for which they are used. Small angles of incidence are used to minimize polarization and angular position uncertainties. The laser sources used for these calibration measurements with the primary standards consist of the following types (subject to change): (1) helium-neon (632.8 nm and 1523 nm), (2) argon ion (488.0 nm and 514.5 nm), (3) Nd:YAG (1064 nm and 1319 nm CW, and

* See Chapter 1, Section C for information on other thermodynamic property measurement standards available from the Standard Reference Materials Program.

Table 7.4. Laser Power and Energy Measurement Capabilities

Primary Standard	Wavelength	Power Range	Typical Relative Expanded Uncertainty** (%)
C-series	488.0, 514.5 nm	1 nW to 500 mW	0.5 to 1.0
	632.8 nm	1 nW to 20 mW	0.5 to 1.0
	830 nm	100 μW to 20 mW	0.5 to 1.0
	1064 nm	1 mWto 1 W	0.5 to 1.0
	1319 nm	100 μW to 100 mW	0.5 to 1.0
	1523 nm	100 μW to 1 mW	0.5 to 1.0
Q-series (Q-switched)	1.06 μm	1 mJ/pulse to 60 mJ/pulse 1 mWto 1 W	1.1 to 1.9
K-series	1.06 μm	1 W to 300 W	1.6 to 2.5
	10.6 μm	35 mWto 900 W	1.6 to 2.5
QUV-series	248 nm (pulsed)	0.4 mJ/pulse 150 mJ/pulse 3 nW to 7.5 W	1.0 to 3.0

**See Chapter 1, Section H for more information about uncertainty.

1064 nm Q-switched), (4) diode laser (825 nm to 833 nm), (5) carbon dioxide (10.6 μm) and (6) KrF excimer (248 nm).

Laser Power and Energy Measurement Assurance Program (MAP) (42120M)

The Measurement Assurance Program (MAP) is available at the wavelengths and powers listed in Table 7.4. The laser MAP intercomparisons are implemented by means of transfer standards, which have been evaluated and characterized relative to the national primary standards. The measurement system and primary standards discussed above are used to calibrate the transfer standards for the intercomparisons. The characteristics of these transfer standards are well understood, and their associated accuracies do not differ significantly from those associated with direct comparisons to the primary standards. For a specified wavelength and power or energy, the appropriate transfer standard is selected and sent from NIST to the MAP participant. The participant calibrates the NIST transfer standard using their measurement system and then returns both his data and the transfer standard to NIST. Before and after the NIST transfer standard is shipped to the participant, NIST performs calibration measurements on the detector to provide continuity during the intercomparison. At the completion of the intercomparison, NIST evaluates the participant's measurement results relative to the NIST calibration results on this same meter. A MAP intercomparison report summarizing the intercomparison and listing the associated measurement uncertainties is then submitted to the participant. Customers who have the capability and require higher accuracy may request MAP services using appropriate high-accuracy transfer standards such as the photodiode trap detectors.

Optical Fiber Power Meter (or Detectors Used with Lasers) Calibrations (42130C–42131C)

Optical fiber power meters are calibrated using an automated calibration system in which the test meter and the laboratory standard are alternately exposed to a stable diode laser source. During the measurement process, the input power to the test meter is monitored with a fiber coupler and reference detector assembly. Table 7.5 summarizes the current capabilities of this system. The laboratory standard used for these measurements is an electrically calibrated pyroelectric radiometer (ECPR) which has been calibrated against a primary standard calorimeter. Various diode laser sources are used to provide the available wavelengths. The calibrations can be accomplished with either a collimated beam or a connectorized fiber configuration. We can accommodate most commonly used fiber connectors (such as FC/PC, ST, biconic, SC, SMA, FC/APC, HMS-10 etc.).

Table 7.5. Measurement Capabilities of Automated Calibration System for Optical Fiber Power Meters

Laboratory Standard	Wavelength Window (nm)	Power Range (μW)	Typic Uncertaint (%)
ECPR	670	10 to 200	0.5 to 1.
ECPR	780	10 to 200	0.5 to 1.
ECPR	850	10 to 200	0.5 to 1.
EPCR	980	10 to 200	0.5 to 1.
EPCR	1300	10 to 200	0.5 to 1.
EPCR	1500	10 to 200	0.5 to 1.

*See Chapter 1, Section H for more information about uncertainty.

Optical Fiber Power Meter Measurement Assurance Program (MAP) (42140M)

NIST maintains a set of calibrated transfer standards, which are available for MAP intercomparisons of optical fiber power meters. These transfer standards are calibrated at the wavelengths listed in Table 7.6 using the optical fiber power meter calibration system discussed above. If the MAP is to be conducted using a fiber with attached connector, then customers are asked to provide the specific fiber and connector which is used in their laboratories. As in the laser MAP procedures listed above, measurements are made on the NIST transfer standard both before and after the MAP participant's measurements are conducted. At the conclusion of the MAP process, a calibration report that summarizes the measurements and associated uncertainties is sent to the participant.

Low-Level Laser Radiometer Calibrations and Measurement Assurance Program (MAP) (42150M)

NIST has designed and constructed special silicon and germanium diode detectors to measure pulse energy and peak power of low-level, 1064 nm laser pulses of about 10 ns to 150 ns duration. These diode detectors have been evaluated for spatial uniformity, bandwidth, and linearity, and are used as transfer standards for intercomparisons. The output response of each detector has been calibrated against a transfer standard which, in turn, has been calibrated against the C-series calorimeter. The system for calibrating these transfer standards uses a CW Nd:YAG laser whose radiation is acousto-optically modulated to produce short, well defined pulses. The beam intensity is attenuated to low-levels using a multiple reflection precision wedge beamsplitter. The transfer standards are available for intercomparisons at the powers listed in Table 7.6.

Table 7.6. Low-Level MAP Transfer Standards

Transfer Standard	Energy [Power Range]	Relative Expanded Uncertainty* (%)
Silicon PIN	10^{-14}(J/cm^2)/[pulse] to 10^{-11} (J/cm^2)/[pulse]	6 to 8
Germanium PIN	10^{-15} (J/cm^2)/[pulse]	15
Silicon APD	10^{-8} W/cm^2 [peak] to 10^{-4} W/cm^2 [peak]	6 to 8

Special Test for Frequency Response Measurements of Detectors Used with Lasers (42160S)

NIST measures the frequency response of photodetectors using the difference frequency beat note from 2 single frequency Nd:YAG lasers operating at 1319 nm. Measurements can be performed between 300 kHz and 50 GHz. Normalized frequency response is proportional to the ratio of the generated microwave power to the DC power supplied through the bias current. A photodetector suitable for calibration includes a connectorized fiber pigtail and precision coaxial microwave connector. Highest accuracy measurements are attained when the photodiode and power sensor are calibrated as one unit. A transfer standard of this type can be used to determine the optical modulation index of an arbitrary optical source with sinusoidal modulation. Options available include measurement of frequency response of a separate photodetector using NIST power sensors, or normalization to optical power to give absolute response. Each of these options gives a degradation in measurement uncertainty due to power sensor calibration and fiber connector insertion loss, respectively. Measurements may also include correction for electrical impedance mismatch when separate power sensors are used.

* See Chapter 1, Section H for more information about uncertainty.

Special Test for Impulse Response Measurements of Detectors Used with Lasers (42161S)

NIST uses a Ti:sapphire laser to generate 150 fs optical pulses in the 750 nm to 850 nm wavelength region. The electrical impulse resulting from the optical input to the detector is measured on a calibrated oscilloscope with 50 GHz bandwidth. The resulting waveform is Fourier-transformed, and the frequency response of the oscilloscope is deconvolved to give the magnitude of the photodetector frequency response.

High Accuracy Laser and Optical Fiber Power Measurements (42162S)

A cryogenically cooled electrical substitution radiometer (ESR) has been installed in our measurement laboratory and is now being thoroughly evaluated. Using this instrument as a reference, uncertainties smaller than those listed in Tables 7.5 and 7.6 are available on request for certain wavelengths and measurement conditions. These high accuracy measurements are appropriate only for certain transfer standards (such as photodiode trap detectors) capable of maintaining high accuracies.

Special Test for Linearity Measurements of Laser and Optical Fiber Power Meters (or Detectors Used with Lasers) (42163S)

Linearity of optical fiber power meters and detectors used with lasers can be measured at the three nominal wavelength regions of 850 nm, 1300 nm and 1550 nm using automated NIST-designed measurement systems. These systems are based on dual beam superposition, in which the radiation from two optical paths is incident (both jointly and individually) onto the detector. The system can provide linearity characterizations covering a 60 dB to 90 dB power range. Various other wavelengths and powers are also available upon request.

Special Test for Spectral Responsivity Measurements of Laser and Optical Fiber Power Meters (or Detectors Used with Lasers) (42164S)

Spectral responsivity measurements on laser power meters and detectors used with lasers can be performed over the wavelength region 450 nm to 1700 nm. High resolution spectral responsivity measurements can be performed over limited wavelength regions centered on 850 nm, 1300 nm, and 1550 nm. These limited-range spectral response measurements can be performed with or without connectorized fibers attached. Measurements over the wider wavelength region are also available at lower accuracy.

Special Test for Spatial Uniformity of Laser and Optical Fiber Power Meters (or Detectors Used with Lasers) (42165S)

Detector uniformity is measured using a specially designed system which provides a small beam of laser radiation (at nominal wavelengths of 850 nm, 1300 nm, or 1550 nm) which is scanned across the detector surface. The resulting detector output response is displayed graphically and analyzed statistically. This information is useful for characterizing the quality of a detector used with lasers and or identifying interference effects caused by, for example, windows with parallel surfaces. Other wavelengths are available upon request.

Special Test for General Laser Measurements (42170S)

The Optoelectronics Division conducts research not described specifically above on a variety of problems in the characterization of optoelectronics components. Consequently, we are interested in discussing and supporting all measurements involving laser detectors, sources, components, and instrumentation. Examples of measurement areas include beam profile, relative intensity noise (RIN), optical density or attenuation, and polarization (retardance).

Special Test for General Optical Fiber Power Measurements (42180S)

In support of instrumentation used with optical fiber power systems, various optical fiber power related measurements are available by request and prearrangement. These include power measurements at customer-selected wavelengths (in the ± 20 nm regions around 850 nm, 1300 nm, and 1550 nm), optical attenuator characterization, high power measurements, and power meter measurements involving unusual connector or fiber types.

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Chapter 8

A. Radioactivity Sources

Technical Contacts:

M. P. Unterweger	Jeffrey T. Cessna	Pamela A. Hodge	Diana Chatterton
All Services	43010C, 43020C, 43060C, 43070S	43030C–43050C	Administration and Logistics
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For shipping, see below.

Service ID No.	Items
43010C	Gamma-Ray-Emitting Radionuclides in Solution (Half Lives Greater Than 15 Days)
43020C	Gamma-Ray-Emitting Radionuclides in Solution (Half Lives Less Than 15 Days)
43030C	Alpha-Particle-Emitting Solid Sources, NIST 2 $\pi\alpha$ Proportional Counter
43040C	Alpha-Particle-Emitting Solid Sources, NIST 0.8 $\pi\alpha$ Defined-Solid-Angle Counter
43050C	Alpha-Particle-Emitting Solid Sources, Using Both Counting Systems
43060S	Special Tests of Beta-Particle-Emitting Solution Sources—Liquid Scintillation Counting
43070S	Special Tests of Beta-Particle-Emitting Solution Sources, Other Techniques
43090S	Special Tests of Alpha-Particle-Emitting Solid Sources

Radioactivity Sources—General Information (43010C–43090S)

The National Institute of Standards and Technology offers calibration services for over 50 radionuclides. Calibrations are provided to meet the requirements of industry, research, environmental monitoring, and the life sciences. Radioactivity calibration services are available for alpha-particle solid sources, beta-particle solutions, and gamma-ray solutions.

In order to offer such a broad range of services, NIST must place stringent limitations on the physical and chemical form and activity range of sources that can be accepted. To ensure that these specifications are understood, it is essential that there be good communication between the technical user and the technical contact at NIST. When planning to have a source calibrated, the user should discuss the following points with the NIST contact:

A. Type of calibration: More than one type of calibration is often available for a given source. A cobalt-60 source, for example, may be calibrated in terms of total activity or gamma-ray-emission rate. (Inquiries regarding the calibration of radioactive sources for exposure rate should be directed to the Dosimetry Group. See Service ID Numbers 47010C to 47040S.) The required uncertainty in the calibration should also be discussed.

B. General packaging and shipping requirements: Two general requirements apply to all sources submitted for calibration: (1) all shipments must conform to applicable Nuclear Regulatory Commission (NRC) and Department of Transportation (DOT) packaging and transport; and (2) source descriptions, including approximate activity, must be provided in advance. The NIST Health Physics Group must approve the receipt of radioactive material, and sources may be refused if the necessary information is not available.

C. Reports of Calibration: A Report of Calibration is sent upon completion of a radioactivity calibration service. If the user has particular requirements for documentation of the calibration, these should be discussed with the technical contact at NIST before the services are performed.

D. Sample Preparation, Packaging, and Shipping: All samples submitted for calibration must be chemically and physically stable. The chemical form of solutions suggested for beta-particle emitters and gamma-ray emitters are described later in this document. A special lot of borosilicate-glass ampoules must be used for gamma-ray emitters. Empty ampoules are provided for this purpose. The volume of material in the ampoule should be (5.0 ± 0.2) mL.

Packaging for all sources must be in compliance with DOT and NRC regulations. Copies of regulations may be obtained from Operations Division, Office of Hazardous Materials, Department of Transportation, Washington, DC 20950. Postal regulations prohibit the mailing of radioactive materials that require a caution label under DOT regulations.

Alpha-particle solid sources must be supplied in special source holders designed so that the active area is not touched by any material. For sources to be measured in the 2 πα counter (Service ID No. 43030C), the diameter of the source must be less than 10 cm and that of the active surface less than 9 cm. For the 0.8 πα counter (Service ID No. 43040C), the maximum diameter is 1.6 cm.

All sources arriving at NIST are checked by the Health Physics Group for radiation level and source integrity. Sources should be shipped to the attention of the technical contact at NIST, addressed, for example, as follows:

National Institute of Standards and Technology
Health Physics (Radioactivity Group)
Attn: (Name of technical contact)
Building 245, Room B131
Quince Orchard and Clopper Roads
Gaithersburg, MD 20899-0001

Gamma-Ray-Emitting Solution Sources (43010C–43020C)

Tables 8.1 and 8.2 list 41 radionuclide solutions that may be calibrated in the NIST "4π"γ ionization chamber. The sources must be submitted flame-sealed in the special ampoules provided by NIST. The operation of this type of chamber is described in NCRP Report 58, A Handbook of Radioactivity Measurements Procedures, Section 4.4 "Ionization Chambers," and in NBS SP 250-10, Radioactivity Calibrations with the "4π" Gamma Ionization Chamber and other Radioactivity Calibration Capabilities (see references).

Table 8.1. Specifications for Calibration of Solutions of Gamma-Ray Emitting Radionuclides Having Half Lives Greater Than 15 Days

Radio-nuclide	Typical Relative Expanded Uncertainty**(a) (%)	Activity Range(b) (Mbq)	Suggested Chemical Form(c)	
			Carrier	Solution
^{22}Na	1.1	0.4 to 40	NaCl	1 mol/L, HCl
^{46}Sc	0.5	0.4 to 40	$ScCl_3$	1 mol/L, HCl
^{51}Cr	0.7	2 to 60	$CrCl_3$	0.5 mol/L, HCl
^{54}Mn	0.8	2 to 60	$MnCl_2$	1 mol/L, HCl
^{57}Co	0.5	2 to 60	$CoCl_2$	1 mol/L, HCl
^{59}Fe	0.9	0.4 to 40	$FeCl_3$	1 mol/L, HCl
^{60}Co	0.5	0.4 to 40	$CoCl_2$	1 mol/L, HCl
^{75}Se	1.6	2 to 60	H_2SeO_3	1 mol/L, HNO_3
Sr	1.3	2 to 60	$SrCl_2$	1 mol/L, HCl
^{88}Y	0.5	0.4 to 40	YCl_3	1 mol/L, HCl
^{109}Cd–^{109m}Ag*	1.1	2 to 60	$CdCl_2$	1.3 mol/L, HCl
^{110m}Ag–^{110}Ag	0.6	0.4 to 40	$AgNO_3$	1 mol/L, HNO_3
^{113}Sn–^{113m}In(d)	2.0	2 to 60	$SnCl_2$ or $SnCl_4$	4 mol/L, HCl
^{114m}In	0.7	2 to 200	$InCl_2$	3 mol/L, HCl
^{123m} Te	0.7	2 to 100	TeCl	2 mol/L, HCl
^{133}Ba	1.0	2 to 60	$BaCl_2$	1 mol/L, HCl
^{134}Cs	0.7	2 to 60	CsCl	1 mol/L, HCl
^{137}Cs–^{137m}Ba	1.0	2 to 60	CsCl	1 mol/L, HCl
^{139}Ce	0.7	2 to 60	$CeCl_3$	1 mol/L, HCl
^{141}Ce	1.3	2 to 60	$CeCl_3$	1 mol/L, HCl
^{144}Ce*	0.9	2 to 740	$CeCl_3$	1 mol/L, HCl
^{152}Eu	1.1	0.4 to 40	$EuCl_3$	1 mol/L, HCl
^{153}Gd*	1.3	2 to 60	$GdCl_3$	1 mol/L, HCl
^{154}Eu	0.5	0.4 to 40	$EuCl_3$	4 mol/L, HCl
^{155}Eu	1.0	2 to 60	$EuCl_3$	4 mol/L, HCl
^{169}Yb*	1.7	2 to 60	$YbCl_3$	0.1 mol/L, HC
^{195}Au*	1.5	2 to 60	$KAu(CN)_4$	10 g/L, KCN 10 g/L, KCl
^{203}Hg	0.9	2 to 60	$Hg(NO_3)_2$	0.1mol/L,HNC

(a) The uncertainty will depend upon the activity level and the chemical form.
(b) The source activity should be in the indicated range when it arrives at NIST. The calibration scheduling must be coordinated with the NIST technical contact.
(c) This information is based in large part on the NIST Standard Reference Materials for these radionuclides. For those radionuclides marked with an asterisk, the carrier should be discussed with the NIST technical contact.
(d) The calibration for ^{113}Sn–^{113m}In are in terms of gamma-ray-emission rate rather than activity.
**See Chapter 1, Section H for more information about uncertainty.

Table 8.2. Specifications for Calibration of Gamma-Ray-Emitting Radionuclides Having Half Lives Less Than 15 Days

Radio-nuclide	Typical Relative Expanded Uncertainty**(a) (%)	Activity Range(b) (MBq)	Suggested Chemical Form(c) Carrier	Solution
^{24}Na	0.5	0.4 to 40	NaCl	1 mol/L, HCl
^{67}Ga	0.9	0.4 to 40	$GaCl_3$	2 mol/L, HCl
$^{99}Mo-^{99m}Tc$	1.1	2 to 60	Na_2MoO_4	4 mol/L, HNO_3
^{99m}Tc	1.0	2 to 60	No carrier added/ Na/TeO_4	Saline
^{111}In	0.9	2 to 60	$InCl_2$	3 mol/L, HCl
^{123}I*(c)	1.0	2 to 60	KI, Na_2SO_3	0.01 mol/L, LiOH
^{131}I*(c)	0.9	2 to 60	KI, Na_2SO_3	0.01 mol/L, LiOH
$^{140}Ba-^{140}La$	2.3	0.4 to 40	$Ba(NO_3)_2$, $La(NO_3)_3$	1 mol/L, HCl
^{186}Re	0.6	2 to 600	$ReCl_3$	Saline
^{197}Hg	1.6	2 to 60	$Hg(NO_3)_2$	0.1 mol/L, HNO_3
^{198}Au	0.9	2 to 60	$KAu(CN)_4$	10 g/L, KCl, 10 g/L, KCN
^{201}Tl	1.3	2 to 60	$Tl(NO_3)_3$	0.9 mol/L, HNO_3
^{203}Pb	1.1	2 to 60	$PbCl_2$	0.5 mol/L, HCl

(a) The uncertainty will depend upon the activity level and chemical form.
(b) The source activity should be in the indicated range when it arrives at NIST. The calibration scheduling must be coordinated with the NIST technical contact.
(c) This information is based in large part on the NIST Standard Reference Materials for these radionuclides. For those radionuclides marked with an asterisk, the carrier should be discussed with the NIST technical contact.
**See Chapter 1, Section H for more information about uncertainty.

Alpha-Particle-Emitting Solid Sources (43030C–43050C)

Alpha-particle sources may be calibrated using the NIST 2 π proportional counter, or the NIST 0.8 πα defined-solid-angle counter. The former calibration is in terms of alpha-particle-emission rate into 2 πα steradians, while the latter is in terms of total activity. Sources to be measured by 2 πα proportional counting should be on an electrically conductive backing. A more detailed comparison of these counting systems is given in NCRP Report 58 (Section 3.7) and in NBS SP 250-5, Alpha-Particle Calibrations.

Backscattering corrections for a variety of source-mount materials are discussed in the references given. The source thickness must be such that more than 99.5 % of the emitted alpha particles have an energy greater than 400 keV. Further specifications for these calibration services are given in Table 8.3. Service ID No. 43050C includes calibration of the same source using both counting systems.

Large area sources of plutonium-238 may also be measured providing the source thickness is as above. The activity range is 10^2 Bq to 10^5 Bq utilizing large-area internal and external counters.

Table 8.3. Specifications for Calibrations Using the 2 πα Proportional Counter and the 0.8 πα Defined Solid Angle Counter

	Service ID No. 43030C	Service ID No. 43040C
Counting System	NIST 2 πα proportional counter	NIST 0.8 πα defined-solid-angle-counter
Sources Calibrated For:	Alpha-particle-emission rate into 2 πα steradians either above 400 KeV or extrapolated to zero KeV	Total activity
Typical Relative Expanded Uncertainty**(a) (%)	1.0	1.0
Activity Range	$\approx(0.4 \text{ to } 10^4)$Bq	$\approx(40 \text{ to } 10^4)$Bq
1.0 %Maximum Source Diameter	10 cm (9 cm active surface)	1.6 cm

(a)The uncertainty will depend upon the activity level and source geometry.
**See Chapter 1, Section H for more information about uncertainty.

Table 8.4. Specifications for Special Tests of Beta-Particle-Emitting Solution Sources

Radio-nuclide	Typical Relative Expanded Uncertainty*[(a)] (%)	Suggested Chemical Composition[(b)] Carrier	Solution
^{3}H	0.7	H_2O	H_2O
^{14}C	1.0	Na_2CO_3	0.001 mol/L, NaOH
^{32}P[(c)]	0.7	H_3PO_4	0.0034 mol/L, H_3PO_4
^{33}P	0.7	H_3PO_4	0.0034 mol/L, H_3PO_4
^{35}S	0.7	Li_2SO_4	0.1 mol/L, HCl
^{36}Cl	1.3	NaCl	H_2O
^{89}Sr	0.7	$SrCl_2$	1 mol/L, HCl
$^{90}Sr-^{90}Y$	0.7	$SrCl_2/YCl_3$	1 mol/L, HCl
^{90}Y	0.7	YCl_3	1 mol/L, HCl
^{147}Pm	0.7	$PmCl_3$	1 mol/L, HCl
^{204}Tl	1.3	$Tl(NO_3)_3$	1 mol/L, HNO_3

(a) The uncertainty will depend upon the activity level and the chemical form.
(b) The chemical composition is critical for these calibrations and should be discussed before sending the source.
(c) This calibration includes a half-life fit to determine the ^{33}P impurity.
*See Chapter 1, Section H for more information about uncertainty.

Special Tests of Beta-Particle-Emitting Solution Sources (43060S and 43070S)

Beta-particle-emitting solutions that conform to the physical, chemical, and activity specifications for measurement are assayed by liquid-scintillation counting. The specifications are shown in Table 8.4. The suggested radioactivity concentration range is (20 to 2000) kBq/g.

No examination is made for beta-particle-emitting impurities, except in the case of phosphorus-32 where a half-life fit is made. The sources will be examined for gamma-ray emitting impurities.

Measurement of beta-particle-emitting solutions by techniques other than liquid-scintillation may be made by special arrangement.

Special Alpha-Particle-Emitting Solid Sources (43090S)

Special arrangements may be made for measurements of solid alpha-particle-emitting sources with emission rates exceeding 1.1×10^4 Bq.

References—Radioactivity Sources

NBS Measurement Services: Radioactivity Calibrations with the "4π" Gamma Ionization Chamber and Other Radioactivity Calibration Capabilities, J. M. Calhoun, Natl. Bur. Stand. (U.S.), Spec. Publ. 250-10 (Oct. 1987).

NBS Measurement Services: Alpha-Particle Calibrations, J. M. R. Hutchinson, Natl. Bur. Stand. (U.S.), Spec. Publ. 250-5 (July 1987).

NCRP Report 58, A Handbook of Radioactivity Measurements Procedures, Section 3.7—Alpha-Particle Counting, W. B. Mann, Ed., Natl. Council Rad. Protect. and Meas., Washington, DC (1985).

Study of the Scattering Correction for Thick Uranium-Oxide and Other-Particle Sources, I: Theoretical, L. L. Lucas and J. M. R. Hutchinson, Int. J. Appl. Radiat. Isotopes **27**, 35 (1976).

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An Experimental Study of the Backscattering of 5.3 MeV-Alpha Particles from Platinum and Monel Metal, D. H. Walker, Int. J. Appl. Radiat. Isotopes **16**, 183 (1965).

B. Neutron Sources and Neutron Dosimetry

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Service ID No.	Items
44010C	Radioactive Neutron Sources (emission rates 10^5 s^{-1} to 10^8 s^{-1})
44020C	Radioactive Neutron Sources (emission rates 10^8 s^{-1} to 10^{10} s^{-1})
44060C	Personnel Protection Instrumentation, Californium Source Bare and Moderated
44070C	Activation Detector Dosimetry, Thermal Neutrons
44080C	Activation Detector Dosimetry, Californium Fission Neutrons
44090C	Activation Detector Dosimetry, ^{235}U Cavity Fission Source
44100S	Special Tests of Neutron Sources and Dosimeters

Radioactive Neutron Sources (44010C–44020C)

NIST provides calibration services for radioisotope neutron sources with emission rates from 5×10^5 s^{-1} to 1×10^{10} s^{-1}. Neutron source emission rates are determined by the manganous sulfate bath method, in which the emission-rate of the source to be calibrated is compared to the emission-rate of NBS-1, the national standard Ra-Be photoneutron source. Neutron source calibrations typically have a relative expanded uncertainty* of about 3.4 %, depending on the details of the source encapsulation.

*See Chapter 1, Section H for more information about uncertainty.

Personnel Protection Instrumentation (44060C)

Neutron personnel instruments, both passive (e.g., dosimeters) and active (e.g., remmeters) are calibrated on the basis of a certified free-field dose-equivalent or dose equivalent rate. Two ^{252}Cf source-driven neutron fields are available on a routine basis for this purpose: bare source and heavy-water-moderated ^{252}Cf fission neutron sources. Thermal neutron beams are also available for special requirements under Service ID No. 44100S. For both bare and moderated ^{252}Cf source exposures, maximum dose-equivalent rates are about 5 mSv/h. The relative expanded uncertainty* is 10 %.

