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NBS PHYSICAL MEASUREMENT SERVICES STATUS REPORT

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National Bureau of Standards

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NBS PHYSICAL MEASUREMENT SERVICES STATUS REPORT

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

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U.S. Department of Commerce
National Bureau of Standards

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FOREWORD

An essential element of the mission of the National Bureau of Standards (NBS), a major technical agency of the Department of Commerce, is to provide the basis for a complete and consistent national system of physical measurements. The Bureau accomplishes this in a variety of ways, the calibration of instruments and devices being one of the most familiar. This publication is intended to provide the reader with a brief summary of each of the currently available NBS Physical Measurement Services. More detailed technical and general information on each of the services will be provided in the upcoming 1984 Edition of NBS Special Publication 250 entitled "Calibration and Related Measurement Services of the NBS."

Information of five types is provided for each of the NBS services - description of service; documentation associated with the service; training programs available on that service; future directions; and contact person at NBS. To assist the reader in locating particular services by number, the previously assigned NBS classification number for each measurement service is listed along with the title of the service (e.g., Mass (1.1), Acoustic Measurements (2.1), etc.). A list of NBS measurement seminars to be held during 1984 is also included in this publication.

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

National Conference of Standards Laboratories
c/o NCSL Secretariat
National Bureau of Standards
Boulder, CO 80303
(303) 497-3787
(Note: NCSL Directories are also available from the Office of Measurement Services, NBS-Gaithersburg.)

American Council of Independent Laboratories, Inc.
1725 K Street, NW
Suite 301
Washington, DC 20006
(202) 887-5872

Additional information regarding NBS measurement services can be obtained from:

George Uriano, Director
Office of Measurement Services
National Bureau of Standards
Bldg. 220, Rm. A363
Washington, DC 20234
(301) 921-2606

ACKNOWLEDGMENT

This report represents the joint efforts of many who have contributed to this compilation. The editors want to express their appreciation to all who have made it possible to produce this document in a short few months.

MASS (1.1)

Description of Services

The National Bureau of Standards (NBS) maintains the national standards for mass in the form of the prototype kilograms (K4 and 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 and the establishment of measurement assurance programs that will assist users in establishing and maintaining a state of statistical control for the measurements, the determination of the offset of the process from the national system, and assisting in the determination of the uncertainty of measurements made by the user's process.

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

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

NBS calibrates individual weights or sets in the range of 30 kg to 1 mg or 50 lb to 1 μlb in decimal subdivisions. If the weights are designated as reference standards, they must be of design, material, and surface finish comparable to present Classes A, B, M, S, or S-1. NBS also calibrates large mass standards (60 to 60,000 lbs) 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.

The values of true mass (and an apparent mass correction) included in the report will be determined by using computed volumes based on the manufacturer's statement of density of the material, on the density computed from measured volumes, or, in the absence of this information, on estimated density values. The apparent mass corrections are computed for 20 °C with reference to Normal Brass (density 8.4 g/cm^3 at 0 °C, volume coefficient of expansion 0.000054/°C) and to stainless steel (density 8.0 g/cm^3 at 0 °C, volume coefficient of expansion 0.000045/°C) in an ideal air density of 1.2 mg/cm^3. Apparent mass corrections to any other basis can be furnished if requested. Typical uncertainties range from 50 parts per billion at 1 kilogram up to 500 parts per million at one milligram and 1 part per million for weights from 2 kilograms to 30 kilograms.

NBS will calibrate metal volumetric reference standards which have volumes in the range 1 gill (4 fluid ounces) to 100 gallons and glass volumetric apparatus which have volumes in the range 1 milliliter to 1 gallon if suitable service is not available otherwise. Acceptance of an item for calibration or test is based on discussion with the user to determine that the item and its intended use meet requirements for a volumetric reference standard.

NBS will accept requests for density determinations of liquids if the need is critical, as in the support of standard sample programs or scientific studies. Limitations on the mass, physical dimensions, or volume of the sample are available on request. At NBS, liquid densities usually are determined by gravimetric (that is, weighing) methods. Other methods are available depending on the requirements. Reference hydrometers (0.62 - 3.0 g/cm^3 range) are normally used as laboratory standards for transfer of measurement capability/traceability to other hydrometers.

Documentation

Measurement Philosophy of the Pilot Program for Mass Calibration, P. E. Pontius, Natl. Bur. Stand. (U.S.), Tech. Note 288, 41 pages (May 1966).

Introduction to Intercomparison Methods in Mass Measurement, H. E. Almer, Natl. Bur. Stand. (U.S.), Report 9487, 15 pages (Feb. 1967).

Realistic Uncertainties and the Mass Measurement Process, P. E. Pontius and J. M. Cameron, Natl. Bur. Stand. (U.S.), Monogr. 103, 18 pages (Aug. 1967).

Method of Calibrating Weights for Piston Gages, H. E. Almer, Natl. Bur. Stand. (U.S.), Tech. Note 577, 49 pages (May 1971).

On Uncertainty in Mass Measurement, J. R. Donaldson, Natl. Bur. Stand. (U.S.), NBSIR 73-151, 10 pages (Mar. 1973).

Weight Cleaning Procedures, H. E. Almer, Natl. Bur. Stand. (U.S.), NBSIR 74-443, 7 pages (Nov. 1973).

Mass and Mass Values, P. E. Pontius, Natl. Bur. Stand. (U.S.), Monogr. 133, 39 pages (Jan. 1974).