Activation Detector Dosimetry (44070C-44090C)

Passive neutron detectors, generally activation foils, can be irradiated to a certified neutron fluence (or average fluence-rate) in a fission neutron spectrum or a Maxwellian thermal neutron field. Typical irradiation parameters are given in Table 8.5.

Table 8.5. Irradiation Parameters for Fission Spectra and Maxwellian Thermal Neutron Fields

Neutron Field	Typical Maximum Neutron Fluence (cm^{-2})	Typical Maximum Neutron Fluence Rate (cm^{-2}·s^{-1})	Relative Expanded Uncertainty* (%)
^{252}Cf Fission Source	5×10^{12}	2×10^{7}	2.6[(b)]
^{235}U Cavity Fission Source[(a)]	5×10^{15}	2×10^{10}	4.6[(b)]
Thermal Neutrons Beam[(c)]	1×10^{13}	8×10^{7}	5
Isotropic	$>1\times10^{16}$	2×10^{11}	5

(a) Threshold detectors only. Maximum size of detector disks: 12.7 mm dia.× about 3 mm thick. The radial gradient of the fluence: is about 20 % center-to-edge.
(b) Uncertainty includes neutron scattering corrections.
(c) Maxwellian distribution corresponding to a temperature of about 40 °C.
*See Chapter 1, Section H for more information about uncertainty.

Special Tests of Neutron Sources and Dosimeters (44100S)

Other tests of dosimetry instrumentation may be undertaken by special arrangement with the Ionizing Radiation Division. In particular for personnel protection instruments, a thermal beam can provide dose equivalent rates of up to approximately 10 mSv/h across a 30 cm diameter circle.

References—Radioactive Neutron Sources

NBS Measurement Services: Neutron Source Strength Calibrations at NBS by the Manganese Sulfate Bath Method, E. D. McGarry and E. W. Boswell, Natl. Bur. Stand. (U.S.), Spec. Publ. 250-18 (Mar. 1988).

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References—Personnel Protection Instrumentation

NBS Measurement Services: Neutron Personnel Dosimetry, R. B. Schwartz, Natl. Bur. Stand. (U.S.), Spec. Publ. 250-12 (July 1987).

Procedures for Calibrating Neutron Personnel Dosimeters, R. B. Schwartz, Natl. Bur. Stand. (U.S.), Spec. Publ. 250-12 (July 1987).

Calibration Techniques for Neutron Personnel Dosimetry, C. M. Eisenhauer, J. B. Hunt and R. B. Schwartz, Radiat. Prot. Dosim. **10**, 43–57.

The Design and Construction of a D_2O-Moderated ^{252}Cf Source for Calibrating Neutron Personnel Dosimeters Used at Nuclear Power Reactors, R. B. Schwartz and C. M. Eisenhauer, U.S. Nucl. Reg. Com. Doc. NUREG/CR-1204 (Jan. 1980).

References—Activation Detector Dosimetry

NBS Measurement Services: Activation Foil Irradiations at NBS by Californium Fission Sources, G. P. Lamaze and J. A. Grundl. Natl. Bur. Stand. (U.S.), Spec. Publ. 250-13 (Mar. 1988).

NBS Measurement Services: Activation Foil Irradiations at NBS by Reactor Cavity Sources, G. P. Lamaze and J. A. Grundl, Natl. Bur. Stand. (U.S.), Spec. Publ. 250-14 (Mar. 1988).

Derivation of Neutron Exposure Parameters from Threshold Detector Measurements, J. A. Grundl, Proc. Sixth ASTM-Euratom Symp. on Reactor Dosimeter, Jackson, WY (June 1987).

Compendium of Benchmark Neutron Fields for Reactor Dosimetry, J. A. Grundl and C. M. Eisenhauer, Natl. Bur. Stand. (U.S.), NBSIR 85-3151 (Apr. 1985).

The U.S. ^{235}U Fission Spectrum Standard Neutron Field Revisited, E. D. McGarry, C. M. Eisenhauer, D. M. Gilliam, J. A. Grundl, G. P. Lamaze, and A. Fabry, Proc. Fifth ASTM-Euratom Symp. on Reactor Dosimetry, Geesthacht, Germany (Sept. 1984).

National Standards for Neutron Measurements, J. A. Grundl, Proc. of a Meeting on Traceability for Ionizing Radiation Measurements, Natl. Bur. Stand. (U.S.), NBS Spec. Publ. 609 (Feb. 1982).

Utilization of Standard and Reference Neutron Fields at NBS, C. M. Eisenhauer, D. M. Gilliam, J. A. Grundl, and V. Spiegel, Proc. Second ASTM-Euratom Symp. on Reactor Dosimetry, Palo Alto, CA (Oct. 1977).

A Californium-252 Fission Spectrum Irradiation Facility for Neutron Reaction Rate Measurements, J. A. Grundl, V. Spiegel, C. M. Eisenhauer, H. T. Heaton II, D. M. Gilliam (NBS), and J. Bigelow (ORNL), Nucl. Tech. **32**, 315 (Mar. 1977).

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

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Service ID No.	Items
C.0	**Special Instructions for Using Electron and Photon Dosimetry Services (46010C–48020S)**
C.1	**X-Ray and Gamma-Ray Measuring Instruments**
46010C	Radiation Detectors—Calibration/Correction Factor, One Beam Quality (See Tables 8.6, 8.7 and 8.8)
46011C	Each Additional Beam Quality or Condition
46020C	Passive Dosimeters—Irradiation of Up to Six, One Beam Quality at One Set-Up
46021C	Up to Six Additional Dosimeters at Same Set-Up and Beam Quality
46030S	Special Tests of High-Gain Electrometers—Charge Sensitivity, One Set of Switch Positions, with 46010C/46011C, by Prearrangement
46040S	Special Tests of X-Ray Penetrameters, Ardran-Crookes Type
46050S	Special Tests of X-Ray and Gamma-Ray Measuring Instruments
C.2	**Gamma-Ray Sources, Beta-Particle Sources, and Measuring Instruments**
47010C	Gamma-Ray Sources Similar to NIST Standards—^{60}Co or ^{137}Cs Having Air-Kerma Strengths 10 μGy m^2/h to 1500 μGy m^2/h, and ^{125}I or ^{192}Ir Sources: Same Type Seeds Used to Calibrate Reentrant Chamber Having Air-Kerma Strengths 0.1 μGy m^2/h to 30 μGy m^2/h
47011C	Each Additional Gamma-Ray Source of Same Radionuclide
47030C	Beta-Particle Sources Calibrated for Surface Dose Rate
47035C	Beta-Particle Sources Calibrated for Radiation Protection
47036C	Ionization Chambers Calibrated with Beta-Particle Sources for Radiation Protection
47040S	Special Tests of Gamma-Ray and Beta-Particle Sources
C.3	**Dosimetry of High-Energy Electron Beams**
48010M	Dose Interpretation of NIST-Packaged Dosimeters Irradiated by Customer—Two Dosimeters
48011M	Each Additional Dosimeter
48020S	Special Tests of Electron-Beam Dosimeters

C.0 Special Instructions for Using Electron and Photon Dosimetry Services (46010C–48020S)

The NIST dosimetry calibration and test services for x rays, gamma rays, beta particles, and electrons are performed in NIST's laboratories at Gaithersburg, Maryland. Inquiries should be addressed to the appropriate technical contacts listed at the beginning of this section. The inquirer must provide the name and telephone number of an individual who can answer technical questions that may arise in any inquiry, order, or shipment.

Upon receipt of a purchase order, a report number is assigned. Calibrations are generally performed in the sequence established by those numbers, except when greater efficiency can be achieved by combining similar calibrations, or when work for a calibration laboratory is given a higher priority. Arrangements for calibration must be made in advance by letter, fax, e-mail or telephone, so that the instrument or source to be calibrated will not be shipped to NIST until the time of its scheduled calibration approaches. Inquiry should be made as to scheduling and turn-around time.

Except in the event of negligence by its personnel, NIST assumes no responsibility for loss of or damage to the instruments or sources while in its possession. The risk should be covered by insurance.

The report of calibration or test will carry a DG number (e.g., DG 9603/95). Subsequent reference to that calibration or test should cite the DG number.

C.1 X-Ray and Gamma-Ray Measuring Instruments (46010C–46050S)

X-ray measuring instruments are calibrated in terms of air kerma or exposure by a substitution method in an x-ray beam at a point where the rate has been determined by means of a free-air ionization chamber standard. In order to provide instrument calibrations over a wide range of x-ray beam qualities, many combinations of generating potential and filtration are available. Tungsten (W) anode, x-ray beams with U.S. established beam qualities are listed Table 8.6 as lightly (L), moderately (M), and heavily (H) filtered beams. Two beam qualities that do not fit into these categories are considered as special (S) qualities. Cobalt-60 and cesium-137 gamma-ray beams are also available. New W-anode, ISO x-ray beam qualities, listed in Table 8.7 are being installed; check for availability. Molybdenum (Mo) and rhodium (Rh) anode x-ray beam qualities, with application to mammography, are listed in Table 8.8. Beam qualities are identified by beam codes given in the first column. The calibration beam qualities requested should be appropriate to the instrument submitted.

Gamma-ray measuring instruments are calibrated in terms of air kerma, 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 (or water) calorimeter. Rates at the time of calibration are computed from the original beam standardization data and appropriate decay corrections. Ionization chambers submitted for an air kerma calibration should have sufficient wall thickness to provide electron equilibrium for the highest energy selected. Ionization chambers submitted for an absorbed-dose calibration must be suitable for calibration in a phantom.

An ionization chamber and electrometer combination, with the electrometer scale in units of air kerma, exposure, or absorbed dose, is calibrated by providing a dimensionless correction factor for the electrometer scale. An ionization chamber and electrometer combination marked in electrical units is calibrated as follows: (1) the chamber is calibrated in terms of air kerma or absorbed dose per unit charge using an NIST electrometer; (2) the customer's electrometer is checked for linearity and charge measurement accuracy; and (3) the combination of chamber and electrometer is checked for consistency. An ionization chamber submitted without an electrometer is calibrated in terms of air kerma or absorbed dose per unit charge. Calibration can be based on measurements for positive or negative polarizing potential, or on the mean of measurements for both potentials, as requested. The ratio of ionization currents for full and half polarizing potentials and the corresponding ionization current will be stated in the calibration certificate, based on pre-calibration measurements.

Table 8.6. Tungsten-Anode X-Ray and Gamma-Ray Beam-Quality Parameters

Beam Code	Added Filter				Half-Value Layer		Homogeneity Coefficient		Effective Energy	Air-Kerma Rate	
	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)	Al	Cu	(keV)	Min. (μGy/s)	Max. (mGy/s)
X-Ray Beams											
L10	0				0.029		79			0.009	15
L15	0				0.05		74			0.009	37
L20	0				0.071		76			0.009	29
L30	0.265				0.22		60			0.009	4
L40	0.5				0.49		57			0.009	4
L50	0.639				0.75		58			0.009	4
L80	1.284				1.83		58			0.009	4
L100	1.978				2.8		59			0.009	4
M20	0.23				0.152		79			0.009	4.4
M30	0.5				0.36		64			0.009	3
M40	0.786				0.73		66			0.009	4
M50	1.021				1.02	0.032	66	62		0.009	4
M60	1.51				1.68	0.052	68	64		7	2
M80[a]					3						
M100	5				5	0.2	72	55		9	3
M120[a]					7						
M150	5	0.25			10.2	0.67	87	62		9	4
M200	4.1	1.12			14.9	1.69	95	69		9	3
M250	5	3.2			18.5	3.2	98	86		9	2
M300	4.		6.5		22	5.3	100	97		4	0.7
H10	0.105				0.048		89			0.009	0.03
H15	0.5				0.152		87			0.009	0.03
H20	1.021				0.36		88			0.009	0.03
H30	4.13				1.23	0.038	93	94		0.009	0.03
H40	4.05	0.26			2.9	0.093	94	95		0.009	0.03
H50	4			0.1	4.2	0.142	92	90	38	3	0.6
H60	4	0.61			6	0.24	94	89	46	0.2	0.04
H100	4	5.2			13.5	1.14	100	94	80	0.04	0.02
H150	4	4	1.51		17	2.5	100	95	120	0.3	0.09
H200	4	0.6	4.16	0.77	19.8	4.1	100	99	166	0.2	0.05
H250	4	0.6	1.04	2.72	22	5.2	100	98	211	0.3	
H300	4.1		3	5	23	6.2	99	98	252	0.4	0.03
S75	1.504				1.86		63			0.009	4
S60	4.0				2.8	0.089	75	70		3	0.5
Gamma-Ray Beams											
^{137}Cs						10.8			662	1.5	1.1
^{60}Co						14.9			1250	0.11	6.2

For the x-ray beam codes, the letter indicates light (L), moderate (M), heavy (H), and special (S) filtration and the number is the constant potential in kilovolts.

The inherent filtration is approximately 1.0 mm Be for beam codes L10–L100, M20–M50, H10–H40, and S75; and 3.0 mm Be for beam codes M60–M300, H50–H300, and S60.

The half-value layers for ^{137}Cs and ^{60}Co are calculated.

The homogeneity coefficient is taken as 100 (1st HVL/2nd HVL).

[a] Beam parameters are nominal; actual values should be available by 1998.

Table 8.7. Tungsten-Anode ISO X-Ray Beam Quality Parameters (available 1998)

Beam Code	Added Filter				Half-Value Layer		Homogeneity Coefficient	
	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)	Al	Cu
HK10	0.15				0.036	0.010	88	90
HK20	0.15				0.12	0.007	75	78
HK30	0.52				0.38	0.013	63	72
HK60	3.2				2.42	0.079	74	72
HK100	3.9	0.15			6.56	0.30	81	64
HK200		1.15			14.7	1.70	95	71
HK250		1.6			16.6	2.47	96	75
HK280		3.0			18.6	3.37	98	84
HK300		2.5			18.7	3.40	97	82
WK60		0.3				0.18		86
WS80		0.5				0.35		80
WS110		2.0				0.96		86
WS150			1.0			1.86		89
WS200			2.0			3.08		93
WS250			4.0			4.22		96
WS300			6.5			5.20		97
NS10	0.1				0.047		90	
NS15	0.5				0.14		88	
NS20	1.0				0.32		86	
NS25	2.0				0.66		90	
NS30	4.0				1.15		88	
NS40		0.21				0.084		92
NS60		0.6				0.24		92
NS80		2.0				0.58		94
NS100		5.0				1.11		95
NS120		5.0	1.0			1.71		97
NS150			2.5			2.36		96
NS200		2.0	3.0	1.0		3.99		99
NS250			2.0	3.0		5.19		99
NS300			3.0	5.0		6.12		100
LK10	0.3				0.058		99	
LK20	2.0				0.42		99	
LK30	4.0	0.18			1.47		99	
LK35		0.25			2.20		99	
LK55		1.2				0.25		99
LK70		2.5				0.49		99
LK100		0.5	2.0			1.24		99
LK125		1.0	4.0			2.04		99
LK170		1.0	3.0	1.5		3.47		99
LK210		0.5	2.0	3.5		4.54		100
LK240		0.5	2.0	5.5		5.26		100

In the beam codes, the letters indicate low air kerma rate (LK), high air kerma rate (HK), narrow spectrum (NS), and wide spectrum (WS); and the number is the constant potential in kilovolts.

The inherent filtration is approximately 1.0 mm Be for beam codes LK10–LK30, NS10–NS30, HK10–HK30; for all other techniques the inherent filtration is adjusted to 4 mm Al. Values of half-value layers and homogeneity coefficients are nominal; actual values and available air-kerma rates are being determined.

Ionization chambers are tested, prior to calibration, for connection to the atmosphere. Chambers found unsuitable for calibration will be returned with a statement of the reason for rejection. A charge may be made for time incurred on the tests.

Each instrument submitted to NIST for dosimetry calibration or test must be uniquely identified, usually by the manufacturer's name, model number, and instrument serial number. When the serial number is lacking, an alternative identifying mark should be provided. If none is found, NIST will mark the piece with an identification number. If the apparatus submitted has been calibrated previously by NIST, the serial number or identifying mark should be given on the new order so that a continuing record of stability can be maintained.

All shipments to NIST of instruments for dosimetry calibration must be in reusable containers. Even if properly packed, there can be no assurance that a calibrated instrument has maintained its calibration during shipment unless a method of verifying instrument stability has been established. Measurement should be made of the instrument response both before and after shipment, using a long-lived radioactive source and a highly reproducible measurement procedure. A long-term record of instrument stability using a suitable constancy check procedure is the most effective method for assuring the validity of the instrument calibration.

Irradiation of passive dosimeters, for readout by the customer, is available for most of the beam qualities listed in Table 8.6. These irradiations are generally in terms of air kerma; 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.

Calibrations of x-ray and gamma-ray measuring instruments and of passive dosimeters, described above, have a relative expanded uncertainty* of 1 %.

*See Chapter 1, Section H for more information about uncertainty.

Table 8.8. Mammography X-Ray Beam-Quality Parameters

Beam Code	Tube Voltage (kVp)	Added Filter (mm)	Half-Value Layer (mm Al)	Homogeneity Coefficient (Al)
Mo Anode				
Mo/Mo23	23	0.032 Mo	0.271	70
Mo/Mo25	25	0.032 Mo	0.296	72
Mo/Mo28	28	0.032 Mo	0.332	74
Mo/Mo30	30	0.032 Mo	0.351	75
Mo/Mo35	35	0.032 Mo	0.392	78
Mo/Rh28	28	0.029 Rh	0.408	80
Mo/Rh32	32	0.029 Rh	0.445	82
Mo/Mo25x	25	0.030 Mo + 2.0 Al	0.566	91
Mo/Mo28x	28	0.030 Mo + 2.0 Al	0.626	96
Mo/Mo30x	30	0.030 Mo + 2.0 Al	0.660	95
Mo/Mo35x	35	0.030 Mo + 2.0 Al	0.748	90
Rh Anode				
Rh/Rh25	25	0.029 Rh	0.351	76
Rh/Rh30	30	0.029 Rh	0.438	81
Rh/Rh35	35	0.029 Rh	0.512	86
Rh/Rh40	40	0.029 Rh	0.559	90
Rh/Rh30x	30	0.029 Rh + 2.0 Al	0.814	96
Rh/Rh35x	35	0.029 Rh + 2.0 Al	0.898	95

The beam codes are a combination of the chemical symbol of the anode and the filter respectively, followed by the constant potential in kilovolts. The letter "x" ends the beam codes which denote "exit" beams. The exit beam qualities, which are intended to represent the transmission of the x-rays through the breast, are generated by an additional filtration of 2.0 mm of aluminum.

The inherent filtration is 1 mm Be for all beam qualities. The calibration distance is 1 m. The half-value layers were determined through direct measurements with the primary standard free-air ionization chamber. The air kerma rates for the entrance beams are between 0.5 mGy/s and 1 mGy/s, and less than 0.2 mGy/s for the exit beams.

C.2 Gamma-Ray Sources, Beta-Particle Sources, and Measuring Instruments (47010C–47040S)

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

A. 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.

B. Packaging for shipment: Packages must be in compliance with the regulations of the Department of Transportation as specified in DOT 49CFR173.401-173.476. Radionuclides must be packaged as Limited Quantities (DOT 49CFR173.421-173.422) or in Type A packages (DOT 49CFR173.412 and 173.433). Type A packages must bear the appropriate radioactive-hazard labels (DOT 49CFR172.403). If the source is considered by the shipper to be in DOT Special Form, a Special Form certificate must be furnished to NIST in strict compliance with DOT 49CFR173.476. Copies of the regulations cited above are available from the Government Printing Office, Washington, DC 20402.

All shipments to NIST of gamma-ray and beta-particle sources should be in reusable containers. A drawing showing the source container and a description of the method of source removal should be provided before the shipment is received at NIST.

If the nature of the shipment requires a Type B container subject to an NRC quality assurance program, documentation should be supplied to NIST certifying that the use of the container by NIST is part of the program of the shipper.

C. Possession of licensed materials: In submitting a source for calibration, it is 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 that has entered into agreement with the Nuclear Regulatory Commission, State regulations are applicable to all sources. In the case of other individuals, NRC regulations are applicable. 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 air kerma strength (air kerma rate in free space times the square of the distance of the calibration point from the source center along the perpendicular bisector) is provided for gamma-ray sources of cobalt-60, cesium-137, iridium-192, and iodine-125. 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. The beta-particle sources may be either small-area sources such as ophthalmic applicators, or large-area plaques, and will be calibrated for absorbed dose rate to water either at the source surface or at a specified distance.

Ionization chambers to be calibrated with beta-particle sources must be parallel-plate chambers with thin walls. They can be calibrated with the radionuclides ^{90}Sr + ^{90}Y, or ^{204}Tl, or ^{147}Pm.

Measurement services in this series have uncertaities listed in Tables 8.9 and 8.10.

Table 8.9: Uncertainties for Gamma-Ray Source Calibrations, 47010C and 47011C

Source	Relative Expanded Uncertainty* (%)
^{60}Co	2
^{137}Cs	2
^{192}Ir	2
^{125}I (no marker)	5[a]
^{125}I (Ag wire)	6[a]
^{125}I (Au wire)	7[a]

[a] A new standard and calibration measurement is under development for ^{125}I seed sources. The new calibrations are anticipated to be available in 1998, with smaller uncertainties than those listed above.
*See Chapter 1, Section H for more information about uncertainty.

Table 8.10. Uncertainties for Beta-Particle Source and Instrument Calibrations

Service ID	Item	Relative Expanded Uncertainty* (%)
47030C	Sources calibrated for surface dose rate	12
47035C	Sources calibrated for radiation protection, ^{90}Sr + ^{90}Y	4.5
	^{204}Tl	4.5
	^{147}Pm	9
47036C	Transfer ionization chambers for radiation protection	same as 47035C
	Extrapolation chambers for radiation protection, absolute	same as 47035C
	Extrapolation chambers for radiation protection, relative to NIST standard chamber in reference field	1[a]

[a] Typical value. Actual value depends on response characteristics of submitted chamber.
*See Chapter 1, Section H for more information about uncertainty.

C.3 Dosimetry of High-Energy Electron Beams (48010M–48020S)

Dosimeters are provided twice a year to users requesting assistance with absorbed-dose measurements in high-energy electron beams. The dosimeters are alanine dosimeters. The user irradiates the two furnished dosimeters to between 50 Gy and 80 Gy (5000 and 8000 rad) to water at electron energies between 5 MeV 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 are returned to NIST for evaluation in terms of absorbed dose in the phantom, using the appropriate methods. These dose interpretations ignore certain corrections for the effects of spectral perturbations, and so represent a measurement quality assurance service rather than a calibration service.

The measurement procedure with alanine dosimeters is undergoing refinement; for the current procedure, the corresponding estimate of the relative expanded uncertainty* is 2.3 %.

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C.1 X-Ray and Gamma-Ray Measuring Instruments

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C.3 Dosimetry of High-Energy Electron Beams

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D. Dosimetry for High-Dose Applications

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Service ID No.	Items
49010C	Calibration Irradiations of Customer-Supplied Dosimeters with ^{60}Co Gamma Rays
49020C	Dose Interpretation of NIST Transfer Dosimeters Irradiated by Customer, Three Dosimeters Plus Control(s)
49030C	Dose Interpretation of Each NIST Transfer Dosimeter in Addition to Those Supplied under 49020C
49040S	Special Tests of Dosimeters by Reading with Spectrophotometer, Optical Absorbance at One to Five Wavelengths (Each Dosimeter)
49041S	Spectrophotometric Readings of Dosimeters, Ultra-Violet and Visible Spectrum Scan (Each Dosimeter)
49050S	Special Measurement Services for Dosimeter Response and Dose Distributions

Calibration Services and Special Tests of Dosimeters (49010C–49050S)

The following dosimetry services are for individual users of intense radiation fields, in particular large gamma-ray sources and electron accelerators up to approximately 10 MeV. These services include the administering of known absorbed doses of photons to customer-supplied dosimeters; supplying calibrated transfer standard dosimeters to customers for irradiation and subsequent readout and dose interpretation; and special measurement services such as the determination of temperature dependence, dose-rate dependency or reproducibility of dosimeter response.

Calibration of Dosimeters Irradiated with ^{60}Co Gamma Rays (49010C)

Calibration irradiations are available for customer-supplied dosimeters (such as solid radiochromic or liquid chemical types) or test samples that are sent to NIST, where they are packaged appropriately to provide electron equilibrium conditions. They are irradiated in the NIST standard ^{60}Co calibration facility to specific agreed-upon absorbed dose values in the nominal range of (10 to10^6) Gy (10^3 rad to 10^8 rad). The dosimeters are then sent back to the customer for analysis and evaluation. Dosimeters must fit within a cylindrical volume 5 cm in height and 5 cm diameter. For our standard calibrated geometries (radiochromic film, alanine pellets, 2 mL ampoules, and red perspex), the absorbed dose (water) delivered to the dosimeter has a relative expanded uncertainty* of 1.8 %.

Transfer Reference Standard Dosimeters (49020C and 49030C)

NIST provides transfer standards in the form of sets of calibrated radiochromic or alanine dosimeters packaged in polystyrene. The sealed, packaged dosimeters are sent to the customer for irradiation to nominal agreed-upon absorbed dose levels in a prescribed geometrical arrangement. The unopened packaged dosimeters are then returned to NIST to be read and evaluated and the results reported, thus providing calibration of the customer's irradiator. The absorbed dose range that is suitable for use with the transfer dosimeters is 50 Gy to 200 KGy (5 rad to 20 Mrad) in water, silicon, aluminum, graphite, or certain plastics. The transfer standard calibrations (absorbed dose in water) have a relative expanded uncertainty* of 2.2 % for alanin dosimeters and 4.5 % for radiochromic dosimeters.

*See Chapter 1, Section H for more information about uncertainty.

Special Tests of Dosimeters: Spectrophotometric Reading (49040S–49041S)

Dosimeters may be read at several specific ultraviolet or visible optical wavelengths or as a spectral scan over an appropriate wavelength region of interest.

Special Measurement Services for Dosimeter Response and Dose Distributions (49050S)

Tests of dosimeter response, such as temperature dependence, dose rate dependence, and dose distributions in specific irradiation geometries, can be provided as special measurement services. These dose distribution measurements can include dose profiles in heterogenous absorbers and at interfaces of different materials.

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Chapter 9

A. Resistance Measurements

A.1 DC Resistance Standards and Measurements

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Service ID No.	Items
51100S	Special Resistance Measurement Services, by Prearrangement
51110M	Measurement Assurance Program Services for Resistance
51130C	Standard Resistor, Thomas-Type, 1 Ω
51131C	Standard Resistor, Evanohm Wirewound High Precision, 10 kΩ
51132C	Standard Resistor, Four-Terminal, 0.0001 Ω
51133C	Standard Resistor, Four-Terminal, 0.001 Ω
51134C	Standard Resistor, Four-Terminal, 0.01 Ω
51135C	Standard Resistor, Four-Terminal, 0.1 Ω
51136C	Standard Resistor, Four-Terminal, 1 Ω
51137C	Standard Resistor, Four-Terminal, 10 Ω
51138C	Standard Resistor, Four-Terminal, 100 Ω
51139C	Standard Resistor, 1 kΩ
51140C	Standard Resistor, 10 kΩ
51141C	Standard Resistor, 100 kΩ
51142C	Standard Resistor, 1 MΩ
51143C	Standard Resistor, 10 MΩ
51144C	Additional Voltage, 10 MΩ
51145C	Standard Resistor, 100 MΩ

Service ID No.	Items
51146C	Additional Voltage, 100 MΩ
51147C	Standard Resistor, 1 GΩ
51148C	Additional Voltage, 1 GΩ
51149C	Standard Resistor, 10 GΩ
51150C	Additional Voltage, 10 GΩ
51151C	Standard Resistor, 100 GΩ
51152C	Additional Voltage, 100 GΩ
51153C	Standard Resistor, 1 TΩ
51154C	Additional Voltage, 1 TΩ
51160C	Standard Resistor for Current Measurements (Shunts), with All Determinations at 300 A or Below, One Range, One Current Level
51161C	Standard Resistor for Current Measurements (Shunts), with at Least One Determination Above 300 A (maximum current 2000 A) One Range, One Current Level
51162C	Standard Resistor for Current Measurements (Shunts), Additional Range of a Multi-Range Resistor
51163C	Standard Resistor for Current Measurements (Shunts), Additional Determination at Another Current Level

Special DC Resistance Measurements, by Prearrangement (51100S)

Testing or evaluation of prototype resistance standards or measuring instruments; unique resistance measurements; and other calibration services not specified below, such as the determination of the pressure coefficient of Thomas-type or 10 kΩ resistors, the determination of the temperature coefficient of standard resistors, and the calibration of resistance standards in oil at temperatures other than 25 °C, are carried out under this Service ID number. Such measurements are made at the discretion of the NIST technical staff in a manner specifically agreed upon by the customer and the expert involved. Testing of component resistors will only be considered under the rare circumstance that the behavior of the resistors has been observed to approximate that of state-of-the-art standards under the same conditions.

Measurement Assurance Program for Resistance (51110M)

Resistance MAP transfers are generally carried out at the 1 Ω and 10 kΩ levels. Four well-characterized commercial standard resistors are used as transport standards at each level. The suggested measurement schedule at the client laboratory consists of measurements on each transport resistor three times a week for a period of 4 to 6 weeks, depending upon the settling time of the resistors due to transportation effects.

Participation in this program is generally not advisable unless one is required to support resistance measurements with state-of-the-art or near state-of-the-art uncertainties and is willing to adopt a system for the continuous surveillance of standards during the intervals between NIST 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 NIST 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 the laboratory's own measurement process.

Special Standard Resistors 1 Ω and 10 kΩ (51130C and 51131C)

Thomas-type 1 Ω resistors or their equivalent are calibrated directly against the NIST 1 Ω reference group that is used to maintain the U.S. legal ohm. The values of the reference group are known in terms of the quantum Hall effect. Special 10 kΩ standard resistors designed for air or oil use are calibrated directly against the NIST 10 kΩ working standards. The special 10 kΩ standard resistors (Evanohm wirewound high-precision or equivalent) are characterized by resistance corrections within 10×10^{-6} of nominal value, temperature coefficients of $0 \pm 1 \times 10^{-6}$/°C at the operating temperature, and drift rates of $\leq 1 \times 10^{-6}$/year.

The customer's resistors are acclimatized in their respective test environments for approximately 1 week prior to their calibration. Measurement parameters of temperature and current level are shown in Table 9.1.

Table 9.1. Temperatures and Current Levels for Customer's Resistors

Resistor	Medium	Temperature (°C)	Current (mA)
1 Ω	oil	25.000±0.003	100
10 kΩ	oil	25.000±0.005	1
10 kΩ	air	23.0±1.0	1

The temperature of the customer's resistor at the time of the measurement is given in the report of calibration. Since some of these resistors exhibit a significant pressure coefficient, the barometric pressure at the time of the measurement is also reported. Uncertainties are based upon (1) the random behavior of the measurement process as characterized by data from a large population of individual calibrations, and (2) an estimate of the systematic errors arising from such sources as temperature inaccuracies, pressure inaccuracies, scaling errors, etc. Uncertainties are listed in Table 9.2.

Table 9.2. Calibration Uncertainties for DC Resistance Standards

Test Number	Nominal Resistance (Ω)	Terminal Connection	Maximum Power (mw)	Nominal Relative Expanded Uncertainty* ($\times 10^{-6}$)
51130C	1 (Thomas)	4	10	0.05
51131C	10^4 (Special)	5	10	0.15
51132C	10^{-4}	4	100	11
51133C	10^{-3}	4	100	5
51134C	10^{-2}	4	100	3
51135C	10^{-1}	4	100	2
51136C	1	4	50	1
51137C	10	4	50	1
51138C	10^2	2	10	0.5
51139C	10^3	2	10	0.5
51140C	10^4	2	10	0.5
51141C	10^5	2	10	2
51142C	10^6	2	10	3
51143C	10^7	3	•	14 to 140
51145C	10^8	3	•	40 to 400
51147C	10^9	3	•	140 to 700
51149C	10^{10}	3	•	400 to 700
51151C	10^{11}	3	•	700
51153C	10^{12}	3	•	1400

*See Chapter 1, Section H for more information about uncertainty.
•Resistors at this level are tested at customer-specified voltages up to 1 kV.

Standard Resistors 10^{-4} to 10^6 Ω (51132C–51142C)

Standard resistors with nominal decade values in the range between 10^{-4} Ω and 10^6 Ω are calibrated by comparison with NIST working standards of equivalent value, known in terms of the Quantum Hall effect. In general, these standards are characterized by (1) resistance corrections within 500×10^{-6} of nominal value, (2) temperature coefficients of $\leq 10 \times 10^{-6}$/°C at the temperature of use, and (3) drift rates of $\leq 5 \times 10^{-6}$/year. Normally, standard resistors are measured in an oil bath maintained at (25.0 ± 0.05) °C, and at a power level of ≤0.1 W. Resistors in temperature-controlled enclosures with fixed terminations are also accepted for calibration. At the levels of accuracy involved, four-terminal measurements are required for resistors whose nominal values are 100 Ω or less. Expanded uncertainties* are based upon (1) the random behavior of the measurement process as characterized by data from a large population of individual calibrations, and (2) an estimate of the systematic errors. Uncertainties are given in Table 9.2.

High-Value Standard Resistors: 10^7 Ω to 10^{12} Ω (51143C–51154C)

High-value standard resistors in the range between 10^7 Ω and 10^{12} Ω are calibrated in an air bath maintained at a temperature of (23.0 ± 0.1) °C and at a relative humidity of (35 ± 5) %. The resistors are maintained at these conditions at least 24 hours prior to testing. Customer resistors are compared 1:1 with NIST working standards of the same nominal value up to and including the 10^{10} Ω level. Above 10^{10} Ω, 10:1 and 100:1 ratio techniques are employed. The maximum test voltage is 500 V for resistors < 10^{10} Ω and 1000 V for resistors ≥ 10^{10} Ω. Uncertainties depend upon the stability and performance of the specific resistor involved and are given in Table 9.2. Only resistors that are mounted in a shielded enclosure with a permanent identifying number and have suitable terminations are accepted for calibration.

The resistance of thin-film, high-valued resistance standards is frequently highly voltage dependent. Hence, the magnitude of the test voltage should be specified by the customer when a resistor is submitted for calibration. The temperature, relative humidity, and test voltage of the resistor are given in the report of calibration.

High-Current Standard Resistors—Shunts (51160C–51163C)

Four-terminal standard resistors for use in the precise measurement of high direct currents (shunts) are calibrated by NIST only during May and November of the calendar year. Arrangements should be made with NIST prior to submitting a resistor for calibration. Normally only resistors of 0.04 % relative uncertainty

* See Chapter 1, Section H for more information about uncertainty.

or less are calibrated. The maximum test current available is 2000 A. The uncertainty of measurement depends largely upon the performance of the customer's resistor involved.

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Calibration Procedures for Direct Current Apparatus, P. Brooks, Natl. Bur. Stand. (U.S.), Monogr. 39 (Mar. 1962).

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Methods, Apparatus, and Procedures for the Comparison of Precision Standard Resistors, F. Wenner, J. Res. Natl. Bur. Stand. (U.S.), **25**, Res. Paper RP1323 (Aug. 1940).

A. Resistance Measurements
A.2 High-Voltage Standard Resistors

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Service ID No.	Items
51210C	High-Voltage Standard Resistors

High-Voltage Standard Resistors (51210C)

A routine calibration service is maintained for resistors designed for dc high-voltage applications. This service is for corona-free resistors designed for dc operation between 10 kV and 150 kV.

Resistors may be hand-carried or shipped to NIST. If they are shipped, they should be packaged in sturdy reusable containers with convenient access to the resistor. The design of many high-voltage resistors makes them vulnerable to shear-type forces, so provisions should be made to minimize the likelihood of damage due to such forces when the device is in the shipping container.

Users of this service should first discuss scheduling of calibrations with a NIST technical contact. The purchase order should indicate the voltage test points, a mailing address for the calibration report, and a shipping address for the resistor.

References—High-Voltage Standard Resistors

High-Voltage Divider and Resistor Calibrations, M. Misakian, Natl. Bur. Stand. (U.S.), Tech. Note 1215 (July 1985).

Special Shielded Resistor for High-Voltage Measurements, J. H. Park, J. Res. Natl. Bur. Stand. **66C** (1), 1924 (Jan.-Mar. 1962).

A. Resistance Measurements
A.3 High-Frequency Standard Resistors

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Service ID No.	Items
51310S	High-Frequency Standard Resistors; Two-Terminal

High-Frequency Standard Resistors (51310S)

The overall frequency range covered is 10 kHz to 250 MHz. The range of resistance that can be calibrated depends upon the measurement frequency, as follows:

Frequency Range	Resistance Range
10 kHz to 2 MHz	0.1Ω to 10 kΩ
2 MHz to 10 MHz	50 Ω to 10 kΩ
10 MHz to 250 MHz	20 Ω to 1 kΩ

Measurement uncertainties are given in the reference; the relative expanded uncertainties* start at 0.1 %.

Reports of Calibration or Tests 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.

*See Chapter 1, Section H for more information about uncertainty.

References—High-Frequency Standard Resistors

The Measurement of Lumped Parameter Impedance: A Metrology Guide, R. N. Jones, Natl. Bur. Stand. (U.S.), Monogr. 141 (June 1974).

Impedance of Lumped Circuits, L. E. Huntley and R. N. Jones, Proc. IEEE, **55** (6), 900 (June 1967).

B. Impedance Measurements (Except Resistors)
B.1 Low-Frequency Capacitance and Inductance Measurements and Standards

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Service ID No.	Items
52110S	Special LF Impedance Measurements, by Prearrangement
52120S	Special Measurement Assurance Program for Standard Capacitors (100 pF and 1000 pF, at a Frequency of 1000 Hz)
52130C	Fixed Fused-Silica Dielectric Standard Capacitors (1, 10, and 100) pF, at a Frequency of (100, 400, or 1000) Hz
52131C	Additional Measurement at One of the Above Frequencies
52140C	Fixed Three-Terminal, High-Precision Nitrogen Dielectric Standard Capacitors with Coaxial Connectors, Small Uncertainty (10, 100, and 1000) pF, at a Frequency of (100, 400, or 1000) Hz
52141C	Additional Measurement at One of the Above Frequencies
52150C	Physical Tests for Three-Terminal Nitrogen Dielectric Capacitors (at 1000 Hz only) as an Optional Supplement to the Small Uncertainty Calibration (52140C)
52160C	Fixed Three-Terminal Standard Capacitors with Coaxial Connectors, Large Uncertainty (0.001 pF to 10,000 pF), at a Frequency of (100, 400, or 1000) Hz
52161C	Additional Measurement at One of the Above Frequencies
52170C	Two- or Three-Terminal Mica Dielectric Standard Capacitors with Binding Post Connectors (0.001 μF to 1 μF), at a Frequency of (66, 100, 400, 1000, or 10,000) Hz
52171C	Additional Measurement at One of the Above Frequencies
52176C	Two-Terminal Standard Capacitors with Precision High Frequency (HF) Coaxial Connectors (0.001 pF to 10,000 pF), at a Frequency of 1000 Hz
52180C	Fixed Standard Inductors (0.00005 H to 10 H), at a Frequency of (100, 400, 1000, or 10,000) Hz
52181C	Additional Measurement at One of the Above Frequencies

Low-Frequency Capacitance and Inductance Measurements and Standards (52110S–52181C)

These services cover the calibration of standard capacitors and inductors in the audio-frequency range. Three-terminal standard capacitors having fused-silica (1, 10, and 100) pF, nitrogen (10, 100, and 1000) pF, and air, from 0.001 pF to 10 000 pF, dielectrics can be measured at (100, 400, and 1000) Hz. Two- or three-terminal capacitors with mica dielectrics in the range from 0.001 μF to 1 μF can be measured at (66, 100, 400, 1000, and 10 000) Hz. Two-terminal air and mica dielectric capacitors with high frequency (HF) coaxial connectors, from 1 pF to 10 000 pF, including GR900 terminations, are calibrated only at 1 kHz. Air-core standard inductors having nominal values between 0.05 mH and 10 H can be measured at (100, 400, and 1000) Hz. Standard inductors of 100 mH or less also can be measured at 10 kHz. Calibration of impedance standards other than those mentioned above will be considered for Special Test Under Service ID Number 52110S (see below).

The calibration of some types of high frequency capacitance standards at frequencies as low as 1 kHz can be provided by the NIST Electromagnetic Fields Division in Boulder, CO, provided the uncertainty required exceeds 0.01 %. In some circumstances this can eliminate the necessity of sending a standard to both Gaithersburg and Boulder Laboratories for a complete calibration. See also Service ID Numbers 52210C–52310C for calibration of capacitors at higher frequencies. For additional details please inquire at NIST/Boulder: Telephone (303) 497-3609.

Special LF Impedance Measurements, by Prearrangement (52110S)

This service provides for the testing or evaluation of prototype impedance standards or measurement instrumentation at the state-of-the-art, and other impedance measurements (such as the calibration of decade or variable capacitance standards), at the discretion of NIST technical experts. Component capacitors, inductors, and resistors are not considered for testing by NIST unless their performance approximates that of the best available standards. Even under those conditions, calibration will only be done on a limited basis to ascertain the possible use of the components in precision measurement applications.

The cost for such tests are determined on a case-by-case basis, and may be considerably higher than the posted fee for Calibration Services because of needed additional preparation and extra measurements required to perform an uncertainty assessment.

Special Measurement Assurance Program for Standard Capacitors (52120S)

The Capacitance MAP (C-MAP) transfers are carried out for standard capacitors at the 1000 pF and 100 pF levels, at a frequency of 1 kHz. A commercial 1 kHz capacitance meter is used as the transport standard. The client laboratory (Lab) is responsible for performing measurements (using the Lab calibration system and the transport standard) on its own reference and/or check standards, and on the two pairs of dummy capacitors from NIST of the same nominal values. Prior to the initiation of the C-MAP, the Lab is required to complete a CAPACITANCE MAP INFORMATION SHEET, and to provide a description of its calibration procedures. At the time the transport standard and the dummy capacitors are shipped to the Lab for a C-MAP transfer, the Lab will also receive detailed instructions for carrying out the C-MAP and the software for enabling the transport standard (commercial capacitance meter) to make measurements automatically. The Lab is also required to collect and reduce the data from its calibration system, and to enter the results on to the CAPACITANCE MAP DATA SHEET.

The transport standard and the dummy capacitors are normally kept in the Lab for about 4 to 6 weeks, as eight to twelve sets of measurements are required. After the completion of post MAP measurements and a data analysis at NIST, a REPORT OF CALIBRATION from NIST is issued to the Lab. This report provides the difference between the unit of capacitance maintained by the Lab and the farad, and the assigned values for the Lab reference standards (and their uncertainties) to bring the difference to zero.

Fused-Silica Dielectric Standard Capacitors (52130C-52131C)

Air-bath type, fused-silica dielectric standard capacitors are generally submitted in temperature-controlled ovens due to their $(10 \times 10^{-6})/°C$ temperature coefficient. Because of the magnitude of the temperature coefficient, it is recommended that a reliable temperature sensor having a resolution of 0.001 °C, or better, be permanently mounted in the oven and thus included as part of the calibration. For baths not so equipped, the temperature is measured in terms of the International Temperature Scale of 1990 (ITS-90), using a standard platinum resistance thermometer.

Some capacitance standards consist of a fused-silica dielectric capacitor completely sealed within a temperature-controlled oven and the ancillary circuitry required for its operation, but with no means of measuring or monitoring the oven's internal temperature. Since the actual temperature of the capacitor cannot be measured, it is not reported. Some such standards measure and display the ambient temperature. For these, the mean value of the display readings taken at the times of measurement is reported, but the significance of this value is decided by the user.

Oil-bath type, fused-silica dielectric capacitors are calibrated in an NIST oil bath maintained at (25 ± 0.01) °C, if the normal temperature of use for these capacitors is approximately 25 °C. If the capacitors are supplied with built-in sensors, the sensors and the oil temperature are both measured. Requests for the calibration of oil-bath type, fused-silica dielectric capacitors are accepted as Special Tests (52110S).

Calibrations are carried out at (100, 400, or 1000) Hz, or any combination of these frequencies chosen by the client. A minimum of five measurements is made over a 2-week or longer period, comparing the test capacitor directly with an NIST fused-silica standard at 10 pF. The number of readings taken depends on the stability of the temperature of the test capacitors. The averages of the measured values of capacitance and temperature are reported. The uncertainty of the reported capacitance value depends on the stability of the temperature as well as on the performance of the capacitance standard itself. Because the temperature coefficients of individual standards are usually not known quantitatively, the results cannot be temperature corrected. Despite these factors, the Type A standard uncertainty* can be as low as 2×10^{-8} of the capacitor's nominal value.

Standard Capacitors (52140C–52176C)

The following guidelines apply to the calibration of standard capacitors having dielectrics other than fused-silica.

Calibrations are ordinarily performed at a normal laboratory ambient temperature of (23 ± 1) °C except for measurements of high-stability nitrogen dielectric capacitors. These are measured more than once in a period of several days to observe their stabilities and to ensure that the variation of the measurements is within the required limit of the standard errors for these measurements. Simultaneously, a digital thermometer with a resolution of 0.001 °C is placed near the capacitors to monitor the temperatures during calibrations. The calibration temperature, nominally 23 °C, is reported to within ± 0.01 °C. Relative humidity is maintained at 50 % or less in all cases.

Precision three-terminal nitrogen dielectric capacitors, such as ESI Model SC1000 and GENRAD Model 1404, have been found to be variously affected by mechanical shock and orientation. Accordingly, two types of calibrations, featuring different levels of uncertainty are offered. See Table 9.3. A qualification test (52150C) is available to supplement the small uncertainty calibration (52140C) in order to determine the effects of various impacts (physical shocks) and orientation on the capacitors. Results of this test should be coupled with the Type-B uncertainty* of the precision calibration that follows to provide an expanded uncertainty for the calibration of a particular standard. Requests for the small uncertainty calibration without the physical tests are also accepted. For the large uncertainty test (52160C), a similar calibration, but with reduced resolution, is performed. Three-terminal air dielectric capacitors are accepted for the large uncertainty calibration (52160C) only.

In the case of direct or three-terminal capacitance standards, the connectors are assumed to be coaxial, such as the GENRAD Type 874. 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.

Capacitors requiring terminal plugs (banana plugs) for parallel connection should be sent to NIST together with the plugs that will be used with the capacitor after calibration. If such a capacitor arrives without plugs, NIST must attach plugs temporarily in order to calibrate

*See Chapter 1, Section H for more information about uncertainty.

the capacitor. Those used by NIST are GENRAD Type 274-P plugs. If, after calibration with these plugs, the capacitor is used with plugs of even slightly different length and base, the capacitance can differ significantly from that reported, and such differences will not be reflected in the calibration uncertainties reported.

Unless otherwise requested, the measured value reported by NIST is the added capacitance when the standard is plugged directly into the binding posts of the NIST bridge. For two-terminal GENRAD capacitors, Type 509 and Type 1409 (when used as a two-terminal capacitor), a capacitance increase ranging from 0.01 pF to 0.04 pF has been found for different plugs. 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 measurements can be realized if standards are provided with precision coaxial connectors.

The terminal connections, either as two-terminal or three-terminal capacitors, for capacitors with mica dielectric, should be specified in the customer's purchase order. Otherwise, they will be calibrated as two-terminal capacitors (with the case "Ground" connected to the "Low" terminal).

The capacitance value given is the equivalent parallel capacitance. In general, an accurate determination of the equivalent parallel conductance with high accuracy is not available. However, for mica dielectric capacitors in an approximate conductance value for each capacitor is also given.

The frequencies available for capacitance calibrations depend upon the type of capacitor and its connectors. In general, capacitors with binding posts or GR 274-P plugs can be calibrated at (66, 100, 400, 1000, and 10 000) Hz. Capacitors with high frequency coaxial connectors (GENRAD Type 900) are calibrated only at 1000 Hz.

The expanded uncertainty* stated in the Report of Calibration is determined by the random behavior of each type of capacitor (determined from the analysis of measurement data taken from a large population of individual calibrations), as well as an estimate of the systematic errors of the NIST measurement process. These are calculated using the approach of NIST Technical Note 1297, per NIST policy. The expanded uncertainties are given in Table 9.3 and Table 9.4.

The stated uncertainties are sufficiently broad to allow for variations in the stray capacitance at the connectors, in temperature of a few degrees Celsius, in relative humidity and atmospheric pressure, and in frequency deviations of a few percent from the stated test conditions. Depending on the frequency and the capacitance value, the relative expanded uncertainty* usually lies between 0.0004 % and 0.05 % (see Tables 9.3 and 9.4). The uncertainties do not include allowances for effects of transportation; these must be determined by the owner using pre- and post-calibration data from the owner's facility.

Standard Inductors, Self or Mutual (52180C–52181C)

Air-core standard inductors for use in ac bridges are tested at a room temperature of (23 ± 1) °C and a relative humidity of 50 % 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. A metal-encased standard is calibrated with the case "Ground" connected to the "Low" terminal of the inductor unless other conditions are specified. The reported values are the self inductance values of the inductors.

*See Chapter 1, Section H for more information about uncertainty.

Table 9.3. Calibration Uncertainties for Capacitance Standards with Coaxial Connectors

Service ID No.	Dielectric	Terminal Connection	Nominal Capacitance (pF)	Relative Expanded Uncertainties* (× 10^{-6}) Frequency 100 Hz	400 Hz and 1 kHz
52130C	Fused-Silica	3	1	10	4.1
and			10	4	2.5
52131C			100	4	2.5
52140C	Nitrogen	3	10	6	4
and			100	6	4
52141C			1000	6	4
52160C	Nitrogen	3	10 to 1000	25	25
and					
52161C	Air	3	0.001	NA	2000
			0.01	1500	200
			0.1	230	100
			1 to 1000	100	100
			10000	NA	150
					(only at 1 kHz)
52176C	Air	2	1	NA	840
			2	NA	420
			5	NA	200
			10	NA	100
			20	NA	75
			50 to 1000	NA	60
	Mica	2	1000	NA	60
			5000 to 10000	NA	65
	Open-Circuit	2	0.172	NA	1000
	Termination	2	2.670	NA	450

*See Chapter 1, Section H for more information about uncertainty.

Table 9.4. Calibration Uncertainties for Capacitance Standards with Terminal (Banana) Plugs

Service ID. No.	Dielec-tric	Terminal Connec-tion	Nominal Capaci-tance (μF)	Expanded Uncertainties* Capacitance Frequency 66 Hz to 1 kHz (%)	Capacitance Frequency 10 kHz (%)	Conductance 66 Hz & 100 Hz (μS)	Conductance Frequency 400 Hz & 1 kHz (μS)	Conductance 10 kHz (μS)
52170C and 52171C	Mica	2	0.001	0.018	0.018	0.0003	0.0006	0.001
			0.002	0.016	0.016	0.0003	0.0008	0.002
			0.005	0.016	0.016	0.0003	0.001	0.005
			0.01	0.018	0.018	0.0006	0.002	0.01
			0.02	0.018	0.018	0.0006	0.003	0.02
			0.05	0.018	0.020	0.002	0.006	0.01
			0.1	0.018	0.040	0.005	0.02	0.4
			0.2	0.018	0.060	0.008	0.04	1
			0.5	0.018	0.10	0.02	0.13	6
			1	0.018	0.20	0.04	0.4	20
	Mica	3	0.001	0.012	0.012	0.0003	0.0006	0.001
			0.002	0.010	0.010	0.0003	0.0008	0.002
			0.005	0.010	0.010	0.0003	0.001	0.005
			0.01	0.010	0.010	0.0006	0.002	0.01
			0.02	0.010	0.012	0.0006	0.003	0.02
			0.05	0.010	0.015	0.002	0.006	0.01
			0.1	0.010	0.03	0.005	0.02	0.4
			0.2	0.010	0.05	0.008	0.04	1
			0.5	0.010	0.10	0.02	0.13	6
			1	0.015	0.20	0.04	0.4	20

*See Chapter 1, Section H for more information about uncertainty.

References—Low-Frequency Capacitance and Inductance Standards

NIST Measurement Assurance Program for Capacitance Standards at 1 kHz, Y. May Chang, NIST Technical Note 1417 (March 1996).

NIST Capacitance Measurement Assurance Program (MAP), Y. May Chang, Measurement Science Conference, Anaheim, CA, (January 1993).

New Realization of the Ohm and Farad Using the NBS Calculable Capacitor, J. Q. Shields, R. F. Dziuba, and H. P. Layer, Conf. Precision Electromagnetic Meas. (CPEM '88), June 7-10, 1988, Tsukuba Science City, Japan, Special Issue CPEM '88 IEEE Trans. Instrum. Meas. **38** (2), 249–251 (April 1989).

Testing to Quantify the Effects of Handling of Gas Dielectric Standard Capacitors, C. R. Levy, Natl. Bur. Stand. (U.S.), Tech. Note 1161 (1982).

New Measurements of the Absolute Farad and Ohm, R. D. Cutkosky, IEEE Trans. Instrum. Meas., **IM-23** (4), 305 (Dec. 1974).

Applications of Coaxial Chokes to AC Bridge Circuits, D. N. Homan, J. Res. Natl. Bur. Stand. (U.S.), **72C** (2) (June 1968).

Improved Ten-Picofarad Fused Silica Dielectric Capacitor, R. D. Cutkosky and H. L. Lee, J. Res. Natl. Bur. Stand. (U.S.), **69C** (3), 173 (Sept. 1965).

Calibration of Inductance Standards in the Maxwell-Wein Bridge Circuit,T. L. Zapf, J. Res. Natl. Bur. Stand. (U.S.), **65C** (3) (Sept. 1961).

Capacitance Bridge NBS Type 2, R. D. Cutkosky, Natl. Bur. Stand. (U.S.), Report 7103 (Mar. 1961).

NIST Calibration Service for Capacitance Standards at Low Frequency, Y. May Chang and Summerfield B. Tillett, NIST Technical Note (to be published).

Error Analysis and Calibration Uncertainty of Capacitance Standards at NIST, Y. May Chang, NIST Technical Note (to be published).

B. Impedance Measurements (Except Resistors)
B.2 High-Frequency Standard Capacitors and Inductors

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Service ID No.	Items
52210S	Two-Terminal, Low-Loss Standard Capacitors—10 kHz to 250 MHz; 1 pF to 20 pF
52211S	Two-Terminal, Low-Loss Standard Capacitors (High Accuracy)—10 kHz to 30 MHz; (50, 100, 200, 500, and 1000) pF
52221C	Three-Terminal, Low-Loss Standard Capacitors (High Accuracy)—10 kHz to 30 MHz; (10^{-2}, 10^{-1}, 1, 10, 10^2, and 10^3) pF
52310S	Two-Terminal, High-*Q* Standard Inductors (10^{-2} μH to 1 H)

High-Frequency Standard Capacitors and Inductors (52210S–52310S)

Services provided in this category (and also Service ID Numbers 51310S and 52710C) are for passive devices over the frequency range from 10 kHz to 250 MHz. Highest accuracy is obtained only for standards equipped with precision coaxial connectors. Standards submitted for calibration should be in good repair and, except for very minor cleaning of connector surfaces, should require no pre-calibration maintenance. NIST does not provide repair services; items received that require maintenance will be returned to the sender and a handling fee charged.

Calibration services for some types of capacitance standards at frequencies as low as 1 kHz can be provided by the NIST Boulder Laboratory if the accuracy requirement does not exceed 0.01 %. In some circumstances this can eliminate the necessity of sending a standard to both the Gaithersburg and Boulder Laboratories for a complete calibration. For additional details, please consult with the technical contact listed at the beginning of this section.

Calibration services are not provided for measuring instruments such as bridges or meters. The uncertainty of these instruments should be verified by the owner through the use of stable standards especially selected for particular values and frequencies appropriate to the instrument in question.

All calibrations are performed under typical ambient laboratory conditions of 23 °C, and an atmospheric pressure of approximately $((8.4 \pm 0.2) \times 10^4)$ Pa at Boulder, Colorado. Services at ambient conditions outside these limits are not provided. Also, the power applied to any device being calibrated does not exceed 1 W. Additional information about immittance (impedance and admittance) measurement and standards are contained in the references.

Two-Terminal, Low-Loss Standard Capacitors (52210S–52211S)

In the frequency range from 10 kHz to 250 MHz, capacitance calibrations are available from 1 pF to 1000 pF depending upon frequency. The upper capacitance limit for calibration decreases as the frequency increases and is 50 pF above 30 MHz.

From 100 kHz to 30 MHz, a special high-accuracy service is available for capacitors with nominal values of (50, 100, 200, 500, and 1000) pF if equipped with 14 mm coaxial connectors.

The minimum relative expanded uncertainty* is 0.01 % for the high accuracy device and 0.1 % for the other other calibrations.

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

A technique for extrapolating the 1 kHz values of capacitance standards to high frequencies is described by R. N. Jones (see 1963 reference). That 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. The same technique, with some modifications, is usable for three-terminal and four-terminal pair capacitors. It is emphasized that these extrapolation procedures are only usable for air dielectric capacitors or capacitors with insulating materials whose dielectric constant does not change with frequency.

Three-Terminal, Low-Loss Standard Capacitors (52221C)

Fixed-value reference standards are maintained by NIST for values of 10 pF, 100 pF, and 1000 pF. High-quality three-terminal air dielectric capacitance standards should have low residual series inductance (< 0.1 μH). This being the case, it may be assumed that, to within an expanded uncertainty* of 0.10 %, the capacitances of standards of 1 pF or less with air-dielectric 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.

*See Chapter 1, Section H for more information about uncertainty.

Two-Terminal, High-*Q* Standard Inductors (52310S)

In the frequency range from 10 kHz to 250 MHz, inductance calibrations to a minimum expanded uncertainty* of 0.1 % are available from 0.01 μH to 1 mH. 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. Service is available only for air-core inductors or inductors whose value is independent of current.

References—High-Frequency Standard Capacitors and Inductors

Calibration Service for Low-Loss, Three-Terminal Capacitance Standards at 100 kHz and 1 MHz, G. M. Free and R. N. Jones, Natl. Inst. Stand. Technol. (U.S.), Tech. Note 1348 (Feb. 1992).

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B. Impedance Measurements (Except Resistors)
B.3 Power-Frequency Capacitors

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Service ID No.	Items
52400C	Power-Frequency Capacitors

Power-Frequency Capacitors (52400C)

A calibration service is maintained for capacitors designed for 60-Hz operation, especially at voltages above 100 V. Typical expanded uncertainties* for a calibration are 100×10^{-6} of the capacitance, and 1 % of the dissipation factor plus 1×10^{-5}. Routine calibrations are limited to devices with a dissipation factor of 0.011 or smaller and which are operated at sufficient voltages that at least 40 μA passes through the device under test.

The high-power limit for routine tests is 10 kVA. Some capability to perform tests outside of these limits exists, and NIST should be contacted to discuss special arrangements for such tests.

*See Chapter 1, Section H for more information about uncertainty.

References—Power-Frequency Capacitors

A Calibration Service for Voltage Transformers and High-Voltage Capacitors, W. E. Anderson, Natl. Bur. Stand. (U.S.), Spec. Publ. 250-33 (June 1988).

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A Wide Range High-Voltage Capacitance Bridge with One-ppm Accuracy, O. Petersons and W. E. Anderson, IEEE Trans. Instrum. Meas. **IM-24** (4), 336 (Dec. 1975).

B. Impedance Measurements (Except Resistors)
B.4 Q-Standards

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Service ID No.	Items
52710C	Inductive Q-Standards; 50 kHz to 45 MHz, 0.25 μH to 25 mH
52711C	Each Additional Frequency for 52710C

Q-Standards (52710C–52711C)

Standards for Q-measurements are maintained at NIST. 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. Relative expanded uncertainties* are of the order of 0.2 % for capacitance and 2 % 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.

*See Chapter 1, Section H for more information about uncertainty.

References—Q-Standards

Standards for the Calibration of Q-Meters, 50 kHz to 45 MHz, R. N. Jones, J. Res. Natl. Bur. Stand. (U.S.), **58C** (4), 243 (Oct.-Dec. 1964).

C. Voltage Measurements
C.1 DC Voltage Measurements and Standards

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Service ID No.	Items
53110S	Special DC Voltage Measurements, by Prearrangement
53120M	Measurement Assurance Program for DC Voltage
53130C	First Saturated Standard Cell in a Group
53131C	Each Additional Cell
53140C	Platinum Resistance Thermometer Temperature Determination for Standard Cell Calibration
53150C	Unsaturated Standard Cells
53160C	Tests of Solid-State Voltage Reference Standard (One Output, 1 V to 10 V)
53161C	Each Additional Output
53180S	Special Handling (Equipment Pickup or Delivery)
53190S	Special Handling (Cleaning, Minor Repair, Return Service Charge)

General Information—DC Voltage Measurement Standards

The service described in this section provides for the calibration of standards of direct voltage, saturated and unsaturated standard cells, and solid-state standards, and for dc voltage MAP services at the 1.02-volt level. The U.S. Representation of the Volt is maintained by monitoring the emfs of several groups of saturated standard cells in ovens on a monthly basis using the ac Josephson effect. Customer cells are calibrated by measuring the difference between their emfs and those of working groups of standard cells using automated systems comprised of low thermal emf, computer-controlled switches and high-resolution digital voltmeters.

Special DC Voltage Measurements, by Prearrangement (53110S)

The evaluation, testing, or calibration of prototype dc voltage standards and measuring apparatus or unique voltage measurements are provided by this service. These measurements are performed only when deemed reasonable by the appropriate technical staff and serving the best long-term interests of the client, the measurement community, and NIST.

Table 9.5. Expanded Uncertainties* of NIST DC Voltage Measurement

	($\times 10^{-6}$
Josephson Calibrations of Primary Cells (1.018 V)	0.04
Unsaturated Standard Cells	≥ 50
Saturated Standard Cells	≥ 0.15
Volt Transfer Program (Saturated Standard Cells)	≥ 0.20
Solid-State References (1.018 V, 10 V)	≥ 0.19
Solid-State References (5 V to 10 V)	≥ 0.19

Measurement Assurance Program Service (53120M)

This MAP service provides a measurement of the error of dc voltage measurements in the customer laboratory at the 1.02-volt level, the uncertainty of the results, and an updated assigned value for the client's reference standards. A transport standard, which consists of a standard cell enclosure containing four saturated standard cells, maintaining constant temperature via line and battery power, is used. Preferably, it is hand-carried between NIST and the client laboratory, but arrangements may be made for air shipment. The standard is calibrated by NIST, the customer laboratory, and again by NIST to obtain the required data. The transport standard is capable of performing at the relative expanded uncertainty* level of 0.2×10^{-6} to 0.3×10^{-6} when hand-carried, and 0.5×10^{-6} to 0.8×10^{-6} otherwise.

*See Chapter 1, Section H for more information about uncertainty.

The measurement uncertainty achieved in this service contains primarily random errors. The major components of random error can be attributed to:

A. Day-to-day fluctuations in temperature-corrected cell emfs caused by temperature-hysteresis effects;
B. The finite resolution of the measurement apparatus at both the client laboratory and NIST;
C. Thermal emfs, unstable with time, which occur in the measuring circuit due to room temperature and humidity changes and drafts;
D. Temperature coefficients of the enclosures as a whole, not compensated for by temperature corrections;
E. Lack of resolution or instability of the apparatus used to monitor the cell temperatures;
F. Slow changes in temperature gradients or enclosure temperatures possibly due to atmospheric "pumping" of cool air into the enclosures, or vibration effects on the control circuitry;
G. Controller instability caused by power-line noise;
H. Effects of electrostatic or electromagnetic pick-up on the measuring system;
I. Detector drift; and
J. Momentary upsets in cell emfs caused by small electrical currents passing through the cells.

The experimental design described for making the intercomparison measurements removes the effects of average "left-right" or offset errors. One potentially significant source of error not corrected for or quantified in the MAP service is that caused by scale-factor errors in the instrumentation used to measure the differences between cell emfs. An error from this source can be eliminated by using calibrated instruments and applying the appropriate calibration corrections to the results.
The transport standard is normally kept in the client's laboratory for about 4 weeks, since eight to 12 measurement sets are generally required. Data analysis and issuance of the test report by NIST takes 4 to 5 weeks following the return of the transfer standards.

If the participating laboratory has a quality instrument that has been accurately calibrated and also has quality standards, the relative expanded uncertainty* of a single transfer of the unit of voltage using NIST transport standards is generally of the order of 0.5×10^{-6} or less. The best achievable long-term relative expanded uncertainty*, resulting from five or more transfers over an extended time, is of the order of 0.2×10^{-6} to 0.3×10^{-6}.

In this service, NIST provides detailed instructions for carrying out the transfer and making the required measurements. The participant must have in-house standards and instrumentation capable of sustained performance at the 0.1×10^{-6} level. When a new participant (or group of participants) expresses a desire to use the voltage MAP service, NIST requests that a complete description of the participant's measurement system, including instruments, standards, wires, switches, and their use, be sent to the NIST technical staff. This description enables NIST personnel to assist in resolving measurement problems by telephone.

NIST requires evidence in the form of control charts of the existence of a formal quality-control program in the laboratory as a prerequisite to participation in the service. This requirement has been established to enable problems to be addressed in advance of the transfer and to reduce delays in returning the standards to NIST.

Saturated Standard Cells (53130C–53140C)

Routine calibrations of saturated standard cells involve the following considerations:

A. 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.

* See Chapter 1, Section H for more information about uncertainty.

B. Saturated standard cells of the shippable type housed in portable thermoregulated enclosures should be packed carefully and shipped under power if possible. Any liquid-in-glass thermometer mounted in such a device 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 overheating. Enclosures should not be energized by using the ac power mains while they are in shipping containers as heat from the transformer will cause them to go over-temperature.

C. Saturated standard cells, which are maintained continuously at their nominal temperature of use during shipment, will undergo test starting 1 week after receipt for a period not to exceed 6 weeks, unless other arrangements are made. If such cells perform abnormally, 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.

D. 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 1 month after they initially attain use temperature, daily readings will be taken to observe the stability of the cells. When the cells stabilize, 10 daily readings will be taken and averaged to assign values to them. This process will not exceed 90 days without special arrangements being made.

E. For an additional fee, the temperature of air bath enclosures for saturated standard cells will be determined using a calibrated NIST platinum resistance thermometer (Service ID Number 53140C). Daily readings are taken and reported. The reported cell emfs are assumed to correspond to the mean of the temperatures measured on the same days as the emf readings were taken.

The client must understand that, when this is done, the uncertainties of the reported emfs include the emf equivalent of the uncertainty of the measured temperatures in terms of the International Temperature Scale of 1990 (ITS-90). Moreover, estimates of the uncertainties of any voltage measurements made by clients using these cells as a reference must include corresponding uncertainties of their own temperature measurements.

F. NIST accepts cells used in oil baths for calibration in NIST oil baths maintained at 28 °C. Cells used in oil baths operating at other nominal temperatures can best be calibrated using transport standards as in the MAP service. (See 53120M above.)

Calibration relative expanded uncertainties* generally range from 0.15×10^{-6} to 0.50×10^{-6}. The stated uncertainties are those of the NIST-measured average values, i.e., they do not reflect long-term behavior of the cells, transportation effects, etc.

Unsaturated Standard Cells (53150C)

Unsaturated cells require approximately 3 weeks for a complete calibration. The emfs of such cells are read daily for a minimum period of 10 days. These cells are compared with NIST saturated cells using a precision digital voltmeter to measure the difference emf directly. The calibration relative expanded uncertainty* is 0.005 % of the measured voltage unless the cell is abnormal. If the measured emf fluctuates unduly or is unusually low, or if the cell behaves abnormally, the reported uncertainty will be increased appropriately. 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 extremely cold weather should be avoided.

*See Chapter 1, Section H for more information about uncertainty.

Solid-State Voltage Reference Standards (53160C and 53161C)

Solid-state voltage standards with outputs in the range from 1 V to 10 V are calibrated using a self-calibrating automated system which scales to any multiple up to 10 V of 1.018 V from the emf of a working group of NIST saturated standard cells. It then measures the difference between the emf of the standard under test and the emf of its own output closest in voltage to that of the standard being measured and computes its emf. Measurements are taken daily for 12 to 15 working days and the mean value of the results reported.

Due to the limited battery life of many commercial standards, special shipping arrangements are advisable and can be made by contacting the Electricity Division.

Many solid-state standards have multiple outputs; to ensure proper testing, the outputs to be calibrated should be specified on the shipping papers as well as on the purchase order.

Voltmeter calibrators, multirange instruments with up to eight decimal digits of adjustability, are not considered by NIST to be standards and are not to be submitted routinely for calibration under this test category. Likewise, NIST will not accept component solid-state devices for routine calibration. However, new, state-of-the-art devices and instruments may be accepted for test under special circumstances (see Service ID Number 53110S) at the discretion of NIST technical staff.

The NIST calibration service for voltage is directly tied to NIST Josephson-junction voltage-standard arrays. This 1-V standard fabricated from niobium trilayer resists the effects of cycling between its operating temperature of liquid helium and room temperature better than previous designs.

References—Voltage Measurements and Standards

Guidelines for Implementing the New Representation of the Volt and Ohm Effective January 1, 1990, N. B. Belecki, R. F. Dzuiba, B. F. Field, and B. W. Taylor, Natl. Inst. Stand. Technol., Tech. Note 1263 (June 1989).

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A Sub-PPM Automated One-to-Ten Volt Measuring System, B. F. Field, IEEE Trans. Instrum. Meas. **IM-34**, 327 (1985).

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A High-Resolution Prototype System for Automatic Measurement of Standard Cell Voltages, D. W. Braudaway and R. E. Kleinmann, IEEE Trans. Instrum. Meas. **IM-23**, 282 (1974).

Volt Maintenance at NBS via 2e/h: A New Definition of the NBS Volt, B. F. Field, T. F. Finnegan, and J. Toots, Metrologia **9**, 155 (1973).

Designs for Surveillance of the Volt Maintained by a Small Group of Saturated Standard Cells, W. G. Eicke and J. M. Cameron, Natl. Bur. Stand. (U.S.), Tech. Note 430 (Oct. 1967).

Standard Cells Their Construction, Maintenance, and Characteristics, W. J. Hamer, Natl. Bur. Stand. (U.S.), Monogr. 84 (Jan. 1965).

C. Voltage Measurements
C.2 AC Voltage Measurements

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Service ID No.	Items
53200S	Special Tests of High-Accuracy Digital Multimeters, Multifunction Calibrators, by Prearrangement
53201S	Special Tests of Low-Voltage AC-DC Transfer Standards, by Prearrangement
53202S	Special 25-Point Test of Digital Multimeters (DMMs), by Prearrangement
53203S	Each Additional DMM Test Point for 53202S

Digital Multimeters (DMMs) and Multifunction Calibrators (53200S)

Voltage measurements are performed at dc at amplitudes between 1 mV and 1 kV. Relative expanded uncertainties* as low as 1×10^{-6} are possible in the mid-voltage range.

Low-frequency (0.1 Hz to 100 Hz) measurements of ac voltage are made between 1 mV and 7 V using a NIST-developed calculable voltage standard in which waveforms are digitally synthesized using a lookup table and a digital-to-analog converter. Relative expanded uncertainties* as low as 5×10^{-6} are possible around 7 V.

Wideband ac voltage measurements between 10 Hz and 30 MHz are made between 1 mV to 1 kV using a thermal voltage converter standard in an automatic calibration system. Relative expanded uncertainties* range from 10×10^{-6} to 0.2 %.

AC current measurements are performed on the same automatic calibration system using a thermal current converter. Current sources can be measured from 10 Hz to 100 kHz at current levels between 1 mA and 2 A. Digital multimeters (DMM) tests are normally limited to an upper frequency of 5 kHz; however, special arrangements may be made for tests at higher frequencies and currents. Realtive expanded uncertainties* are typically less than 100×10^{-6}.

Direct current resistance measurements are performed between 1 Ω to 100 MΩ, for both DMMs and calibrators. Relative expanded uncertainties* of 2×10^{-6} are possible for certain resistance values.

* See Chapter 1, Section H for more information about uncertainty.

Low-Voltage AC-DC Transfer Standards (53201S)

Measurements of the ac-dc difference of low-voltage (1 mV to 200 mV) thermal transfer standards, micropotentiometers, and voltage dividers are also offered as a Special Test in the dc to 1 MHz frequency range. Relative expanded uncertainties* of 15×10^{-6} are possible in the audio-frequency range at 100 mV.

Special 25-Point Test of Digital Multimeters (DMMs), by Prearrangement (53202S–53203S)

This is a special reduced cost, 25-point test covering all five functions (ac and dc voltage and current, and dc resistance) of most precision DMMs. DMMs submitted for test must have an IEEE-488 interface bus, and a list of DMM bus commands for the instrument may be required. The 25 test points available are shown in Table 9.6 below, together with the best possible expanded uncertainties*. Additional test points are available over a wide range of amplitudes and frequencies.

Table 9.6. 25-Point Standard DMM Test

Point	Function	Magnitude	Frequency (kHz)	Relative Expanded Uncertainty* (× 10^{-6})
1	DC Voltage	0.1 V		4
2	DC Voltage	1 V		2
3	DC Voltage	10 V		1
4	DC Voltage	100 V		2
5	AC Voltage	0.1 V	0.3	50
6	AC Voltage	0.1 V	10.0	50
7	AC Voltage	0.1 V	1000.0	1000
8	AC Voltage	1 V	0.3	20
9	AC Voltage	1 V	10.0	20
10	AC Voltage	1 V	1000.0	500
11	AC Voltage	10 V	0.3	20
12	AC Voltage	10 V	10.0	20
13	AC Voltage	10 V	1000.0	500
14	AC Voltage	100 V	1.0	20
15	AC Voltage	100 V	100.0	50
16	DC Current	10 mA		10
17	DC Current	1 A		20
18	AC Current	10 mA	0.3	75
19	AC Current	10 mA	5.0	100
20	AC Current	1 A	0.3	100
21	AC Current	1 A	5.0	200
22	Resistance	10 Ω		8
23	Resistance	1 kΩ		3
24	Resistance	100 kΩ		5
25	Resistance	10 MΩ		30

* See Section H, Chapter 1, for more information about uncertainty.

References—AC Voltmeters and Sources

New Low-Voltage Standards in the DC to 1 MHz Frequency Range, N. M. Oldham and R. M. Henderson, Conf. Record of CPEM '90, Ottawa, Canada (June 1990).

A Calculable, Transportable Audio-Frequency AC Reference Standard, N. M. Oldham, P. S. Hetrick, and X. Zeng, IEEE Trans. Instrum. Meas. **38** (2), 368–371 (April 1989).

A High-Accuracy, 10 Hz– 1 MHz Automatic AC Voltage Calibration System, N. M. Oldham, M. E. Parker, A. Young, and A. G. Smith, IEEE Trans. Instrum. Meas. **36**, 883–887 (Dec. 1987).

C. Voltage Measurements

C.3 AC-DC Thermal Voltage and Current Converters (to 1 MHz)

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Service ID No.	Items
53310S	Special AC-DC Measurement Services, by Prearrangement
53350C	Set-up (No Test Points Included) for an AC-DC Difference Calibration of a Standard or Set of Standards (Voltage or Current)
53351C	First Frequency Point for Each Applied Voltage or Current Level
53352C	Additional Points for Each Applied Voltage and Current Level (Additonal Frequency/Voltage or Frequency/Current Points)

General Information—Thermal Voltage and Current Converters

Alternating voltage and current are most accurately measured by comparing the heating effect of the alternating quantity to the average heating effect of both polarities of the direct quantity using thermal transfer standards. These devices may be simple thermoelements, thermal voltage converters consisting of high-performance thermal sensors and resistors, or thermal current converters consisting of a precision shunt used with a thermal sensor. Good quality thermal converters generally have small ac-dc differences which are constant with respect to frequency in the range from about 100 Hz to 20 kHz at voltages from about 0.5 V to 100 V or currents up to about 5 A. The ac-dc differences generally increase (to large values in some cases) as the applied voltage or current is increased, or as the frequency departs from the audio region.

Special AC-DC Measurement Services, by Prearrangement (53310S)

This service provides for the measurement or evaluation of prototype ac voltage or current standards, sources, or measurement instrumentation, and for other measurements of alternating voltage, alternating current, or ac-dc difference not provided for below, at the discretion of NIST technical experts. Components used for ac-dc conversions will generally not be tested unless they show promise of standards-level behavior. Even then, such components will only be tested in very limited numbers to explore their possible use for precision measurements.

Special ac-dc difference calibrations of appropriate thermal voltage and thermal current converters are now offered with a relative expanded uncertainty* of 0.8×10^{-6}. This calibration service is the result of an extensive study of the group of multijunction thermal converters that make up the NIST primary standards. Thermal converters will be accepted for calibration with the 0.8×10^{-6} expanded uncertainty* provided that their performance, including stability and square-law response, is compatible with the NIST standards and high-precision comparator system. In general, the uncertainty below 1×10^{-6} is available for voltages from 2 V to 12 V, currents from 5 mA to 20 mA, and frequencies from 30 Hz to 10 kHz. As in the case of the other special ac-dc difference calibrations with reduced uncertainty, an additional cost and an extended turnaround time at NIST are required. Prospective clients are asked to contact J. R. Kinard to discuss the requirements and arrangements related to this service.

*See Chapter 1, Section H for more information about uncertainty.

AC-DC Difference Calibration of a Standard or Standards Set (Voltage or Current) (53350C-53352C)

This service covers the calibration of thermal voltage and current converters, ac shunts, and primary standard thermoelements covering the ranges 2 Hz to 1 MHz, 1 mA to 20 A, and 0.2 V to 1000 V. Measurements are recommended at all voltages or currents and frequencies where the transfer standard is used by the customer. In addition, if 1000 V or 1200 V ranges are measured, tests at 600 V are recommended to evaluate the effect of self-heating on the ac-dc difference of the resistor. Since some thermal transfer standards show large ac-dc differences at frequencies below about 40 Hz, additional measurements may be required to define the low-frequency performance of the instrument. Unless the instrument has a previous calibration history, the user may wish to discuss the calibration parameters with the appropriate NIST staff.

The uncertainties offered and parameter space covered in Table 9.7 for this calibration service are presently being reevaluated. Significant reductions in the uncertainties and expansion of the parameter space are expected. To obtain the most recent information, customers are requested to contact the NIST staff. Routine calibrations of thermal voltage and current converters generally are carried out on a demand basis. However, occasional extensive calibration requests may create scheduling problems; therefore, to facilitate rapid turnaround, please contact T. E. Lipe or J. R. Kinard at the telephone numbers/addresses cited above before sending the equipment.

Ongoing research at NIST will help to improve the Nation's capability to provide accurate alternating voltage and current and ac-dc difference calibrations to NIST customers. The present research focuses on the development of cryogenic resistive transition-edge sensors as new primary standards of ac-dc difference, and the design and fabrication of thin-film multijunction converters as working standards for ac-dc difference measurements.

Ac-dc difference calibrations at frequencies above 1 MHz are performed in the NIST Boulder Laboratory.

Table 9.7. AC-DC Difference Calibration Service[(a)]

Frequency:	**2 Hz to 5 Hz**	**5 Hz to 10 Hz**	**10 Hz to 20 kHz[(b)]**	**20 kHz to 50 kHz**	**50 kHz to 100 kHz[(b)]**	**100 kHz to 1 MHz**
Voltage Limits (V)	50	100	1000	1000	1000	100
Current Limits (A)		0.05	20	20	20	
Relative Expanded Uncertainties ($\times 10^{-6}$)*[(c)]						
Multirange Thermal Voltage Converters (TVCs)						
> 100 V			30	50	70	
≤ 100 V	200	100	20	30	50	100
Coaxial Single Range TVCs						
> 100 V			20	30	50	
≤ 100 V	200	100	15[(d)]	25	40	70
Special[(e)]						
10 V ≤ x ≤ 100 V			10			
1 V ≤ x ≤ 10 V			5			
Thermal Current Converters (TCCs)						
> 5 A			100	150	[(a,b)]	
≤ 50 mA < x ≤ 5 A			50	70	[(a,b)]	
≤ 50 mA	200	100	50	70	[(a,b)]	

[(a)] The uncertainties offered and parameter space covered in the table for this calibration service are presently being reevaluated. Significant reductions in the uncertainties and expansion of the parameter space are expected. To obtain the most recent information, customers are requested to contact the NIST staff.
[(b)] Some voltage, current, and frequency combinations in this range are available only as a special test with uncertainty determined on an individual basis.
[(c)] The lower uncertainty applies at the crossover frequencies. Uncertainties may be increased if the ac-dc differences are large or affected by self heating or other instability.
[(d)] 20×10^{-6} from 20 Hz to 100 Hz, 15×10^{-6} at 100 Hz and above.
[(e)] Normally available by prearrangement for coaxial, single-range TVCs between 100 Hz and 20 kHz, at additional cost and a longer turnaround time at NIST.
*See Chapter 1, Section H for more information about uncertainty.

References—AC-DC Thermal Converters (to 1 MHz)

Extension of the NIST AC-DC Difference Calibration Service for current to 100 kHz, J. R. Kinard, T. E. Lipe, and C. B. childers, J. Res. Natl. Inst. Stand. Technol. **102** (1), 75 (Jan.-Feb. 1997).

A Reevaluation of the NIST Low-Frequency Standards for AC-DC Difference in the Voltage Range 0.6–100 V, T. E. Lipe, IEEE Trans. Instrum. Meas. **IM-45** (6), 913 (Dec. 1996).

Performance of Multilayer Thin-Film Multijunction Thermal Converters, J. R. Kinard, D. X. Huang, and D. B. Novotny, IEEE Trans. Instrum. Meas. **IM-44** (2), 383 (April 1995).

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NIST Measurement Services: AC-DC Difference Calibrations, J. R. Kinard, J. R. Hastings, T. E. Lipe, and C. B. Childers, Natl. Inst. Stand. Technol., Spec. Publ. 250-27 (May 1989).

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Recharacterization of Thermal Voltage Converters after Thermoelement Replacement, J. R. Kinard and T. E. Lipe, IEEE Trans. Instrum. Meas. **IM-38** (2), 351 (April 1989).

C. Voltage Measurements

C.4 RF-DC Thermal Voltage and Current Converters (100 Hz–1 GHz)

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Service ID No.	Items
53405S	Special Tests of AC Thermal Voltage Converters, by Prearrangement
53410C	Low-Frequency TVC Calibration at One Frequency Selected from Those Given in Table 9.8 at Rated Voltage in the Range 0.1V to 50 V
53411C	Additional Frequency Selected from Table 9.8 for Same TVC as in 53410C
53412S	Same as 53410C, Except Customer Designates a Single Frequency (in Same Frequency Range) Other Than Those Given in Table 9.8
53413C	Low-Frequency TVC Calibration at One Frequency Selected from Those Given in Table 9.8 at Rated Voltage in the Range 50-200 V
53414C	Additional Frequency Selected from Table 9.8 for Same TVC as in 53413C
53415S	Same as 53413C, Except Customer Designates a Single Frequency (in Same Frequency Range) Other Than Those Given in Table 9.8
53420C	High-Frequency TVC Calibration at One Frequency Selected from Those Given in Table 9.9 at Rated Voltage in the Range 0.2 V to 7.0 V
53421C	Additional Frequency Selected from Table 9.9 for Same TVC as in 53420C
53430S	Peak-to-Peak Detector Calibration at One Frequency Selected from Those Given in Table 9.10 at 1.2 V Peak-to-Peak Applied Rf Voltage
53431S	Additional Frequency for Peak-to-Peak Detector in 53430S
53440S	Special Tests of RF Micropotentiometers, by Prearrangement
53441C	RF Micropotentiometer Calibration at One Frequency Selected from the Frequency Bands Given in Table 9.11
53445S	Special Calibration of RF Micropotentiometer (Output Voltage Range, 200 μV to 200 000 μV at Frequency Range, 0.05 MHz to 1000 MHz) with Reduced Limits of Uncertainty

General Information—RF-DC Thermal Voltage and Current Converters, 100 Hz to 1 GHz (53405S–53445S)

Services are available for three types of electromagnetic voltage measuring devices: (1) Thermal Voltage Converters (TVCs), (2) Peak-to-Peak Detectors, and (3) Voltage Comparators and one type of electromagnetic generating device: RF Micropotentiometers.

Assurance of device stability can be obtained by intercomparing a micropot or TVC with another similar device where voltage ranges overlap. For example, a 1 V TVC can be compared with a 3 V TVC at 1 V, etc.

TVC calibrations requiring relative uncertainties* less than 0.05 % at frequencies below 1 MHz are performed at NIST Gaithersburg in the Electricity Division (Service ID Nos. 53350C, 53351C, 53352C).

RF Voltage Comparators (53405S)

Special tests are performed on rf voltage comparators using TVCs and micropotentiometers at selected frequencies from 100 kHz to 1 GHz at voltages ranging from 10 mV to 20 V. Several calibration options are available to the customer. Therefore, consultation by telephone or written correspondence is recommended before the comparator is submitted for calibration.

Thermal Voltage Converters (TVCs) (53410C–53421C)

TVCs also include other devices such as Rawson rf voltmeters, thermal transfer standards, rf voltage standards, and ac-dc transfer standards.

Most converters have rf-dc differences within 0.01 % of zero at 1 MHz and below. Converters with 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.

*See Chapter 1, Section H for more information about uncertainty.

The quantity measured by this calibration service is the rf-dc difference, defined as the percentage difference between the rf and dc input voltages required to produce the same thermocouple output, e.g.,

$$\text{RF-DC Difference (\%)} = \left(\frac{V_{rf}-V_{dc}}{V_{dc}}\right) \times 100.$$

Services available for low-frequency TVCs without a built-in T connector are given in Table 9.8. For high-frequency TVCs with a built-in T connector, the services available are given in Table 9.9. Calibrations above 100 MHz are performed only on the new high-frequency TVCs with a T connector as an integral part of the converter housing. The measurement reference plane is at the Type N male output connector of the converter.

Table 9.8. Measurement Ranges and Uncertainties for Low-Frequency TVC Services

Recommended Frequencies (MHz)	RF Voltage Range (V)	Relative Expanded Uncertainty*[(a)] (%)
0.03, 0.1, 0.3, 1	0.1 to 200	0.04
3 and 10	0.1 to 200	0.08
30	0.1 to 200	0.16
100	0.1 to 200	0.8

[(a)] Rf-dc differences greater than 20 % will not be reported. This normally limits the calibrations to 100 MHz and below.
*See Chapter 1, Section H for more information about uncertainty.

Table 9.9. Measurement Ranges and Uncertainties for High-Frequency TVC Services

Frequency (MHz)	RF Voltage Range (V)	Relative Expanded Uncertainty*[(a)] (%)
10	0.2 to 7.0	0.12
30	0.2 to 7.0	0.24
100, 200, 300, 400	0.2 to 7.0	1.20
500, 600, 700	0.2 to 7.0	1.20
800, 900, 1000	0.2 to 7.0	1.20

[(a)] Rf-dc differences greater than 20 % will not be reported.
*See Chapter 1, Section H for more information about uncertainty.

Peak-to-Peak Detectors (53430S-53431S)

Measurements on peak-to-peak detectors are performed from 100 kHz to 500 MHz and are referenced to the center of a GR 874 T connector. The quantity measured by this service is the rf-ac difference, defined as the percentage of difference between the rf and the ac input voltages required to produce "zero" dc detector output. A 50-kHz ac reference signal is applied instead of dc. The services available are specified in Table 9.10.

Table 9.10. Measurement Ranges and Uncertainties for Peak-to-Peak Detector Services

Frequency (MHz)	Applied RF Voltage for "0" Detector Output (V_{p-p})	Relative Expanded Uncertainty (%)
0.1, 0.3, 1.0	1.2	0.08
3, 10	1.2	0.13
30	1.2	0.24
50	1.2	0.58
100, 200, 300, 400, 500	1.2	1.20

*See Chapter 1, Section H for more information about uncertainty.

RF Micropotentiometers (53440S–53445S)

Radiofrequency micropotentiometers are usually calibrated at their nominal rated output voltages. Frequencies suggested for a normal calibration are (5, 100, 300, 400, 500, 700, and 900) MHz. Special arrangements may be made for calibrations up to 1000 MHz with reduced limits of uncertainty.

Radio frequency micropotentiometers having resistive elements greater than 10 mΩ in combination with thermoelement housings between 5 mA and 100 mA, usually have rf-dc differences within 1 % at 5 MHz. Since the rf-dc difference approaches zero below

5 MHz, calibrations at 50 kHz and 5 MHz would suffice to determine interpolated points of interest between 50 kHz and 5 MHz, with no appreciable loss of accuracy. Uncertainties are shown in Table 9.11.

An rf-dc difference of about 5 % at 1 MHz usually results from the effect of a 1 mΩ resistive element with a thermoelement rated between 5 mA and 100 mA inclusive. Interpolation below 1 MHz is not recommended in this case.

The rf-dc difference is defined as the percentage difference between the rf and dc output voltages required to produce the same thermocouple output, with the resistive element terminated in 50 ohms, e.g.,

Table 9.11. Measurement Ranges and Uncertainties for RF Micropotentiometer Calibrations

Any Frequency within Band (MHz)	RF Voltage Range (μV)	Relative Expanded Uncertainty*[a] (%)
0.05 to 100	1 to 100,000	2
100 to 500	1 to 100,000	3
500 to 900	1 to 100,000	6

[a] For rf-dc differences greater than 20 %, the estimated limits of uncertainty are larger than those listed.
*See Chapter 1, Section H for more information about uncertainty.

RF-DC difference (%) =

$$\left(\frac{V_{\mathrm{rf}} - V_{\mathrm{dc}}}{V_{\mathrm{dc}}}\right) \times 100.$$

As a special service, rf micropotentiometers with rated output voltage greater than 200 μV can be calibrated from 0.05 MHz to 1000 MHz, with reduced limits of relative expanded uncertainty* from 0.2 % to 2 %. This uncertainty is dependent on frequency, output voltage level, and the rf-dc difference vs frequency response. For further details, consult the technical contact cited at the beginning of this section.

References—RF-DC Voltage and Current Converters (100 Hz–1 GHz)

RF-DC Differences of Thermal Voltage Converters Arising from Input Connectors, D. X. Huang, J. R. Kinard, and G. Rebuldela, IEEE Trans. Instrum. Meas. **40** (2) (April. 1991).

NBS RF Voltage Comparator, L. D. Driver, F. X. Ries, G. Rebuldela, Natl. Bur. Stand. (U.S.), NBSIR 78-871 (Dec. 1978).

High-Frequency Microvolt Measurements, F. X. Ries and G. Rebuldela, ISA Proc., **18**, 1, 37.2.63, Instrum. Soc. of Amer. Res. Triangle Park, NC (Sept. 1963).

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Accurate Radio Frequency Microvoltages, M. C. Selby, Trans. AIEE, Pt. 1, Commun. Elect. **72**, 158 (May 1953).

Thermal Converters as AC-DC Transfer Standards for Current and Voltage Measurements at Audio Frequencies, F. L. Hermach, J. Res. Natl. Bur. Stand. (U.S.), **48**, 121 (1952).

*See Chapter 1, Section H for more information about uncertainty.

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C.5 Data Converters (53500S)

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Service ID No.	Items
53500S	Special Data Converter Services, by Prearrangement

General Information—Data Converters

NIST has an active research program in the area of data converters and digital waveform recorders. For D/A converters, special tests of voltage settling response are currently available. For A/D converters, a test bed is under development, having resolution up to 14 bits and sampling rates up to 10^9 samples/s. Test waveforms will include spectrally pure sinewaves, and fast settling step-like waveforms. Available services will include determinations of signal-to-noise ratio and harmonic distortion, as well as determinations of step and impulse response, and frequency response as computed from step response. Prospective clients are asked to contact Michael Souders or John Deyst to discuss the requirements and arrangements related to these services.

References—Data converters

IEEE Standard for Digitizing Waveform Recorder, IEEE Std. 1057–1994, Dec. 1994.

A Custom Integrated Comparator for High Performance Sampling Applications, O. B. Laug, et al., IEEE Trans. Instrum. Meas. **41**, 850–856, (Dec. 1992).

Accurate Frequency Response Determinations from Discrete Step Response Data, T. M. Souders and D. R. Flach, Trans. Instrum. Meas. **36**, 433–439 (June 1987).

D. Precision Ratio Measurements
D.1 Inductive Dividers

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Service ID No.	Items
54110S	Special Ratio Measurements and Tests of Inductive Voltage Dividers, by Prearrangement
54120C	Inductive Voltage Dividers—(Single Frequency, Voltage To Be Specified, Each Setting of 3 Most Significant Dials)
54121C	Additional Frequency Points
54130C	Inductive Voltage Dividers—(Single Frequency, Voltage To Be Specified, Each Setting of Most Significant Dial Only)
54131C	Additional Frequency Points

Special Ratio Measurements and Tests of Inductive Voltage Dividers, by Prearrangement (54110S)

This service category provides for the measurement and/or evaluation of prototype ratio devices and inductive voltage dividers based on new principles, and for unique ratio measurements at the highest accuracy levels, such as the determination of the ratios of Hamon resistance transfer devices or Silsbee-type voltage ratio standards. Such measurements are undertaken at the discretion of NIST technical staff and only when the need for them can be clearly demonstrated.

Inductive Voltage Dividers (54120C–54131C)

Inductive voltage dividers (decade transformer dividers) are accepted for calibration only at (50, 60, 100, 120, 400, 1000, 5000, and 10 000) Hz. The most significant dial only can be calibrated at 15 kHz and 20 kHz.

Calibration voltages may be specified up to 100 V or the manufacturer's specified limit, whichever is lower. The largest contribution to instability in undamaged inductive voltage dividers is wear or dirt 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 voltage-ratio reference standard. Inductive voltage dividers that use pushbutton switching or 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, typically marked "GRD," "Case GND," or "Case GRD." Decade inductive voltage dividers are calibrated at NIST at room temperature (22 °C to 24 °C) by comparison with a two-stage, three-decade transformer of known ratios.

References—Inductive Dividers

American National Standard for Decade Transformer Dividers (Voltage Type), ANSI C100, 1-1972 Amer. Natl. Stand. Inst., New York, NY (Jan. 1972).

Instructions for the Use of the NBS Reference Inductive Divider, Wilbur C. Sze, Natl. Bur. Stand. (U.S.), NBSIR, unpublished (1970). (Available from NIST.)

Two-Stage, Guarded Inductive Voltage Divider for Use at 100 kHz, D. H. Hamon and T. L. Zaf, ISA Transactions, **9**, 3, Instrum. Soc. of Amer. Res. Triangle Park, NC (1970).

Comparator for Calibration of Inductive Voltage Dividers from 1 to 10 kHz, W. C. Sze, ISA Transactions **6**, 4, Instrum. Soc. of America, Res. Triangle Park, NC (1967).

D. Precision Ratio Measurements
D.2 Resistive Dividers

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Service ID No.	Items
54210C	Resistor and Resistive Dividers, Total Resistance or Voltage Ratio, Two Direct Voltage Levels between 10 kV and 150 kV
54211S	Special Tests of Resistor and Resistive Dividers at Direct Voltage Levels, by Prearrangement
54212C	Resistor and Resistive Dividers at 60 Hz, Voltage Ratio and Phase Angle, between 10 kV and 100 kV rms
54213S	Special Tests of Resistor and Resistive Dividers at 60 Hz, by Prearrangement
54214S	Special Tests of Resistor and Resistive Dividers Under Pulsed High-Voltage Conditions, by Prearrangement

Resistor and Resistive Dividers, DC Measurements (54210C–54211S)

A calibration service is maintained at NIST to determine the dc voltage ratio of resistive dividers. The routine calibration service is available for applied voltages from 10 kV to 150 kV. The calibrations are performed with a measurement system which has a relative expanded uncertainty* of 0.006 % of the voltage ratio. To assure adequate sensitivity at the lowest applied voltage levels, calibrations are performed routinely only on dividers with ratios of 10^5:1 or smaller. The routine calibration service is also restricted to dividers with nominal ratios of 10^5:1, 10^4:1, or 10^3:1.

Resistive dividers are accepted for calibration only if they are nearly corona free at the rated operating voltage and are designed to have small temperature and voltage coefficients. Specifically, a device is not generally suitable for calibration by NIST if these coefficients produce a change in the ratio of 0.1 % over the normal range of operating voltages. At a given voltage, dividers should not exhibit instabilities in their ratio value in excess of 0.005 %. NIST staff can provide some assistance in the identification of other calibration laboratories capable of certifying the response of less accurate dividers.

Resistor and Resistive Dividers, 60 Hz Measurements (54212C–54213S)

Resistive dividers of sufficient quality to be considered as transfer standards are calibrated at 60 Hz for applied voltages between 10 kV and 100 kV rms. High-voltage dividers may perform satisfactorily as standards under dc voltages but do not perform well enough to be considered as standards when excited by 60-Hz voltages. The design of an ac divider requires special features, beyond those of a dc divider. In particular, ac dividers

*See Chapter 1, Section H for more information about uncertainty.

designed to be used as transfer standards may have to be equipped with external shielding to minimize the effects of capacitive coupling to surrounding objects.

If the device is not properly shielded, the effects of proximity to surrounding objects and pickup from high-voltage conductors can introduce large uncertainties into the measured value of the divider ratio. In such cases, the measurement of the ratio for one configuration would not necessarily be valid for another configuration. Consequently, a meaningful calibration of the device is difficult or impossible.

We therefore recommend that the following two preliminary proximity tests be performed before an ac divider is submitted for test to determine the suitability of the device as a transfer standard. Place the divider about 2.0 m from a vertical ground plane as measured from the center of the device. Energize the divider to some safe high-voltage level and measure the divider ratio. Repeat the measurement with the same applied high voltage but with the vertical ground plane (or divider) moved into a position 1.0 m from the center of the divider. If the measured divider ratio changes by 0.1 % or more, the device has excessive capacitive coupling and is not suitable as a transfer standard.

To test for pickup, remove the high-voltage connection to the top of the divider and then connect the top of the divider to ground with a thin wire. Measure the output voltage of the divider under these conditions both with and without the high-voltage source energized. If the resulting change in the output voltage exceeds 0.1 % of the expected output voltage when the high voltage is connected to the divider, then, again, there is excessive coupling, indicating that the device is not suitable as a transfer standard.

High-voltage ac dividers sent to NIST are first subjected to tests like those described above before any measurements are attempted. If such tests show variations in the measured ratio of more than 0.1 % for either proximity or pickup, then no further tests will be performed and the device will be returned. Prior to performing any measurements, dividers sent to NIST will also be subjected to a breakdown test at the highest voltage for which measurements are requested. The customer will be charged for the cost of these tests.

NIST calibration of voltage transformers at 60 Hz is generally more accurate than its calibration of dividers at the same frequency. Therefore, customers having a requirement for a calibrated divider may find it advantageous to use a voltage transformer as the transfer standard and to use that transformer to calibrate the divider in their own facilities.

Routine tests are carried out for voltages between 10 kV and 100 kV rms and are performed with a measurement system having relative expanded uncertainties* of 0.03 % in the determination of the ratio and 0.3 mrad in the determination of the phase angle.

Resistor and Resistive Dividers, Pulsed High-Voltage Conditions (54214S)

Resistive divider ratios are also determined under pulsed high-voltage conditions. All pulsed measurements are by prearrangement. Determinations employ special-design pulse dividers and calibrated Kerr cells as reference standards. A variety of pulses may be applied to simulate the conditions under which the divider will be used. Calibrations are made at selected voltage intervals from 20 kV to 300 kV as requested and up to 500 kV with certain pulse shapes. The typical relative expanded uncertainty* is 2 % of the voltage ratio although smaller uncertainties can occasionally be reported as a special test.

Shipping:

Dividers can be hand-carried or shipped prepaid to NIST. Shipped dividers should be packaged in sturdy reusable containers with convenient

*See Chapter 1, Section H for more information about uncertainty.

access to the divider. The design of many high-voltage dividers makes them vulnerable to shear-type forces, so provisions should be made to minimize the likelihood of damage due to such forces when the device is in the shipping container.

References—Resistive Dividers

High-Voltage Divider and Resistor Calibrations, M. Misakian, Natl. Bur. Stand. (U.S.), Tech. Note 1215 (July 1985).

Evaluation of a Multimegavolt Impulse Measurement System, R. E. Hebner, D. L. Hillhouse, and R. A. Bullock, Natl. Bur. Stand. (U.S.), NBSIR 77-1933 (Nov. 1979).

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Special Shielded Resistor for High-Voltage Measurements, J. H. Park, J. Res. Natl. Bur. Stand. (U.S.), **66C** (1), 19 (Jan.-Mar. 1962).

Comparative High Voltage Impusle Measurement, G. J. FitzPatrick and E. F. Kelley, J. Res. Natl. Inst. Stand. Technol. **101** (5), 639 (Sept.–Oct. 1996).

D. Precision Ratio Measurements
D.3 Capacitive Dividers

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Service ID No.	Items
54310S	Special Tests of Capacitive Dividers at 60-Hz, by Prearrangement
54311S	Special Tests of Capacitive Dividers Under Pulsed High-Voltage Conditions, by Prearrangement

Capacitive Dividers, 60-Hz Measurements (54310S)

Determinations of capacitive divider ratios at 60-Hz ac employ the same equipment used for the calibration of ac resistive dividers (see 54212C). The same limitations pertain to shielding (proximity and pickup effects). The NIST measurement system imposes a negligible burden on the divider if its output voltage is 100 volts or less. Otherwise, the burden is equivalent to a 1000-pF capacitor.

Capacitive Dividers, Pulsed High-Voltage Conditions (54311S)

Determinations of capacitive divider ratios under high-voltage pulse conditions employ special-design pulse dividers and calibrated Kerr cells as reference standards. A variety of pulses may be applied to simulate the conditions under which the divider will be used. Calibrations are made at selected voltage intervals from 20 kV to 300 kV as requested and up to 500 kV with certain pulse shapes. The typical relative expanded uncertainty* is 2 % of the voltage ratio although smaller uncertainties occasionally may be negotiated.

References—Capacitive Dividers

Comparative High Voltage Impulse Measurement, G. J. FitzPatrick and E. F. Kelley, J. Res. Natl. Inst. Stand. Technol. **101** (5), 639 (Sept.-Oct. 1996).

High-Voltage Divider and Resistor Calibrations, M. Misakian, Natl. Bur. Stand. (U.S.), Tech. Note 1215 (July 1985).

Evaluation of a Multimegavolt Impulse Measurement System, R. E. Hebner, D. L. Hillhouse, and R. A. Bullock, Natl. Bur. Stand. (U.S.), NBSIR 79-1933 (Nov. 1979).

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Special Shielded Resistor for High-Voltage Measurements, J. H. Park, J. Res. Natl. Bur. Stand. (U.S.), **66C** (1), 19 (Jan.-Mar. 1962).

*See Chapter 1, Section H for more information about uncertainty.

D. Precision Ratio Measurements
D.4 Mixed Dividers

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Service ID No.	Items
54410S	Pulse Voltage Measuring Systems, Including Kerr Cells

Mixed Dividers (54410S)

A mixed divider is one constructed of resistors and capacitors. Ratios of mixed-voltage dividers are determined under pulsed, high-voltage transient conditions. Determinations employ specially-designed pulse voltage dividers and calibrated Kerr cells as reference standards. A variety of pulse waveshapes may be applied to simulate the conditions under which the divider will be used. Calibrations are made at selected voltage intervals from 20 kV to 300 kV as requested and up to 500 kV with certain pulse shapes. The typical relative expanded uncertainty* is 2 % of the voltage ratio although smaller uncertainties can occasionally be reported as a special test.

*See Chapter 1, Section H for more information about uncertainty.

References—Mixed Dividers

Comparative High Voltage Impulse Measurement, G. J. FitzPatrick and E. F. Kelley, J. Res. Natl. Inst. Stand. Technol. **101** (5), 639 (Sept.-Oct. 1996).

Evaluation of a Multimegavolt Impulse Measurement System, R. E. Hebner, D. L. Hillhouse, and R. A. Bullock, Natl. Bur. Stand. (U.S.), NBSIR 79-1933 (Nov. 1979).

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Special Shielded Resistor for High-Voltage Measurements, J. H. Park, J. Res. Natl. Bur. Stand. (U.S.), **66C** (1), 19 (Jan.-Mar. 1962).

D. Precision Ratio Measurements
D.5 Voltage and Current Transformers

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Gaithersburg, MD 20899-0001

Shipping Address:
National Institute of Standards and Technology,
[For 54510C–54513C:
Attn: E. D. Simmon, Bldg. 202, Room 167, ext. 3956]
[For 54520C–54522C:
Attn: T. L. Nelson, Bldg. 220, Room B165, ext. 2986]
I-270 at Quince Orchard Road,
Gaithersburg, MD 20899-0001

Service ID No.	Items
54510C	Voltage Transformer, Ratio & Phase Angle, at 60 Hz on 1 Range, 1 Secondary Voltage, 1 Burden Primary $V_{rms} \leq 150$ kV
54511C	Same as 54510C, Additional Similar Transformer at Same Time
54512C	Same as 54510C and 54511C, Additional Burden or Range
54513C	Same as 54510C–54512C, at Each Additional Secondary Voltage
54520C	Current Transformer, Ratio & Phase Angle, 1 Range at 1 Frequency and 1 Burden, Secondary Currents (0.5, 1, 2, 3, 4, 5) A, Primary Current Not Over 12 000 A
54521C	Current Transformer, Ratio & Phase, 1 Secondary Current, Additional Combination of Range, Frequency, and Burden, Primary Current Not Over 12 000 A
54522C	Current Transformer, Ratio & Phase at Each Additional Secondary Current, Same Combination of Range, Frequency, and Burden as 54520C or 54521C
54600S	Special Tests of Dividers and Transformers, by Prearrangement

Voltage Transformers (54510C–54513C)

NIST provides routine services for the measurement of complex voltage ratios (magnitude and phase angle) of transformers for primary voltages up to 150 kV and for secondary voltages above 50 V, subject to some constraints as to the maximum physical size of the device. Results of these routine tests are reported with expanded uncertainties* of 0.03 % for ratio and 0.3 mrad (1 mrad = 3.438 min) for phase angle. If the test conditions and the device under test warrant, special tests with smaller uncertainties can be performed. These special tests may require an extra fee. The customer must specify the secondary voltage and the secondary burden for each transformer or for each range of a multirange transformer. Ambiguity can be avoided if the impedance and power factor, or the resistance and reactance, are specified, rather than the volt-ampere rating of each burden.

The customer should note that the NIST calibration system represents a minimum burden of 1000 pF for routine calibrations. The customer should give some care to the specification of a burden recognizing that the use of the transformer with a burden different from that used in the calibration can result in significant error.

Calibrations of voltage transformers are performed routinely only at 60 Hz. Measurements are made with one side of both the primary and secondary windings connected together and to ground.

NIST does have some capability to perform measurements at voltages, frequencies, and burdens outside of the ranges described above. Calibrations can occasionally be provided at these nonroutine test points as a special test for an increased fee.

*See Chapter 1, Section H for more information about uncertainty.

Current Transformers (54520C–54522C)

Normally NIST calibrates only current transformers of high quality for use as reference standards. The NIST equipment is designed to test current transformers with a rated secondary current of 5 A, with test points chosen to be one or more of the following values: (0.5, 1, 2, 3, 4, 5) A.

Routine tests are carried out at 50 Hz, 60 Hz, and 400 Hz. For measurements at 50 Hz or 60 Hz, the results are generally reported with expanded uncertainties* of 0.01 % in ratio and 0.1 mrad in phase angle. For measurements at 400 Hz, the reported expanded uncertainty* is 0.03 % in ratio and 0.3 mrad in phase angle.

The customer must specify the test frequency, the secondary currents, and the secondary burdens for each transformer or for each range of a multirange transformer. Current transformers should be tested with burdens equivalent to those which are imposed when the device is used as a transfer standard. Routine calibration using the burdens specified in the American National Standards Institute (ANSI) Standard C-57.13 is not recommended unless these burdens are subsequently used in the customer's factory or laboratory. Large errors can result if the values of ratio and phase angle obtained with an ANSI recommended burden are used for the transformer when it is connected to a different burden.

The burden is preferably specified in terms of the measured resistance and inductance. These values should include the effects of the leads used to make a connection to the transformer secondary. An alternative, which is sometimes feasible, is to submit the transformer together with its normal leads and connected burden for calibration as a unit. If neither of the above are possible, the burden may be stated in terms of the voltampere product and the power factor of the secondary circuit at the test frequency.

*See Chapter 1, Section H for more information about uncertainty.

For reference, it should be noted that the test equipment regularly used at NIST represents a minimum test burden of about 0.03 Ω with a inductance of about 10 μH.

Because of contact resistance and current rectification, loose or dirty primary and secondary terminations may affect the measurement results. These surfaces should be tight and clean when the transformer is shipped to NIST to minimize this source of error.

Unless otherwise specified, current transformers are demagnetized prior to calibration. If it is desired to have a transformer tested as submitted (without demagnetization), this requirement should be stated on the purchase order and NIST staff should be informed by telephone before the transformer is shipped.

Many current transformers are not designed to be used as transfer standards, and most of these do not require calibration at NIST. NIST staff can provide some assistance in the assessment of the appropriateness of the device for NIST calibration and in the identification of alternative calibration sources. If NIST is required to perform laboratory measurements to determine whether or not a particular device can be calibrated, a charge for the cost of these measurements will be made.

Special Tests of Dividers and Transformers (54600S)

NIST maintains an active program of research and development in the area of electrical measurements at high-voltage levels. For this reason, NIST often is able to provide measurement support for high-voltage devices other than those listed above in this section. Special tests will generally be conducted by NIST, if the following criteria are met:

A. The requested tests are fully developed and documented.

B. There is a significant technical or economic justification for traceability of the test on the item to national standards.

C. There has not been a routine or recurrent need for the test.

References—Voltage and Current Transformers

A Calibration Service for Current Transformers, J. D. Ramboz and O. Petersons, NIST Spec. Publ. 250-36 (June 1991).

A Calibration Service for Voltage Transformers and High-Voltage Capacitors, W. E. Anderson, Natl. Bur. Stand. (U.S.), Spec. Publ. 250-33 (June 1988).

An Electronic Ratio Error Set for Current Transformer Calibrations, R. L. Kahler, IEEE Trans. Instrum. Meas. **IM-28** (2), 162 (June 1979).

A Wide-Range High-Voltage Capacitance Bridge with One-ppm Accuracy, O. Petersons and W. E. Anderson, IEEE Trans. Instrum. Meas. **IM-24**, (4), 336 (Dec. 1975).

Wide-Band Two-Stage Current Transformers of High Accuracy, T. M. Souders, IEEE Trans. Instrum. Meas. **IM-21** (4), 340 (Nov. 1972).

E. Phase Meters and Standards and VOR Measurements

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Service ID No.	Items
55110S	Special Tests of Phase Standards and Related Instruments, by Prearrangement
55120C	Phase Meters—One Combination of Input Voltages (0.5 V to 120 V) at One Frequency (2 Hz to 100 kHz)—The Input Voltage Ratio Shall Not Exceed 10
55121C	Phase Meters—Each Additional Combination of Input Voltages (0.5 V to 120 V rms) at the Same or at a Different Frequency (2 Hz to 100 kHz); The Input Voltage Ratio Shall Not Exceed 10
55130C	Phase Meters—One Combination of One Input Voltage (0.5 V to 120 V) and One Input Current (1 A to 5 A) at One Frequency (2 Hz to 5 kHz)
55131C	Phase Meters—Each Additional Combination of One Input Voltage (0.5 V to 120 V) and One Input Current (0.5 A to 5 A)
55140C	Phase Meters—One Input Voltage (120 V to 240 V) and Another Input Voltage (120 V to 240 V) at One Frequency (2 Hz to 5 kHz)
55141C	Phase Meters—Each Additional Combination of One Input Voltage (120 V to 240 V) and Another Input Voltage (120 V to 240 V) at the Same or at a Different Frequency (2 Hz to 5 kHz)

Special Tests of Phase Standards and Related Instruments, by Prearrangement (55110S)

Sinusoidal Phase Measurements

NIST will perform special-test phase angle measurements on phase angle generators, quadrature detectors, and phase bridge-networks. Restrictions apply, and technical limitations and arrangements for these tests should be discussed with NIST; prior arrangements are essential.

VOR Measurements

The NIST Special Tests for VOR (Very-high-frequency Omnidrectional Range) air navigation signals are described in detail in VOR Calibration Service, NBS Technical Note 1069 (see references). Two services are offered to support the calibration of VOR phase meters and generators. NIST has designed and built a standard VOR audio generator, used to calibrate unknown VOR phase meters, and a standard VOR phase meter, used to calibrate unknown audio generators. Direct generation or measurement of standard VOR rf signals are not a part of the service.

Phase Meters (55120C–55141C)

NIST has a capability for characterizing audio frequency phase meters over a frequency range of 2 Hz to 50 kHz. The standard used is a microcomputer-based system that synthesizes two sinusoidal voltages by means of digital techniques. The two signals are displaced relative to one another by a precisely known phase angle. Phase angles can be set with a resolution of 0.002° up to 5 kHz and 0.005° above 5 kHz. The amplitude of the two output signals can be varied independently from 0.5 V to 100 V rms. At power frequencies, one of the signals can be a current from 0.5 A to 5 A. The expanded uncertainty* in setting the standard is less than 0.01° below 5 kHz and increases to 0.04° at 50 kHz if the two output signals have the same amplitude. For unequal amplitudes, this uncertainty increases to 0.015° and 0.09° respectively, if the amplitude ratio is less than 10:1. Measurements at amplitude ratios up to 100:1 are performed as Special Tests.

*See Chapter 1, Section H for more information about uncertainty.

Although the accuracy of the phase angle standard does not rely on the stability of the frequency, the generated output, which can be varied in steps of 1 Hz, is locked to a crystal-controlled frequency synthesizer.

Special requirements for this service are as follows:

A. The voltage inputs of the phase meter to be tested must have impedances such that the current is limited to a few milliamperes at any applied voltage requested. Current inputs must have impedances low enough so that the compliance voltage does not exceed 2 V.

B. NIST will test the instrument in the as-received condition, without making adjustments other than those normally required for testing. Meters that are not in operating condition upon receipt at NIST will be returned to the owner.

C. In some cases, the response of phase meters involves significant time constants; in these cases, readings will be taken 30 s after the setting of the standard.

D. For given voltage and frequency settings, at least three readings will be taken at each specified phase angle. The order of readings will be randomized.

E. The experimental data are fitted to a mathematical model from which the phase meter response can be predicted. From the closeness of fit to the model, it can be determined whether observed deviations from the predicted values are significant.

F. Each phase meter will be operated under power for at least 2 h before test data are taken.

G. Meters that are not in operating condition upon receipt at NIST will be returned to the owner without repairs.

References—Phase Meters

Characterized Generator Extends Phase Meter Calibrations from 50 kHz to 20 MHz, N. M. Oldham and P. S. Hetrick, IEEE Trans. Instrum. Meas. **42** (2), 311–313 (Apr. 1993).

The NIST Sampling System for the Calibration of Phase Angle Generators from 1 Hz to 100 kHz, B. C. Waltrip, M. E. Parker, N. M. Oldham, and B. A. Bell, Proc. 1992 NCSL Workshop and Symp., 613–616 (July 1992).

NBS Measurement Services: Phase Angle Calibration Services, R. S. Turgel, J. M. Mulrow, and D. F. Vecchia, Natl. Bur. Stand. (U.S.), Spec. Publ. 250-26 (May 1988).

Phase Meter Calibrations at NBS, R. S. Turgel, J. Res. Natl. Bur. Stand. (U.S.), **93** (1), 53-59 (Jan. 1988).

Precision Calibration of Phase Meters, R. S. Turgel and D. F. Vecchia, IEEE Trans. Instrum. Meas., **36** (4), 915-922 (Dec. 1987).

NBS 50-kHz Phase Angle Calibration Standard, R. S. Turgel, Natl. Bur. Stand. (U.S.), Tech. Note 1220 (Apr. 1986).

A Wideband Transconductance Amplifier for Current Calibrations, O. B. Laug, IEEE Trans. Instrum. Meas. **34** (4), 639–643 (Dec. 1985).

A Precision Phase Angle Calibration Standard for Frequencies Up to 50 kHz, R. S. Turgel, IEEE Trans. Instrum. Meas. **34** (4), 509-516 (Dec. 1985).

NBS Phase Angle Calibration Standard, R. S. Turgel, N. M. Oldham, G. N. Stenbakken, and T. H. Kibalo, Natl. Bur. Stand. (U.S.), Tech. Note 1144 (July 1981).

A High-Performance Phase-Sensitive Detector, L. A. Marzetta, IEEE Trans. Instrum. Meas., **27** (4), 460-464 (Dec. 1978).

High-Precision Audio-Frequency Phase Calibration Standard, R. S. Turgel and N. M. Oldham, IEEE Trans. Instrum. Meas. **27** (4), 460-464 (Dec. 1978).

VOR Calibration Services, N. T. Larsen, D. F. Vecchia, and G. R. Sugar, Natl. Bur. Stand. (U.S.), Tech. Note 1069 (April 1985).

Fourier Transformation of the Nonlinear VOR Model to Approximate Linear Form, D. F. Vecchia, Natl. Bur. Stand. (U.S.), Tech. Note 1021 (June 1980).

A Wide-Range Current Comparator System for Calibrating Current Transformers, T. M. Souders, IEEE Trans. Power Appar. Syst. **90** (1), 318 (Jan.-Feb. 1971).

F. Power and Energy Measurements, Low-Frequency

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Test No.	Items
56110S	Special Tests of AC-DC Wattmeters, by Prearrangement
56200C	Watt, Watthour, Var or Varhour Meter, Initial Two Determinations of Percentage Registration of Same Meter at 60 Hz
56201C	Each Additional Determination of Percentage Registration of Same Meter at 50/60 Hz
56202C	Initial Two Determinations of One or Two Meters Run Simultaneously with the First (56200C)
56210M	Measurement Assurance Program for Watthour Meters
56220S	Fast Turn-Around Energy Measurements, Low Frequency

Special Tests of AC-DC Wattmeters (56110S)

Wattmeter calibrations at other than power frequencies are considered Special Tests and must be arranged on an individual basis. The following limitations apply:

A. Instruments must have separate voltage and current input terminals.

B. The instrument must have a self-contained power indicator, or provide a direct current or voltage signal which is proportional to power, or provide an output frequency which is proportional to the power.

C. Measurements are generally limited to sinusoidal signals at frequencies between dc and 100 kHz. Input signal levels should not exceed 240 V and 5 A.

D. Instruments will be tested in the as-received condition, and test uncertainties will be based in part on the performance of the instrument during the test.

Power and Energy Measurements, Low-Frequency (56200C–56202C)

Only standard electronic-type watt, watthour, var and varhour meters are accepted for test. Rotating types are no longer accepted except by special arrangement. If necessary, the meters should be cleaned or adjusted by the customer before they are shipped to NIST. NIST does not adjust meters and does not knowingly begin tests of faulty meters.

The test conditions must be specified by the customer. These include the current and voltage ranges to be tested, the frequency, the applied voltages, the applied currents, and the power factors. Values of these parameters which are available for routine testing are summarized in Table 9.12.

Table 9.12. Available Values of the Parameters for Routine Wattmeter, Watthour, Varmeter and Varhour Testing

Parameter	Available Values
Voltage (V)	69 to 480
Current (A)	0.5 to 30
Power Factor	0 to 1.0
Phase Angle	0 to 360°
Frequency (Hz)	50*, 60, 400*

* Tests at 50 and 400 Hz are limited to voltages of 240 V or less and currents of 5 A or less.

If necessary, measurements can sometimes be made at other values of these parameters. These would, however, be considered special tests. Separate, specific arrangements and a higher fee will be charged than for a routine calibration.

Prior to the calibration, the meters are energized for between 1 h and 4 h at rated voltage and current on one range. A calibration consists of at least two sets of measurements taken over a minimum period of 2 d.

For wattmeters, the values of the reported corrections (in watts) generally have relative expanded uncertainties* of 0.05 % of the full scale range in volt-amperes. For watthour meters, the reported values of the percentage registration generally have relative expanded uncertainties* of 0.05 % of the indicated value. Special, higher accuracy tests can be arranged for an additional fee. The relative expanded uncertainties* for power or energy measurements in these special tests may be as low as 0.005 % if the short-term standard deviation of the device under test is appropriately small. For the highest accuracy, voltages are limited to 120 V and currents to 5 A.

Measurement Assurance Program for Watthour Meters (56210M)

The Measurement Assurance Program for electric energy is designed to evaluate the performance of energy-measuring systems at the customer's laboratory. A NIST-owned, transport standard watthour meter of known stability is measured by NIST. It is then shipped to and measured by the customer, and shipped back to NIST. NIST analyzes the data and provides a report to the customer indicating the total uncertainty of the customer's measurement. This procedure enables the customer's standards to be measured relative to NIST standards without the downtime encountered when the customer's standards are shipped to and calibrated by NIST. In addition, and more important to those who calibrate standard watthour meters, the NIST MAP standard can be used by customers to evaluate their measurement process in a convenient and cost-effective way.

*See Chapter 1, Section H for more information about uncertainty.

The uncertainty of a MAP includes the effects of the long-term and short-term instabilities of the NIST calibration system, the customer's calibration system, and the transport standard. Typically, the relative expanded uncertainty* in a well-controlled comparison ranges between 0.03 % and 0.05 %.

The Electricity Division maintains an active program of research and development in the area of electric power and energy measurements. This program often enables NIST to provide measurement support for watt and watthour meters beyond that listed in this section. Special tests will generally be conducted when the following conditions prevail:

A. The requested tests are fully developed and documented.

B. There is a significant technical or economic justification for traceability of the test on the item to national standards.

C. There has not been a routine or recurrent need for the test.

Fast Turn-Around Energy Measurements, Low-Frequency (56220S)

This calibration service is offered for customers interested in a fast turn-around time, and reduced service cost for a limited number of specific test points. The three test points measured for this service are at 120 V and 5 A with power factors of unity, 0.5 lag, and 0.5 lead. These are the only test points offered for this service. If the customer requests additional test points, the price and turn-around time will be those for the routine calibration service (see Service ID Number 56200C). The relative expanded uncertainty* assigned to a watthour meter for this service is 0.02 %. This service will only accept standard watthour meters that have a pulse output. The turn-around time will be two weeks. Due to the short turn-around time of this service, the customer will need to schedule this calibration with the appropriate contact, and a purchase order must be submitted either with the instrument, or be received before the instrument arrives at NIST.

References—Power and Energy Measurements, Low Frequency

Digitally Synthesized Power Calibration Source, N. M. Oldham, O. B. Laug, and B. C. Waltrip, IEEE Trans. Instrum. Meas. **IM-36** (2), 341 (June 1987).

NBS Wideband Sampling Wattmeter, G. N. Stenbakken, O. B. Laug, A. G. Perry, B. A. Bell, and T. H. Kibalo, Natl. Bur. Stand. (U.S.), Tech. Note 1221 (May 1987).

A Wideband Sampling Wattmeter, G. N. Stenbakken, IEEE Trans. Power Appar. Syst. **PAS-103** (10), 2919 (Oct. 1984).

A Calibration Service for Wattmeters and Watthour Meters, J. D. Ramboz and R. C. McAuliff, Natl. Bur. Stand. (U.S.), Tech. Note 1179 (July 1983).

A Measurement Assurance Program for Electric Energy, N. M. Oldham, Natl. Bur. Stand. (U.S.), Tech. Note 930 (Sept. 1976).

Transfer of the Kilowatthour, S. R. Houghton, IEEE Trans. Power Appar. Syst. **PAS-94** (4), 1232 (July-Aug. 1975).

Sampling Techniques for Electric Power Measurement, R. S. Turgel, Natl. Bur. Stand. (U.S.), Tech. Note 870 (June 1975).

A Current Comparator System to Establish the Unit of Electrical Energy at 60 Hz, K. J. Lentner, IEEE Trans. Instrum. Meas. **IM-23** (4), 334 (Dec. 1974).

G. RF, Microwave and Millimeter-Wave Measurements

G.1 Thermistor Mounts

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Service ID No.	Items
	The following tests are for thermistor mounts with coaxial connectors.
61110S	Coaxial Mounts at a Single Frequency in the Range of 0.1 MHz to 10 MHz
61111S	Each Additional Frequency for 61110S
61120S	Coaxial Mounts at 10 MHz Intervals within the Frequency Range of 10 MHz to 100 MHz
61121S	Additional Mount at the Same Frequencies as 61120S
61122S	Coaxial Mounts at 50 MHz Intervals within the Frequency Range of 100 MHz to 1 GHz
61123S	Additional Mount at the same Frequencies as 61122S
61124S	Coaxial Mounts at 10 MHz Intervals within the Frequency Range of 10 MHz to 100 MHz, and 50 MHz Intervals within the Frequency Range of 100 MHz to 1 GHz
61125S	Additional Mount at the same Frequencies as 61124S
61126S	Coaxial with GPC-7 Connectors at Frequencies shown in Table 9.13 from 10 MHz to 18 GHz
61127S	Additional Mount at the same Frequencies as 61126S
61128S	Coaxial Mounts with GPC-7 Connectors at 1 GHz Intervals within the Frequency Range of 1 GHz to 18 GHz
61129S	Additional Mount at the same Frequencies as 61128S
61130S	Coaxial Mounts with Type N Connectors at Frequencies shown in Table 9.13 from 10 MHz to 18 GHz
61131S	Additional Mount at the same Frequencies as 61130S
61132S	Coaxial Mounts with Type N Connectors at 1 GHz Intervals within the Frequency Range of 1 GHz to 18 GHz
61133S	Additional Mount at the same Frequencies as 61132S
61134S	Coaxial Mounts with 3.5 mm Connectors at 1 GHz Intervals within the Frequency Range of 2 GHz to 18 GHz

Service ID No.	Items
61135S	Coaxial Mounts with 3.5 mm Connectors at 1 GHz Intervals within the Frequency Range of 18 GHz to 26 GHz
61136S	Additional Mount at the same Frequencies as 61134S and 61135S
61137C	NIST Model CN Coaxial Mounts at 124 Frequencies within the Frequency Range of 50 MHz to 18 GHz
61138C	NIST Model CN Coaxial Mounts at Customer Selected Frequencies within the Frequency Range of 50 MHz to 18 GHz
	The following tests are for thermistor mounts with waveguide flanges.
61144S	Rectangular Waveguide Mounts with WR90 Flanges at 200 MHz Intervals within the Frequency Range of 8.2 GHz to 12.4 GHz
61145S	Additional Thermistor Mount at the Same Frequencies as 61144S
61146S	Rectangular Waveguide Mounts with WR62 Flanges at 250 MHz Intervals within the Frequency Range of 12.4 GHz to 18.0 GHz
61147S	Additional Thermistor Mount at the Same Frequencies as 61146S
61148S	Rectangular Waveguide Mounts with WR42 Flanges at 1 GHz Intervals within the Frequency Range of 18 GHz to 26.5 GHz
61149S	Additional Thermistor Mount at the Same Frequencies as 61148S
61150S	Rectangular Waveguide Mounts with WR28 Flanges at 1 GHz Intervals within the Frequency Range of 26.5 GHz to 40 GHz
61151S	Additional Thermistor Mount at the Same Frequencies as 61150S
61152S	Rectangular Waveguide Mounts with WR22 Flanges at 1 GHz Intervals within the Frequency Range of 33 GHz to 50 GHz
61153S	Additional Thermistor Mount at the Same Frequencies as 61152S
61154S	Rectangular Waveguide Mounts with WR15 Flanges at a Single Frequency within the Frequency Range of 50 GHz to 75 GHz
61155S	Rectangular-Waveguide Mounts with WR10 Flanges at a Single Frequency within the Frequency Range of 92 GHz to 98 GHz
	High Power Wattmeters
61160S	Calibration Factor of Continuous Wave (CW) High Power Wattmeters at Several Points within the Frequency Range of 2 MHz to 30 MHz (1 watt to 1000 watts) and 30 MHz to 400 MHz (1 watt to 500 watts)
61190S	Special Microwave and RF Power Measurement Services, by Prearrangement

General Information

Calibration services are available for thermistor mounts with GPC-7, Type N, and 3.5 mm coaxial connectors and several waveguide sizes (8.2 GHz to 96 GHz).

Assistance is available for applying published, technically valid measurement techniques in lieu of previously available NIST calibration services for coaxial and waveguide calorimeters, thermoelectric 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.

The Reports of Calibration and Special Test give the magnitude and phase of the reflection coefficient, effective efficiency, and calibration factor of the thermistor mount.

Definitions:

Effective Efficiency η_e
The effective efficiency η_e is the ratio of the bolometrically substituted dc power in the thermistor mount to the net CW rf microwave power delivered to the thermistor mount.

Bolometrically Substituted dc Power
The bolometrically substituted dc power is the change in dc (or audio frequency) bias power required to maintain the resistance of the thermistor element at a constant value following the application of rf or microwave power.

Calibration Factor, K_B
The calibration factor is the ratio of the bolometrically substituted dc power in the thermistor mount to the CW rf microwave power incident upon the thermistor mount. $K_B = \eta_e(1-|\Gamma|^2)$.

Reflection Coefficient Magnitude, $|\Gamma|$ and Arg (Γ)
The reflection coefficient magnitude and phase (argument of reflection coefficient) is the ratio of the reflected wave voltage amplitude to the incident wave voltage amplitude and phase.

Commercial Coaxial Thermistor Mounts (61110S-61136S)

Specify frequencies in the range from 0.1 MHz to 10 MHz for special low-frequency thermistor mounts (Service ID Number 61110S). Values for η_e and $|\Gamma|$ are calculated from voltage and resistance measurements.

$\eta_e = (P_{dc})/(P_{rf})$, where $P_{rf} = V^2/R_P$, and R_P is the parallel equivalent resistance, and P_{dc} is the bolometrically substituted dc power in the bolometer.

The following table lists the frequencies at which measurements are made on thermistor mounts with GPC-7 or Type N connectors.

Table 9.13. Measurement Ranges and Uncertainties for Coaxial Thermistor Mounts

Frequency Range	Interval	Relative Expanded Uncertainty*[a] in η_e (%)
10 MHz to 100 MHz	10 MHz Intervals	0.3 to 0.5
100 MHz to 1 GHz	50 MHz Intervals	0.3
1 GHz to 2 GHz	50 MHz Intervals	0.3
2 GHz to 4 GHz	100 MHz Intervals	0.3
4 GHz to 8 GHz	200 MHz Intervals	0.4
8 GHz to 12.4 GHz	200 MHz Intervals	0.4
12.4 GHz to 18 GHz	250 MHz Intervals	0.5 to 0.7

[a] These expanded uncertainties are typical for thermistor mounts with Type N connectors.
* See Chapter 1, Section H for more information about uncertainty.

Uncertainties for the effective efficiency and calibration factor depend on the frequency and the characteristics of the unit being calibrated such as connector type, reflection coefficient, and repeatability.

NIST Model CN Reference Standard (61137C-61138C)

This premium service provides η_e measurements as a function of frequency for a NIST-designed coaxial reference standard with a Type N connector. The reference standard, designated Model CN (Coaxial with a Type N connector), is a bolometric, dc-substitution power detector that must be used with a NIST Type IV power meter (available from several commercial sources). The mount is designed as an optimum transfer standard which can be measured directly in the NIST coaxial microcalorimeter. To use this service, the customer needs to have a CN mount (contact Fred R. Clague for information).

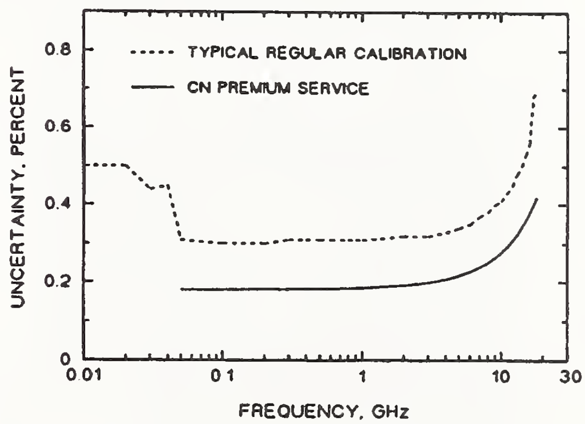

Figure 9.1. Expanded Uncertainty in η_e.

Measurements are made at 124 frequencies over the range from 50 MHz to 18 GHz (Service ID Number 61137C) or customer specified frequencies (Service ID Number 61138C). Figure 9.1 compares the expanded uncertainty of the premium service with that of the regular service for coaxial thermistor mounts.

Waveguide Thermistor Mounts (61144S-61155S)

Measurements of effective efficiency, efficiency factor, and reflection coefficient are made for various waveguide sizes as follows:

Table 9.14. Measurement Range and Uncertainties for Waveguide Thermistor Mounts

Waveguide Band	Frequency Range (GHz)	Measurement Frequency or Interval	Expanded Uncertainty* in η_e (%)
WR90	8.2 to 12.4	200 MHz Intervals	1.1
WR62	12.4 to 18	250 MHz Intervals	1.1
WR42	18 to 26.5	1 GHz Intervals	1.1
WR28	26.5 to 40	1 GHz Intervals	1.1
WR22	33 to 50	1 GHz Intervals	2.6
WR15	50 to 75	Specify Frequency	1.3
WR10	92 to 98	Specify Frequency	2.1

*See Chapter 1, Section H for more information about uncertainty.

High-Power Wattmeter (61160S)

A Special Test service is available for continuous wave (CW) high power wattmeters. Measurements are available at several frequencies from 1 MHz to 30 MHz (1 W to 1000 W) and 30 MHz to 400 MHz (1 W to 500 W). Wattmeters must be controllable via an IEEE-488 bus, have a Type N male input connector, and either have a Type N female output connector or an appropriate termination. The calibration factor, defined as the ratio of the wattmeter reading to the power incident upon it, will be supplied at each measurement point. The relative expanded uncertainty* is typically less than 2 %, depending on frequency, power level and electrical characteristics of the wattmeter/load combination. Call the technical contact for further information.

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*See Chapter 1, Section H for more information about uncertainty.

G. RF, Microwave, and Millimeter-Wave Measurements

G.2 Scattering Parameters of Passive Multi-Port Devices

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Service ID No.	Items
	The following tests are for two-port devices with coaxial connectors. See Table 9.15 for Measurement Ranges and Uncertainties.
61210S	Coaxial Fixed and Variable Attenuators with GR900 Connectors
61211S	Additional Two-Port Device at the Same Frequencies as 61210S
61212C	Coaxial Fixed and Variable Attenuators with GPC-7 Connectors
61213S	Additional Two-Port Device at the Same Frequencies as 61212S
61214S	Coaxial Fixed and Variable Attenuators with Type N Connectors
61215S	Additional Two-Port Device at the Same Frequencies as 61214S
61216S	Coaxial Fixed and Variable Attenuators with 3.5 mm Connectors [27 GHz to 33 GHz available by special request]
61217S	Additional Two-Port Device at the Same Frequencies at 61216S
61218S	Coaxial Fixed and Variable Attenuators with 2.92 mm Connectors
61219S	Additional Two-Port Device at the Same Frequencies as 61218S
61220S	Coaxial Fixed and Variable Attenuators with 2.4 mm Connectors
61221S	Additional Two-port Device at the Same Frequencies as 61220S
	The following tests are for two-port devices with waveguide connectors. See Table 9.16 for Measurement Ranges and Uncertainties.
61230S	WR90 Rectangular Waveguide Fixed and Variable Attenuators

Service ID No.	Items
61231S	Additional Two-Port Device at the Same Frequencies as 61230S
61232S	WR62 Rectangular Waveguide Fixed and Variable Attenuators
61233S	Additional Two-Port Device at the Same Frequencies as 61232S
61234S	WR42 Rectangular Waveguide Fixed and Variable Attenuators
61235S	Additional Two-Port Device at the Same Frequencies as 61234S
61236S	WR28 Rectangular Waveguide Fixed and Variable Attenuators
61237S	Additional Two-Port Device at the Same Frequencies as 61236S
61238S	WR22 Rectangular Waveguide Fixed and Variable Attenuators
61239S	Additional Two-Port Device at the Same Frequencies as 61238S
61240S	WR15 Rectangular Waveguide Fixed and Variable Attenuators
61241S	Additional Frequencies for Same Device Done on 61240S
61242S	WR10 Rectangular Waveguide Fixed and Variable Attenuators
61243S	Additional Frequencies for Same Device Done on 61242S
61249S	Special Attenuation Measurements, by Prearrangement
61250S	Time Delay, Coaxial and Waveguide, by Prearrangement
	The following tests are for one-port devices with coaxial connectors. See Table 9.17 for Measurement Ranges and Uncertainties.
61260S	Coaxial One-Port Devices with GR900 Connectors
61261S	Additional One-Port Device at the Same Frequencies as 61260S
61262C	Coaxial One-Port Devices with GPC-7 Connectors
61263S	Additional One-Port Device at the Same Frequencies as 61262S
61264S	Coaxial One-Port Devices with Type N connectors
61265S	Additional One-Port Device at the Same Frequencies as 61264S
61266S	Coaxial One-Port Devices with 3.5 mm Connectors
61267S	Additional One-Port Device at the Same Frequencies as 61266S
61268S	Coaxial One-Port Devices with 2.92 mm Connectors
61269S	Additional One-Port Device at the Same Frequencies as 61268S
61270S	Coaxial One-Port Devices with 2.42 mm Connectors
61271S	Additional One-Port Device at the Same Frequencies as 61270S

Service ID No.	Items
	The following tests are for one-port devices with waveguide connectors. See Table 9.18 for Measurement Ranges and Uncertainties.
61280S	WR90 Rectangular Waveguide
61281S	Additional One-Port Device at the Same Frequencies as 61280S
61282S	WR62 Rectangular Waveguide
61283S	Additional One-Port Device at the Same Frequencies as 61282S
61284S	WR42 Rectangular Waveguide
61285S	Additional One-Port Device at the Same Frequencies as 61284S
61286S	WR28 Rectangular Waveguide
61287S	Additional One-Port Device at the Same Frequencies as 61286S
61288S	WR22 Rectangular Waveguide
61289S	Additional One-Port Device at the Same Frequencies as 61288S
61290S	WR15 Rectangular Waveguide
61291S	Additional Frequencies for same Device Done on 61290S
61292S	WR10 Rectangular Waveguide
61293S	Additional Frequencies for same Device Done on 61292S
61294S	Special Reflection Coefficient Measurements, by Prearrangement
61295S	Coaxial Fixed and Variable Phase Shifters; Frequency Range 1 GHz to 50 GHz, Phase Range 0° to 360°
61296S	Waveguide Fixed and Variable Phase Shifters; Specify Frequencies for Waveguide Sizes WR10, WR15, WR22, WR28, WR42, WR62, and WR90
61297S	Special Tests of Phase Shifters, by Prearrangement

General Information

Microwave devices are characterized by their reflection and transmission properties. Single port devices such as matched terminations and offset shorts are characterized by measuring their reflection properties or voltage reflection coefficient. Multiport devices such as attenuators are characterized by measuring both their reflection and transmission properties.

Figure 9.2 shows the reflected and transmitted voltage waves for a typical two-port device. The voltage waves incident to the device are defined as a_1 and a_2. The voltage waves reflected from the device are defined as b_1 and b_2.

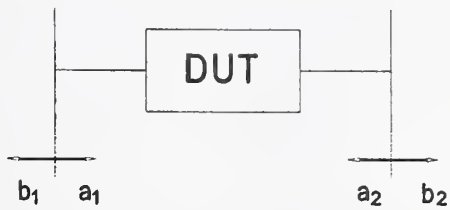

Figure 9.2. Reflected and Transmitted Voltage Waves for a Typical Two-Port Device.

The scattering parameters specify the relationship between the incident and reflected waves. In the case of the two-port in Figure 9.2, the scattering matrix is,

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{12} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}.$$

The scattering matrices shown are complex quantities conveying information on both the magnitude and phase of the quantities of interest.

The attenuation of a two-port device is defined as S_{12} and S_{21}. Most passive microwave devices are reciprocal where $S_{12} = S_{21}$. The magnitude of the attenuation for a reciprocal device is commonly expressed in dB as

$$A = -20 \log_{10}(|S_{12}|), \text{ dB}$$

$$= -20 \log_{10}(|S_{21}|), \text{ dB}$$

Similar definitions exist for single port devices such as terminations and offset shorts. A one port device can be thought of as the special case of a two port device where $S_{12} = S_{21} = 0$. The voltage reflection coefficient for a one port device is commonly given as

$$\Gamma = b / a \,,$$

where a is the voltage wave incident on the device, and b is the voltage wave reflected from the device.

All scattering parameters are referenced to some idealized transmission line. At NIST, all coaxial measurements are referenced to an idealized, air dielectric, 50 Ω transmission line of specified dimensions. Similarly, all waveguide measurements are referenced to an idealized, air dielectric, precision waveguide section of specified dimensions. Details of the reference standard are available on request.

Standards submitted for calibration should be in good repair and require only very minor cleaning of connector surfaces. NIST does not provide repair services. Items received requiring maintenance will be returned to the customer, and a handling fee will be charged.

Coaxial Fixed and Variable Attenuators (61210S–61221S)

Coaxial fixed and variable attenuators are measured on either a NIST Dual Six-Port Vector Network Analyzer (VNA) over the frequency range from 10 MHz to 26.5 GHz or on a commercial VNA over the frequency range from 50 MHz to 50 GHz.

Coaxial attenuators are normally measured relative to a reference characteristic impedance of 50 Ω. For fixed coaxial attenuators, the complete set of complex scattering parameters are measured. For reciprocal devices, the Reports of Calibration give the magnitude and phase of S_{11}, S_{22} and $S_{12} = S_{21}$.

For variable attenuators, normally only the change in attenuation from the zero setting is of interest. The test report for variable attenuators show the change in the magnitude of S_{12} from the zero setting versus frequency for selected attenuator settings. Complete scattering parameter measurements for variable attenuators are available by special request. Uncertainties depend on the nominal attenuation, connector type, and frequency.

Attenuation measurements are available for devices with 2.4 mm, 2.92 mm, 3.5 mm, GPC-7, 14 mm, and Type N connectors as shown in Table 9.15. Measurements not listed may be available and you should call the technical contact to discuss the availability. The cost of such services must be negotiated and will, in general, be higher than other established services. Consultation is available by telephone.

Table 9.15. Measurement Ranges and Uncertainties for Coaxial Two-Port Devices

Coaxial Connector Type	Frequency Range	Attenuation Range (dB)	Expanded Uncertainty* $\lvert S_{12}\rvert = \lvert S_{21}\rvert$ (dB)
GR900	10 MHz to 8.5 GHz	0 to 60	0.01 to 0.2
GPC-7	10 MHz to 18 GHz	0 to 60	0.01 to 0.2
Type N	10 MHz to 18 GHz	0 to 60	0.01 to 0.2
3.5 mm	10 MHz to 33 GHz	0 to 60	0.01 to 0.2
2.92 mm	10 MHz to 40 GHz	0 to 60	0.01 to 0.2
2.4 mm	10 MHz to 50 GHz	0 to 60	0.01 to 0.2

*See Chapter 1, Section H for more information about uncertainty.

Rectangular Waveguide Fixed and Variable Attenuators (61230S–61249S)

Fixed and variable (usually rotary vane) waveguide attenuators are calibrated on the NIST Dual 6-Port VNA. Service is available for frequencies corresponding to waveguide sizes WR10, WR15, WR22, WR28, WR42, WR62, and WR90 as shown in Table 9.16.

Table 9.16. Measurement Ranges and Uncertainties for Waveguide Two-Port Devices

Waveguide Band	Frequency Range (GHz)	Intervals	Attenuation Range (dB)	Expanded Uncertainty* $\lvert S_{21} \rvert$ (dB)
WR90	8.2 to 12.4	200 MHz	0 to 60	0.02 to 0.2
WR62	12.4 to 18	250 MHz	0 to 60	0.02 to 0.2
WR42	18 to 26.5	1 GHz	0 to 50	0.02 to 0.3
WR28	26.5 to 40	1 GHz	0 to 50	0.02 to 0.3
WR22	33 to 50	1 GHz	0 to 50	0.02 to 0.5
WR15	50 to 75	Specify	0 to 50	0.02 to 0.5
WR10	92 to 98	Specify	0 to 40	0.03 to 0.5

*See Chapter 1, Section H for more information about uncertainty.

Time Delay, Coaxial and Waveguide (61250S)

Time delay calibration services are available for both coaxial and waveguide delay lines. The time delay for the device under test is determined from phase measurements that are made on a vector network analyzer. The frequency range for the measurements ranges from 0.1 GHz to 100 GHz depending on the connectors involved. Devices submitted for calibration should be equipped with either precision coaxial connectors or precision waveguide flanges. The length of the device should typically be less than 30 cm. However, delay measurements can be made on longer devices in certain circumstances. Because of the specialized nature of these measurements, prior discussions should be held with NIST staff before submission of any device for testing.

Coaxial One-Port Devices (61260S to 61271S)

Services are available for complex reflection coefficient of passive devices with 2.4 mm, 2.92 mm, 3.5 mm, GPC-7, Type N and GR900 connectors. Available calibration frequencies are listed in Table 9.17.

Table 9.17. Measurement Ranges and Uncertainties for Coaxial One-Port Devices

Coaxial Connector Type	Frequency Range	Expanded Uncertainty* $\lvert S_{11} \rvert$ and $\lvert S_{22} \rvert$ (dB)
GR900	10 MHz to 8.5 GHz	0.002 to 0.004
GPC-7	10 MHz to 18 GHz	0.003 to 0.005
Type N	10 MHz to 18 GHz	0.003 to 0.007
3.5 mm	10 MHz to 33 GHz	0.006 to 0.013
2.92 mm	10 MHz to 40 GHz	0.008 to 0.020
2.4 mm	10 MHz to 50 GHz	0.014 to 0.038

*See Chapter 1, Section H for more information about uncertainty.

Waveguide One-Port Devices (61280S–61294S)

The terminations must be fitted with standard waveguide flange 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 waveguide joint and flanges is also 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. Available calibration frequencies are listed in Table 9.18.

Table 9.18. Measurement Ranges and Uncertainties for Waveguide One-Port Devices

Waveguide Band	Frequency Range (GHz)	Intervals	Expanded Uncertainty* $\|S_{11}\|$ and $\|S_{22}\|$ (dB)
WR90	8.2 to 12.4	200 MHz	0.005
WR62	12.4 to 18	250 MHz	0.002
WR42	18 to 26.5	1 GHz	0.004
WR28	26.5 to 40	1 GHz	0.004
WR22	33 to 50	1 GHz	0.009
WR15	50 to 75	Specify	0.009
WR10	92 to 98	Specify	0.012

*See Chapter 1, Section H for more information about uncertainty.

Phase Shifters, RF and Microwave (61295S–61297S)

The specific phase shift services are available on a limited basis. Because of the specialized nature of coaxial phase shifting components, prior discussions should be held with NIST staff before submission of any devices to NIST. Items to be calibrated must be fitted with connectors having a know plane of reference, such as sexless precision connectors, or Type N connectors meeting Mil. Std. C39012. The phase angle measured is $\Psi + 360n$, where n is an integer. The value of n is not determined. The expanded uncertainty* is 0.5°.

For rectangular waveguide, the measurement services are normally limited to phase shift difference. Measurements are made on continuously variable waveguide phase shifters with the zero value of the scale as the nominal reference position. The expanded uncertainty* is typically 0.5°.

*See Chapter 1, Section H for more information about uncertainty.

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G. RF, Microwave, and Millimeter-Wave Measurements

G.3 High Accuracy Attenuation Measurements

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Service ID No.	Items
61310C	Coaxial Fixed and Variable Attenuators Measured at 30 MHz, Attenuation 0 dB to 120 dB
61320C	Waveguide Below-Cutoff (Piston) Attenuators, Coaxial Connectors Measured at 30 MHz, Attenuation 0 dB to 120 dB (Total Insertion Loss)
61330S	Attenuation Measurements of Three-Port and Two-Port Devices at 1.25 MHz, 0 dB and 6 dB
61350C	Coaxial Fixed and Variable Phase Shifters; Characteristics Phase Shift Difference; Precision Connectors; Measured at 30 MHz, Range 0° to 360°

Coaxial Fixed and Variable Attenuators (61310C)

Coaxial fixed and variable attenuators are measured with reference to the NIST waveguide-below-cutoff (piston) attenuator at a fixed frequency of 30 MHz.

Coaxial attenuators are normally measured in a system having a characteristic impedance of 50 Ω. Typical expanded uncertainties* range from 0.01 dB to 1 dB depending on the nominal attenuation and connector repeatability.

Waveguide-Below-Cutoff (Piston) Attenuator Measurements at 30 MHz (61320C)

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

Measurements on waveguide below-cutoff (piston) attenuators are performed at 30 MHz. In any measurement, the maximum power delivered to the test attenuator is 400 mW. If the attenuator cannot tolerate this power level, some reduction of measurement range will be required.

Piston 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 rf leakage. The uncertainties depend upon the quality of the attenuator and connectors, as well as upon the VSWR (voltage standing-wave ratio) of the attenuator, and the magnitude of attenuation. Typical Type B standard uncertainties* range from 0.003 dB to 0.005 dB per 10 dB of attenuation. Total insertion loss must be less than 120 dB.

Attenuation Measurements at 1.25 MHz (61330S)

An additional measurement service is available for attenuation measurements of special three-port devices at 1.25 MHz. A measurement system has been developed to measure the change in the ratio S_{21}/S_{31} of special stable two-position, three-port devices sometimes called voltage doublers, at 1.25 MHz. The device must have an input for a 1.25 MHz source (port 1), a reference output (port 3), and an output (port 2) with a level switchable to two different values. The two levels of the bi-level output have a nominal ratio of 6.0206 dB.

* See Chapter 1, Section H for more information about uncertainty.

If P_{r1} is the reference power level when the bi-level output is at level 1 (P_{b1}), and P_{r2} is the reference power level when the bi-level output is at level 2 (P_{b2}), then the parameter measured is given by the following equation:

$$10 \log_{10}\left(\frac{P_{b1}}{P_{r1}}\right) - 10 \log_{10}\left(\frac{P_{b2}}{P_{r2}}\right), \text{ dB}$$

where the subscripts (1) and (2) refer to the switch positions 1 and 2, respectively. The above is equivalent to

$$10 \log_{10}\left|\frac{S_{21}(1)/S_{31}(1)}{S_{21}(2)/S_{31}(2)}\right|^2 .$$

The loads presented to the two outputs are 50 Ω. The device must allow the signal input to be of such strength that the bi-level output is at least 10 mW in the high-level position.

The Type A standard uncertainty* of the measurement system in measuring a 6 dB change in attenuation is 8.2 μB. Typical Type B standard uncertainties* are on the order of 0.3 μB to 0.5 μB (1 μB = 10^{-5} dB). Two-port step attenuators having a nominal change in attenuation of 6 dB can also be measured by this system at 1.25 MHz.

Phase Shifters (61350C)

The specific phase shift services are available on a limited basis depending on other demands and staff availability. Measurements not listed may possibly 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. Often a measurement technique can be suggested that will permit the customer to perform calibrations in-house with appropriate reference to other NIST-supported standards. The expanded uncertainty* is 0.5°.

*See Chapter 1, Section H for more information about uncertainty.

References—High Accuracy Attenuation Measurements

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G. RF, Microwave, and Millimeter-Wave Measurements

G.4 Thermal Noise Measurements

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Service ID No.	Frequency	Connector	Device Requirements/ Service
61410S	30 MHz 60 MHz	*Coaxial* N Precision (PIN) GPC 3.5 (PIN) GPC 7 14 mm	Temperature < 15 000 K (ENR < 17 dB) VSWR < 1.2
61420S	1.0 GHz to 12.0 GHz Continuous Frequencies	*Coaxial* N Precision (PIN GPC 3.5 (PIN) GPC 7	Temperature < 15 000 K (ENR < 17 dB) Reflection Coefficient < 0.2
	1 GHz to 4 GHz	14 mm	
61425S	12.4 GHz to 18.0 GHz Continuous Frequencies	*Coaxial* N Precision (PIN) GPC 3.5 (PIN) GPC 7	Temperature < 15 000 K (ENR < 17 dB) Reflection Coefficient < 0.2
61430S	18.0 GHz to 26.0 GHz Continuous Frequencies	*Coaxial* GPC 3.5 (PIN)	Temperature < 15 000 K (ENR < 17 dB) Reflection Coefficient < 0.2
61450S	8.2 GHz 9.0 GHz 9.5 GHz 9.8 GHz 10.0 GHz 10.5 GHz 11.2 GHz 11.8 GHz 12.4 GHz	*Waveguide* WR90	Temperature between 9 000 K and 17 000 K (14.6 dB < ENR < 17 dB) Reflection Coefficient < 0.09
61455S	12.4 GHz to 18.0 GHz Continuous Frequencies	*Waveguide* WR62	Temperature < 15 000 K (ENR < 17 dB) Reflection Coefficient < 0.2
61460S	18.0 GHz to 26.0 GHz Continuous Frequencies	*Waveguide* WR42	Temperature < 15 000 K (ENR < 17 dB) Reflection Coefficient < 0.2
61465S	26.5 GHz to 40.0 GHz Continuous Frequencies	*Waveguide* WR28	Temperature < 15 000 K (ENR < 17 dB) Reflection Coefficient < 0.2
61495S	Special Noise Temperature Measurements, by Prearrangement		

Noise Temperature Measurements (61410S—61465S)

Noise temperature measurements are available on single-port, coaxial and rectangular-waveguide noise sources under conditions of continuous, unmodulated operation. Precision coaxial connectors or clean, smooth, and flat standard EIA waveguide flanges are required. Measurement results on devices submitted with adapters attached may apply only to the source/ adapter combination. Complete operating instructions and special electronic connectors should be supplied, and pertinent operating conditions (voltages, circuits, etc.) should be specified for the noise source to be measured. Devices submitted that are not of sufficient quality or not mechanically compatible with the measuring system will be rejected, and an appropriate fee will be charged. Availability of measurements at specific frequencies and for various connector types are specified above. An attempt is being made to expand services to include additional types of precision connectors and waveguide sizes.

The measurement uncertainty varies with noise temperature, reflection coefficient, and source and connector stability. The relative expanded uncertainty* typically lies between 0.9 % and 1.5 % of the noise temperature.

Special Noise Temperature Measurements (61495S)

Measurements of electromagnetic thermal noise other than those listed above can sometimes be arranged on a case-by-case basis. These may include measurements through adapters, measurements out of the parameter ranges specified above, and measurements on systems currently under development. Such measurements should be discussed with one of the technical contacts before submitting a device for calibration.

References (Noise Temperature Measurements)

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*See Chapter 1, Section H for more information about uncertainty.

G. RF, Microwave and Millimeter Wave Measurements

G.5 Dimensional Verification of Coaxial Air Line Standards

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Service ID No.	Items
61510S	Dimensional Measurement of Air Lines and Verification of Characteristic Impedance from Dimensional Measurements, by Prearrangement

Coaxial Air Lines (61510S)

Dimensional measurements are made on the inner and outer conductors of a beadless, coaxial, air line standard. The characteristic impedance of the air line standard is then computed from these dimensional measurements. The service is currently available for 1.85 mm, 2.4 mm, 2.92 mm, 3.5 mm, GPC-7, 14 mm, and Type N air line standards. The computations for characteristic impedance is made over the normal operating frequency range of the air line standard. Consultation is available by telephone.

G. RF, Microwave, and Millimeter Wave Measurements

G.6 Dielectric and Magnetic Material Measurements

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Service ID No.	Items
61620S	Special Tests for Dielectric and Magnetic Materials 1 kHz to 60 GHz
61640S	Special Consulting and Advisory Services for Dielectric and Magnetic Materials, by Prearrangement

Special Tests for Dielectric and Magnetic Materials (61620S)

A special-test measurement service is available for measuring the complex permittivity, ϵ^* and permeability, μ^* of dielectric and magnetic materials, as well as the surface resistance of conductors, at selected RF/microwave frequencies in the spectral range 1 kHz to 60 GHz. The service is capable of characterizing fluids, powders, or bulk solids at room temperatures (23 °C) and, in some cases, over a temperature range of approximately – 80 °C to 150 °C. Customers interested in high frequency material characterization measurements should contact NIST staff to discuss their specific needs. The optimal measurement technique used is selected from a number of measurement techniques developed at NIST. The selection depends on a number of factors including whether the material is in fluid, powder or solid form, the volume of material available, its shape factor (for solids), its anticipated loss factor, whether the material is anisotropic, and the desired measurement frequencies and ambient temperature. The resulting measurement uncertainties depend on the technique selected as well as the nominal permittivity of the material under test.

Upon request, NIST staff will prepare a detailed cost quotation that includes estimates of the measurement uncertainties. For the case of solids, each measurement method requires accurately machined test samples with optical-standard tolerances for dimensions, flatness and parallelism. NIST can either perform the machining of test samples, the cost of which is included in the price quotation, or furnish drawings of sample specifications for the customer to perform the necessary machining.

The measurement techniques available at NIST can be divided into three categories: a) cavity resonator methods for low-loss materials (tan $\delta < 0.01$), b) broadband transmission line methods for medium to high-loss materials, and c) low-frequency impedance measuring methods. Most cavity resonators operate at frequencies above 100 MHz and usually provide single-frequency data, unless the resonators are tunable or can be operated on higher-order modes. Data are usually provided in tabular form. In general, better measurement uncertainties* are achievable using cavities and are about 0.5 % for ϵ'.

Broadband transmission line techniques include coaxial air lines and waveguides of various dimensions, as well as 1- and 2-port open-ended coaxial probe methods. Measured broadband data are normally provided as linear or logarithmic plots of ϵ', ϵ'' and μ', μ'' as a function of frequency with uncertainties included; relative uncertainties of 5 % to 10 % are typical. The low-frequency impedance measuring methods typically cover the frequency range 1 kHz to 10 MHz and involve measuring capacitance changes for dielectric materials and inductance changes for magnetic materials.

*See Chapter 1, Section H for more information about uncertainty.

References—Dielectric and Magnetic Material Measurements

Complex Permeability of Demagnetized Microwave Ferrites Near and Above Gyromagnetic Resonance, J. Krupka et al, IEEE Trans. Mag. **32** (3) pp. 1924–1933 (May 1996).

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NIST Measurement Service for Electromagnetic Characterization of Materials, J. H. Grosvenor, NIST Internal Report 5006 (Aug. 1993).

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H. Electromagnetic Field Strength and Antenna Measurements

H.1 Microwave Antenna Parameter Measurements

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Service ID No.	Items
63100S	Gain and Polarization Calibrations of Standard Antennas Using Extrapolation Range
63200S	Measurement of Pattern, Gain, and Polarization of Arbitrary Antennas Using Near-Field Scanning Techniques
63300S	Special Test Service for Calibration of Probes Used with Near-Field Scanning Facilities
63400S	Special Consulting, Advisory, and Other Services

Antenna Parameter Measurements (Microwave)—General Information

Accurate measurements of antenna gain, pattern, and polarization are generally available from about 1 GHz to about 75 GHz. However, because the measurement accuracy, capability, and cost depend on the frequency, type, and size of antenna, and the parameters to be measured, a particular measurement service must be negotiated in advance.

Antennas submitted for evaluation should be mechanically and electrically stable in order to retain a calibration for a significant length of time. Antennas with either coaxial or waveguide connectors can be measured; however, if coaxial connectors are employed, they should be precision connectors to minimize uncertainties due to a lack of connector repeatability. In particular, the use of SMA and APC-7 connectors is strongly discouraged because of poor connector repeatability. The following methods and facilities are used for these measurements.

Gain and Polarization Calibrations of Standard Antennas Using Extrapolation Range (63100S)

This calibration service is offered primarily for determining the absolute on-axis gain and polarization of standard gain horns, which, in turn, are used as reference standards in determining the gain and polarization of other antennas by the gain comparison technique. In the extrapolation method, three antennas are normally utilized, and three pairwise combinations are determined. The received signal transmitted between each 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 is the most accurate technique known for absolute gain and polarization measurements. For gain measurements from 2 GHz to 30 GHz, the uncertainties are typically 0.10 dB; above 30 GHz, the uncertainties are typically 0.15 dB. Uncertainties of 0.05 dB/dB for polarization axial ratio measurements are typical. There are antenna size limitations associated with existing NIST 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 whether all requirements can be met.

Measurement of Pattern, Gain, and Polarization of Arbitrary Antennas Using Near-Field Scanning Techniques (63200S)

With this technique, gain, pattern, and polarization parameters are calculated from near-field amplitude and phase measurements taken over a surface close to the test antenna. The absolute gain can be determined to within about 0.2 dB, the polarization axial ratio to within about 0.10 dB/dB, and side lobe levels can be obtained down to –50 dB or –60 dB. The exact uncertainties in these parameters will depend on such factors as the frequency, type and size of antenna. Antennas with apertures up to about 3 m in diameter can be managed. Measurements can be made from about 1 GHz to about 75 GHz. Measurements are most commonly made over a plane surface in front of the antenna being evaluated, but the capability also exists for measuring over a cylindrical or spherical surface surrounding the antenna when it is advantageous to do so. Calibrated probes are normally required for these measurements. These near-field scanning measurements are offered as a special-test service because nearly every measurement is unique and it is difficult to build up a statistical history as required for a regular calibration service.

Special-Test Service for Calibrating Probes Used with Near-Field Scanning Facilities (63300S)

This special-test service is available to support those organizations that have established their own near-field measurement facilities and need to characterize the probes used in performing the near-field measurements. In order to achieve accurate results with either the planar, cylindrical, or spherical near-field method, the transmitting or receiving properties of the probe must be known. With this information, the measured data can be corrected for the nonideal pattern and polarization properties of the probe. Probes are characterized by a three-step process: (1) The on-axis gain and polarization properties are measured using the extrapolation technique described above; (2) the far-field amplitude and phase patterns are measured for two nominally orthogonal polarizations of the incident field; and (3) the on-axis and pattern data are combined to obtain the probe correction coefficients at the desired lattice points for the measurement surface specified by the customer. The final output consists of a computer disk containing the measured far-field patterns and the calculated probe coefficients. Typical types of probes are open-ended waveguides and small horns. Both linearly and circularly polarized probes can be evaluated.

Special Consulting, Advisory, and Other Services (63400S)

A variety of special consultation and advisory services related to the measurements described above are available upon request. These services are offered to disseminate NIST technologies and to assist other organizations in establishing their own measurement facilities and capabilities. Included are cooperative measurement programs. A customer actually participates directly in the measurement of his device in order to become familiar with the measurement methods and assist in the analysis of the results. This is a useful approach when one is attempting to establish a new measurement capability that is related to or based upon NIST measurement techniques.

References—Microwave Antenna Parameter Measurements

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Accurate Determination of Planar Near-Field Correction Parameters for Linearly Polarized Probes, A. G. Repjar, A. C. Newell, and M. H. Francis, IEEE Trans. Antennas and Propagation, Special Issue on Near-Field Scanning, **36** (6), 855-868 (June 1988).

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A Transfer Instrument for the Intercomparison of Microwave Power Meters, G. Engen, IRE Trans. Instrum. Meas. **19**, 202 (Sept. 1960).

A Refined X-Band Microwave Microcalorimeter, G. Engen, J. Res. Natl. Bur. Stand. (U.S.), **63C**, 77 (1959).

H. Electromagnetic Field Strength and Antenna Measurements

H.2 Field Strength Parameter Measurements

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Service ID No.	Items
64100S	Special-Test Service for Antennas/Field Strength Measurements, Utilizing the Transverse Electromagnetic (TEM) Cell Method (10 kHz to 300 MHz)
64200S	Special-Test Service for Antennas/Field Strength Measurements, Utilizing the Open Area Test Site and Standard Antenna Method
64300S	Special-Test Service for Antennas/Field Strength/ Reflectivity Measurements, Utilizing the Anechoic Chamber and Standard Field Method

Special-Test Service for Antennas/Field Strength Measurements, Utilizing the Transverse Electromagnetic (TEM) Cell Method (64100S)

Standard electromagnetic fields are generated in TEM cells and used to calibrate electrically small antennas and antenna systems used for electromagnetic field probes in the frequency range 10 kHz to 300 MHz.

Special-Test Service for Antennas/Field Strength Measurements, Utilizing the Open Area Test Site and Standard Antenna Method (64200S)

These measurements include calibration of antenna factor and gain of antennas used in conjunction with field strength meters, and of electrically small antennas used in electromagnetic field probes. The following methods and facilities are used for these measurements:

A. Dipoles, log-periodic, and other antennas (25 MHz to 1000 MHz) are used to generate electromagnetic fields which are used for calibrating various antennas and electromagnetic field probes. The field strength is established using the standard receiving antenna method.

B. Monopoles (30 kHz to 300 MHz) are used to generate standard electric fields for calibrating antennas and electromagnetic field probes.

C. Loop antennas (14 kHz to 50 MHz) are used to generate standard magnetic fields for calibrating loop antennas used in conjunction with field strength meters.

Special-Test Service for Antennas/Field Strength Measurements, Utilizing the Anechoic Chamber and Standard Field Method (64300S)

A. Open-end waveguides (200 MHz to 450 MHz) are used to generate standard electromagnetic fields for calibrating antennas and electromagnetic field probes.

B. Pyramidal horns (0.45 GHz to 40 GHz) are used to generate standard electromagnetic fields for calibrating antennas and electromagnetic field probes.

Table 9.19 summarizes the field parameters, frequency ranges, and radiating antenna sources for the various NIST field strength measurement facilities.

Table 9.19. Summary of NIST Standard Field Strength Facilities

Field Parameter	Type of Measurement Facility	Frequency Range	Radiating Antenna Source
H	Wood building	14 kHz to 50 MHz	Loop (20 cm)
E (vertical)	Open Area Test Site (ground screen)	30 kHz to 30 MHz	Short monopole
E (vertical)	Open Area Test Site (ground screen)	30 kHz to 30 MHz	Quarter wave length monopole
E (horizontal)	Open Area Test Site (ground screen)	30 MHz to 300 MHz	Dipole, log-periodic antenna, etc.
E and H	TEM cell	25 MHz to 1000 MHz	
Power Density	Anechoic chamber	200 MHz to 450 MHz	Open-end waveguide
Power Density	Anechoic chamber	0.45 GH to 46 GHz	Pyramidal horn

References—Electromagnetic Field Strength Parameter Measurements

Methodology for Standard Electromagnetic Field Measurements, N. S. Nahman, M. Kanda, E. B. Larsen, and M. L. Crawford, IEEE Trans. Instrum. Meas. **IM-34**, 4 (Dec. 1985).

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I. Pulse Waveform Measurements

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Service ID No.	Items
65100S	Impulse Spectrum Amplitude (50 Ω)
65200S	Fast Repetitive Pulse Transition Parameters (50 Ω)
65250S	Fast Repetitive Pulse Settling Parameters (50 Ω)
65300S	Network Impulse Response (Transfer Function) of Coaxial Networks
65400S	Pulse Time Delay Interval

Pulse Waveform Measurements—General Information

NIST offers special-test services for a number of baseband pulse parameters. These are broken down into five categories: impulse spectrum amplitude, fast repetitive pulse transition parameters, fast repetitive pulse settling parameters, network impulse response, and pulse time delay interval. All of the special test services except the fast repetitive pulse settling parameters service are performed using the NIST Automatic Waveform Analysis and Measurement System (AWAMS). The AWAMS consists of a pulse generator, a calibrated wide-band sampling oscilloscope (input impedance 50 Ω, and nominal bandwidth of dc to 20 GHz, equivalent to a step response transition duration of 17.5 ps), and dedicated microcomputer system interfaced to the oscilloscope. The fast repetitive pulse settling parameters test service uses the NIST Sampling Comparator System (SCS), a NIST-designed sampling comparator oscilloscope, controlled by a microcomputer. The SCS has a 50 Ω input impedance, nominal bandwidth of dc to 2.5 GHz (equivalent to a step response transition duration of 140 ps), and settling < 1 % within 1 ns and to 0.1 % within 10 ns. All of these special tests are performed at cost, and by prearrangement. References pertaining to these four services are located at the end of this section.

Impulse Spectrum Amplitude (65100S)

In response to calibration needs from the electromagnetic interference (EMI) community, NIST has a special-test service to calibrate the broadband spectrum amplitude output from impulse generators. Such generators can then be used as transfer standards of broadband impulsive noise for field calibration of spectrum analyzers and field intensity meters. The NIST special-test service uses the time-domain measurement/frequency-domain deconvolution computational method for calibration of impulse generators. The AWAMS wideband (dc to 20 GHz) sampling oscilloscope is used to measure the time-domain waveform from the impulse generator. The spectrum amplitude, $S(f)$, versus frequency is then computed using fast Fourier transform (FFT). NIST will provide 50 to 200 data points over a wide frequency range for a single fee. NIST impulse spectrum amplitude measurement service capabilities are shown in Table 9.20.

Table 9.20. NIST Impulse Generator Spectrum Amplitude Measurement Service Capabilities

Parameter	Limits	Notes
Maximum impulse amplitude without attenuators	600 mV	1, 2
Maximum impulse amplitude with external attenuators	1.2 kV	2, 3
$S(f)$ range	− 15 dB (μV/MHz) < $[S(f) - S_0]$ < + 5 dB (μV/MHz)	4, 5
$S(f)$, expanded uncertainty*	Nominally f < 100 MHz, 0.6 dB, 100 MHz < f < 10 GHz, 0.3 dB 4 GHz < f < 10 GHz, 2.0 dB	4,5,7
Frequency range	10 MHz to 10 GHz	4,5,7
Frequency spacing	$\Delta f \geq$ 10 MHz	7
Frequency, expanded uncertainty	Nominally 0.3 %	
Load impedance	50.0 Ω	
Load impedance, expanded uncertainty	Nominally 0.5 Ω	5, 8
Trigger pulse amplitude	≤ 1.0 V	9
Trigger pulse transition duration	< 5 ns	9
Trigger to impulse delay interval	≥ 45 ns	9
Trigger to impulse jitter	< 10 ps, rms	9

* See Chapter 1, Section H for more information about uncertainty.

Notes:

1. Impulse generator with an adjustable-amplitude impulse output will be calibrated with the generator adjusted to give a peak amplitude in the range of 300 mV to 500 mV.
2. Impulse generators with fixed output amplitudes greater than 600 mV must have the impulse attenuated to a level of 300 mV to 500 mV by 50 Ω wideband coaxial attenuators.
3. Either customer-supplied or NIST attenuators may be used.
4. Data will not be given in the first spectrum null or at frequencies above. Typically about 100 data points are supplied.
5. Only for impulse amplitudes less than 600 mV.
6. If external attenuators and/or a delay-line network are used, then the uncertainties associated with the attenuator and/or network calibration are added to these values.
7. Measurements at frequency spacing less than 10 MHz are available as a special test.
8. Load impedance uncertainty depends upon input impedance of external attenuators when used.
9. If the impulse generator does not supply a trigger output or if the trigger output does not have the proper characteristics, then a delay-line network will be used to provide a suitable trigger pulse.

Fast Repetitive Pulse Transition Parameters, 50 Ω (65200S)

NIST offers a special-test service for fast repetitive pulses, for parameters related to the pulse transition. These parameters are measured with the NIST AWAMS described above. This service is optimized for measuring the durations of very fast pulse transitions (transition durations less than 350 ps, i.e., bandwidths greater than 1 GHz). The parameters, ranges, and estimated uncertainty limits for this service are listed in Table 9.21.

Table 9.21. Uncertainty for Calibration of Fast Repetitive Pulse Transition Parameters

Parameter	Range	Typical Expanded Uncertainty*
Pulse Baseline (0% level)	±500 mV	(0.5 %V + 2 mV)
Pulse Topline (100% level)	±500 mV	(0.5 % V + 2 mV)
Pulse Amplitude	±500 mV	(0.5 % V + 2 mV)
Pulse First Transition Duration (Rise Time)	10 ps to 100 ns	(0.5 % t + 3 ps)
Pulse Second Transition Duration (Fall Time)	10 ps to 100 ns	(0.5 % t + 3 ps)
Pulse Duration (Between 50% levels)	10 ps to 100 ns	(0.5 % t + 3 ps)

*See Chapter 1, Section H for more information about uncertainty.

Restrictions and Notes:

1. Customer's device must generate a repetitive pulse with repetition rate between 100 Hz and 1 GHz. Alternatively, NIST can provide a range of trigger signals.
2. Customer's device must have a nominal output impedance of 50 ohms.
3. Customer's device must have a precision coaxial output connector, e.g., SMA, APC-7, Type N, APC-3.5, etc.
4. Maximum pulse amplitude measurable without attenuators is 600 mV. For larger pulse amplitudes, the customer shall supply an attenuator to decrease the pulse amplitude to 600 mV or less.
5. Pulse topline is measured only for "step-like" pulses.
6. Pulse second transition duration and pulse duration are measured only for "impulse-like" pulses.

Measurements of other pulse parameters or parameter ranges may be provided by special arrangement. Consulting and advisory services also are available.

Repetitive Pulse Waveform Measurements, Including Settling Parameters (65250S)

NIST offers a special-test service for measurement of repetitive pulse waveforms whose major frequency components are below 1 GHz. Waveform measurement data can be provided on diskette, along with a report of measurement uncertainties as a function of the duration from the mesial (50 %) point of the pulse transition. When required, certain derived waveform parameters can also be provided. For step-like waveforms, these include waveform settling errors, with respect to a defined reference level. For impulse-like waveforms, pulse energy into an ideal 50 Ω load can be provided. The waveforms are measured with the NIST Sampling Comparator System described above. Waveforms within ± 2 V into 50 Ω can be accommodated directly. Higher amplitudes require the use of external attenuators. Both 50 Ω and 2 kΩ attenuators are available for amplitudes up to 20 V peak; however, the 2 kΩ attenuator substantially reduces the bandwidth of the measurement system. Typical measurement epochs range from 10 ns to 1 μs, and record lengths range from 1000 to 4000 samples.

Representative uncertainties for settling parameter measurements are listed in Table 9.22.

Table 9.22. Uncertainty for Measurement of Repetitive Pulse Settling Parameters

Pulse Amplitude (V)	Duration from Mesial Point (ns)	Typical Expanded Uncertainty* (% of pulse amplitude)
0.25	1	1.0
	2	0.3
	5	0.1
	10	0.1
	100	0.05
	1000	0.02
0.5 to 2.0	1	0.5
	2	0.2
	4	0.1
	5	0.06
	6	0.05
	8	0.03
	10	0.02
	20	0.02
	50	0.02
	100	0.01
	1000	0.01

*See Chapter 1, Section H for more information about uncertainty.

Restrictions and Notes:

1. All measurements are performed with a 50 Ω input impedance. The input connector is a female SMA type. The sampling probe is connected directly to the output connector of the waveform source; no intervening cables are used unless they are specifically provided for this purpose by the customer.
2. The settling error at time *t* (measured from the mesial point) is defined as the largest absolute difference between the waveform and the reference level occurring in the interval from time *t* to the end of the data record.
3. Unless otherwise requested, the reference level is the final dc or steady state value of the final level. This level is measured by inputting a steady state logic level to the generator under test corresponding to the final level.
4. Short term settling can also be measured with respect to the final level in a specified time epoch, if requested. In this case, long term settling error—the difference between the value at the end of the specified epoch and the dc value—also will be reported.
5. Pulse generators that are internally clocked must provide a separate trigger output pulse. For best results, this should lead the waveform under test by at least 35 ns. If the trigger pulse leads by less than 35 ns, the waveform measurement will begin one cycle later, with a resulting increase in jitter and time-quantization errors. If the pulse generator can be clocked externally, NIST will provide the clock signal and the necessary trigger output signal, when required.
6. The clock pulse requirements should be specified including high level, low level, repetition rate, and duty cycle. Repetition rates between 10 kHz and 10 MHz are preferred.

Measurements of other pulse parameters or parameter ranges may be provided by special arrangement. Consulting and advisory services also are available.

Network Impulse Response (65300S)

The network time-domain impulse response measurement service for coaxial networks has been offered previously at NIST; currently the service is being reworked and is not being offered, except by special arrangement. When available, the measurements will be accomplished by use of the NIST AWAMS described above. Two waveforms are measured, one with the pulse generator connected directly to the oscilloscope, and the other with the unknown network inserted between the generator and the oscilloscope. The time-domain impulse response function and/or the frequency domain scattering parameter, $S_{21}(f)$, are then calculated using an NIST-developed deconvolution algorithm. A wide variety of connectors can be accommodated. The resulting data are in the form of a discrete waveform vector, normally 1024 points in length, with a time window range from 1 ns to 100 ns. Also, using discrete Fourier transforms, the associated frequency-domain transfer function data ($S_{21}[f]$) are provided over a frequency range of 10 MHz to 10 GHz and a gain or loss range of 0 dB to 40 dB. The approximate limits of the expanded uncertainty* are expected to be less than 2 % for all parameters.

Pulse Time Delay Interval (65400S)

NIST offers a special-test service for measuring pulse time delay interval, using the NIST AWAMS described above. The pulse time delay interval range is 10 ps to 100 ns with typical expanded uncertainties* of (0.2 % t + 1 ps).

*See Chapter 1, Section H for more information about uncertainty.

Restrictions:

1. Customer's device must utilize precision coaxial connectors for both delay ports, e.g., SMA, APC-7, Type N, APC-3.5, etc.
2. Customer should provide the driving pulse generator if possible. First transition duration (rise time) of the driving pulse generator should not exceed 10 % of the pulse time delay interval to be measured.

Measurements for other ranges and configurations may be made by special arrangement. Consulting and advisory services are available.

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Chapter 10

A Broadcast and Measurement Services

B Characterization of Oscillators

Time and Frequency Measurements

A. Broadcast and Measurement Services

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Service ID No.	Items
	Broadcast Services (WWW, WWVH, WWVB, GOES, ACTS, and NTS)
76100S	Frequency Measurement Service (Frequency Delivered to User's Site)
76110S	Global Time Service (Frequency and Time Delivered to User's Site)

NIST Broadcasts of Time and Frequency Signals

NIST time and frequency broadcast services are available free of charge to the general public. Services are provided via HF, LF, and UHF radio, as well as via telephone lines and Internet connection. NIST broadcast services are coordinated with similar services in other countries. Commercial receivers (for radio signals) and software packages (for computer time services) are available from several manufacturers. NIST publications are available that explain how to use these services.

HF Signals—Broadcasts from WWV (Fort Collins, Colorado) and WWVH (Kauai, Hawaii) can be received on conventional shortwave receivers nearly anywhere in the world. Broadcast frequencies are 2.5 MHz, 5 MHz, 10 MHz, and 15 MHz for both stations and 20 MHz for WWV only. Standard uncertainties of 1 ms to 10 ms in time and a relative standard uncertainty* in frequency of 1×10^{-7} are typical from these broadcasts. The HF broadcasts provide standard frequencies, standard time intervals, time-of-day announcements, a binary-coded-decimal (BCD) time code, astronomical time corrections, and public service announcements for other government agencies. For individuals without receivers, the audio from both stations is simulcast by telephone. The telephone signal has a standard uncertainty* of 30 ms or less due to delays in cross-country telephone line routings. The phone numbers (not toll free) are (303) 499-7111 for WWV and (808) 335-4363 for WWVH.

LF Signals—Radio station WWVB (Fort Collins, Colorado) provides standard uncertainties of 0.5 ms in time and a relative standard uncertainty* in frequency of 1×10^{-11}. The station broadcasts a 60 kHz carrier and a BCD time code. Effective January 1, 1998, the transmitted power of WWVB will increase by 6 dB to approximately 50 kW and the coverage area will include most of North America.

GOES Satellite—The GOES satellites (Geostationary Operational Environmental Satellite) broadcast NIST time on a frequency of about 468 MHz. The signals are usable in North and South America with a standard uncertainty of 100 µs. Two satellites (GOES-East and GOES-West) are used for this service. The satellites are located at approximately 75° and 135° west longitude, respectively.

Automated Computer Time Service (ACTS)—This service allows computer users with modems to synchronize their clocks by telephone. The phone number for ACTS is (303) 494-4774. Users can connect at speeds of up to 9600 baud and obtain time signals with standard uncertainty* of 5 ms.

Network Time Service (NTS)—This service allows users to synchronize computer clocks via the Internet. The service responds to time requests from any

* See Chapter 1, Section H for more information about uncertainty.

Internet client in several formats including the Daytime (RFC-867), Time (RFC-868), and Network Time Protocol (NTP, RFC-1305). The service is being expanded and uses multiple time servers (call for current server addresses).

Frequency Measurement Service (76100S)

Frequency calibrations with a relative standard uncertainty* of 5×10^{-13} can be obtained using the NIST Frequency Measurement Service (FMS). The FMS uses signals from Global Positioning System (GPS) satellites as reference frequency. Subscribers to the FMS receive a complete frequency measurement system which they install in their lab (the equipment remains the property of NIST). The system includes a GPS receiver and all of the hardware and software necessary to automate the calibration process. The system can simultaneously calibrate up to five frequency standards (quartz, rubidium or cesium), and graphically display the results.

NIST provides all of the equipment, documentation, supplies, and technical support needed to operate the FMS, and offers a free training seminar to teach the subscriber. The subscriber's only requirements are to supply the frequency standards to be measured, and a dedicated phone line. The phone line allows NIST personnel to call each system to verify and analyze the data, and quickly troubleshoot any problems that might arise. If any component fails, NIST replaces it immediately using an overnight delivery service. Each subscriber receives a monthly certificate of calibration which certifies that their primary frequency standard is traceable to NIST. This traceability can assist customers seeking accreditation through NVLAP (National Voluntary Laboratory Accreditation Program) or seeking compliance with ISO requirements.

* See Chapter 1, Section H for more information about uncertainty.

Global Time Service (76110S)

This service uses the Global Positioning System (GPS) satellites in a common-view mode and provides better time and frequency transfer than is afforded directly by GPS. Data from a receiver located at the user's facility are automatically downloaded (by phone) to a NIST computer. The computer stores the data, determines which data are suitable for time transfer calculations, and provides optimally filtered values for the time and frequency of the user's clock relative to UTC (NIST). Monthly reports are sent to the user, and users also receive an account on a NIST computer that allows them to access a daily, preliminary analysis.

Tests between widely separated receivers have demonstrated standard uncertainties* for time comparisons of less than 10 ns and relative standard uncertainties* for frequency comparisons of less than 1×10^{-13}, both for averaging times of 1 d. The uncertainty decreases as the averaging time increases. The frequency uncertainty is limited by the relative standard uncertainty of the NIST primary frequency standard which is 5×10^{-15}.

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B. Characterization of Oscillators

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Service ID No.	Items
77100C	Oscillator Frequency Calibration
77110C	Characterization of Atomic Frequency Standards
77120C	Characterization of Oscillators: Time Domain
77130C	Characterization of Oscillators and Amplifiers: Phase Noise in the Frequency Domain
77131C	Characterization of Oscillators and Amplifiers: Amplitude Noise in the Frequency Domain
77135C	Tests of RF PM/AM Noise Measurement Systems: On-Site Tests
77136C	Tests of Microwave PM/AM Noise Measurement Systems: On-Site Tests
77140S	Special Time/Frequency Measurements: Oscillators and Other Components

Oscillator Frequency Calibration (77100C)

Oscillators with an output frequency of 1 MHz to 50 GHz can be sent to NIST for calibration. The relative standard uncertainty* is nominally that of the NIST frequency standard, which is 5×10^{-15}, but is limited by noise in the oscillator under test. The frequency stability of the oscillator can also limit the calibration, since oscillators often change frequency during shipment. Higher frequencies (50 GHz to 110 GHz) are covered under Service ID Number 77140S.

* See Chapter 1, Section H for more information about uncertainty.

Characterization of Atomic Frequency Standards (77110C)

An atomic standard is characterized by introducing it as a member of the NIST time scale system. The output of the standard is sampled every 2 h in sequence with the other clocks in the time scale, and the performance of the standard under test is readily determined. The standard test involves 30 d of measurements. The square root of the Allan variance $\sigma_y(\tau)$ is measured to 3×10^{-15} for averaging times of 7200 s to 10^6 s. The relative standard uncertainty* of the time scale is 5×10^{-15} and the fractional frequency drift is less than 2×10^{-16} per day. The actual values transferable to the standard are often limited by the oscillator's stability and noise properties.

Characterization of Oscillators: Time Domain (77120C)

For oscillator frequencies of 5 MHz, 10 MHz, and 100 MHz, the stability in terms of the square root of the Allan deviation $\sigma_y(\tau)$ is determined by repeated measurements at 0.5 s intervals. $\sigma_y(\tau)$ is determined to $4 \times 10^{-13}/\tau^{-1/2}$ for averaging times of 0.5 s to 10 000 s and frequency offset is measured with a relative standard uncertainty* of 5×10^{-15}, limited by the noise level and type in the oscillator under test. The frequency measurement transferable to the oscillator is often limited by the oscillator's stability due to transport between laboratories and on-off cycling. Measurements of Allan deviation from approximately 1 μs to 0.5 s can be determined by integration of the oscillator phase noise. This inversion of the data is performed by NIST. Thus, measurements in this range should be done under Service ID Numbers 77130C or 77140S. Characterization of time domain stability at other frequencies is covered under Service ID Number 77140S.

Characterization of Oscillators and Amplifiers: Phase Noise in the Frequency Domain (77130C)

For frequencies of 5 MHz to 26 GHz, phase modulation (PM) noise $S_\phi(f)$ of single oscillators and amplifiers can be determined for Fourier frequency offsets from the carrier of 0.1 Hz to 10 MHz. The PM noise is measured for only a few user-specified frequency offsets (typically 3 points per decade). All measurements of phase noise are made relative to 1 rad^2/Hz. At a carrier frequency of 5 MHz, $S_\phi(f)$ can be measured to −145 dB for a frequency offset of 1 Hz and −190 dB for an offset of 10 kHz. At a carrier frequency of 100 MHz, $S_\phi(f)$ can be measured to −150 dB for a frequency offset of 1 Hz and −190 dB for an offset of 50 kHz. A typical value of standard uncertainty* is 1 dB, but specific values depend on the carrier frequency and the offset frequency. Specific measurement requirements should be discussed prior to placing an order. PM noise for frequencies above this range (but less than 110 GHz) are covered under Service ID Number 77140S.

Characterization of Oscillators and Amplifiers: Amplitude Noise in the Frequency Domain (77131C)

For frequencies from 1 MHz to 26 GHz, amplitude modulation (AM) noise $S_a(f)$ of single oscillators and amplifiers can be determined for Fourier frequency offsets from the carrier of 0.1 Hz to 10 MHz. The AM noise is measured for only a few user specified frequency offsets (typically 3 points per decade). All measurements of amplitude noise are made relative to 1 Hz. At a carrier frequency of 5 MHz, $S_a(f)$ can be measured to − 140 dB for a frequency offset of 1 Hz, and −180 dB for an offset of 10 kHz. At a carrier frequency of 100 MHz, $S_a(f)$ can be measured to −130 dB for a frequency offset of 1 Hz and −180 dB for an offset of 50 kHz. A typical value of standard uncertainty* is 1 dB, but specific values depend on the carrier frequency and the offset frequency. Specific measurement requirements should be discussed prior to placing an order. AM noise for frequencies above this range (but less than 110 GHz) are covered under Service ID Number 77140S.

* See Chapter 1, Section H, for more information about uncertainty.

Tests of RF PM/AM Noise Measurement Systems: On Site Tests (77135C)

The noise floor and performance of PM and AM noise measurement systems can be evaluated at the customer's site using NIST's portable PM/AM noise standard for carrier frequencies of 5 MHz, 10 MHz, and 100 MHz. The PM/AM noise standard produces two signals with approximately 10 dB to 15 dB power (relative to 1 mW). The residual PM noise between the two outputs (relative to 1 rad^2/Hz) is typically less than −190 dB for a frequency offset from the carrier of 100 kHz for the three rf carrier frequencies. The calibrated PM or AM noise is typically constant with Fourier frequency offset to ± 0.1 dB out to 3 % of the carrier frequency. After each calibration a calibration report is issued which certifies that the specific measurement system is traceable to NIST for PM and/or AM measurements at the frequencies tested. This traceability can serve as a solid basis for meeting NVLAP (National Voluntary Laboratory Accreditation Program) and ISO requirements.

Tests of Microwave PM/AM Noise Measurement Systems: On Site Tests (77136C)

The noise floor and performance of PM and AM noise measurement systems can be evaluated at the customer's site using NIST's portable PM/AM noise standard for carrier frequencies of 10.6 GHz, 21.2 GHz, and 42.4 GHz. The PM/AM noise standard produces two signals with approximately + 10 dB power (relative to 1 mW). The residual PM noise between the two outputs (relative to 1 rad^2/Hz) is typically less than −176 dB for a frequency offset from the carrier of 10 kHz and − 190 dBc/Hz for offsets of

1 MHz from the carrier frequency. The calibrated PM or AM noise is typically constant with Fourier frequency offset to ± 0.2 dB out to 100 MHz. After each calibration a report is issued which certifies that the specific measurement system is traceable to NIST for PM and/or AM measurements at the frequencies tested. This traceability can serve as a solid basis for meeting NVLAP (National Voluntary Laboratory Accreditation Program) and ISO requirements.

Special Time/Frequency Measurements: Oscillators and Other Components (77140S)

Frequency and time domain measurements can be made at frequencies other than those cited in the above tests up to 110 GHz, but the uncertainty and cost are dependent upon the specific user requirements. Given two or more oscillators, synthesizers, frequency multiplier/dividers, or amplifiers, relative phase noise can be measured with low uncertainty and the frequency for the measurement is not as restrictive as above. Also, the 1 pulse per second output of atomic frequency standards can be measured with a standard uncertainty of 0.5 ns given an adequately defined pulse. Limited frequency and PM/AM noise measurements can be made from 75 GHz to 110 GHz. Please call to discuss your requirements.

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