Notes on the Fundamentals of Measurement and Measurement as a Production Process, P. E. Pontius, Natl. Bur. Stand. (U.S.), NBSIR 74-545, 65 pages (Sept. 1974).

The Use of the Method of Least Squares in Calibration, J. M. Cameron, Natl. Bur. Stand. (U.S.), NBSIR 74-587, 30 pages (1974).

Surveillance Test Procedures, H. W. Almer, Natl. Bur. Stand. (U.S.), NBSIR 76-999, 73 pages (Feb. 1976).

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, 64 pages (June 1977).

The Air Density Equation and the Transfer of the Mass Unit, F. E. Jones, Natl. Bur. Stand. (U.S.), NBSIR 77-1278, 30 pages (July 1977).

Measurement Assurance, J. M. Cameron, Natl. Bur. Stand. (U.S.), NBSIR 77-1240, 13 pages (1977).

The National Measurement System for Mass, Volume, and Density, P. E. Pontius, J. R. Whetstone, and J. A. Simpson, Natl. Bur. Stand. (U.S.), NBSIR 75-928, 72 pages (May 1978).

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, No. 5, 407-413 (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, No. 5, 419-428 (Sept.-Oct. 1978).

Precision Laboratory Standards of Mass and Laboratory Weights. A reprint of NBS Circular 547, Section 1, Lahof and Macurdy, August 1954, Natl. Bur. Stand. (U.S.), NBSIR 78-1476, 21 pages (Oct. 1978).

National Bureau of Standards Mass Calibration Computer Software, R. N. Varner and R. C. Raybold, Natl. Bur. Stand. (U.S.), Tech. Note 1127, 158 pages (July 1980).

Quick and Accurate Density Determination of Laboratory Weights, R. M. Schoonover and R. S. Davis, Proceedings of the 8th Conference of IMEKO Tech. Comm. TC3, Measurement of Force and Mass, Weighing Technology, Krakow, Poland, Sept. 9-11, 1980.

Air Buoyancy Correction in High-Accuracy Weighing on Analytical Balances, R. M. Schoonover and F. E. Jones, Anal. Chem., 53, No. 6, 900-902 (May 1981).

Procedures for the Calibration of Volumetric Test Measures, J. F. Houser, Natl. Bur. Stand. (U.S.), NBSIR 73-287, 24 pages (Aug. 1973). Order from NTIS as COM 73-11928.

Calibration of Small Volumetric Laboratory Glassware, J. Lembeck, Natl. Bur. Stand. (U.S.), NBSIR 74-461, 34 pages (Oct. 1974). Order from NTIS as PB246623.

The Equivalence of Gravimetric and Volumetric Test Measure Calibration, R. M. Schoonover, Natl. Bur. Stand. (U.S.), NBSIR 74-454, 16 pages (Feb. 1974). Order from NTIS as COM 74-10988.

A Density Scale Based on Solid Objects, H. A. Bowman, R. M. Schoonover, and C. L. Carroll, J. Res. Natl. Bur. Stand. (U.S.), 78A, No. 1, 13-40, (Jan.-Feb. 1974).

Training Programs

None.

Future Directions

Transfer standards used for volumetric test measures (1 to 100 U.S. gallons) will be redetermined using gravimetric techniques. Measurements on the five gallon slicker-plate vessel have been completed. The current results are in agreement with the previous values at the 5 part in 10^5 level. The 30, 50, and 100 gallon test measures will be determined gravimetrically to complete the surveillance measurements. Publication of the new results and comparison with the previous values will be combined in an NBSIR which will provide the most recent documentation of the assessment of the measurement uncertainties for this calibration service.

Efforts are underway to tie the measurements made in the calibration of hydrometers or other liquid density measurement devices to the NBS Single Crystal Silicon density standards, which will provide the tie to the basic units of mass and length.

Relatively recent technology provides a means for liquid density determination which provides an alternative to hydrometry. This technique utilizes an electromechanical resonance technique to compare the density of liquids of unknown density with that of two calibration fluids of known density. Calibration of this comparative device with liquids spanning the density range of interest allows the rapid and accurate measurement of the densities of other liquids. The comparative precision of the instrument approaches one part per million under the best of conditions, which is much better than that routinely required in hydrometry. Given an appropriately selected set of calibration fluids, the density range of normal liquids is easily covered. Therefore, efforts are focused on the development of a set of liquids with densities covering the range 0.7 to 2.0 g/cm^3 with the intent of offering this set as a standard reference material.

The modification of a hydrostatic weighing technique which allows the assignment of density values to solids which are directly tied to the NBS Single Crystal Silicon density standards will enable NBS to assign density values for a variety of liquids. The liquids involved in these modification experiments will become the liquid density SRM and will span the density range of 0.7 to near 2.0 g/cm^3. In addition to a density value, each will be assigned a thermal expansion coefficient value.

Once the liquid density SRM is available and by using distilled water, an alternative is available for liquid density measurement using the electromechanical density comparator discussed previously. This alternative also provides a method to calibrate hydrometers using the density comparator and the SRM to determine the density of the bath used to observe the hydrometer indication, thereby determining the difference between the actual and indicated density values. This difference is the correction for which hydrometers are normally calibrated.

NBS is re-evaluating its activities in the mass area and the results from the evaluation will be reported later.

Contact Person at NBS

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LENGTH MEASUREMENTS (1.3)

Description of Services

These services include the measurement of gage blocks, line standards (40 inches or less), and surveying tapes and leveling rods.

Measurement of the length of gage blocks is determined by either comparison to NBS master gage blocks or by direct interferometry. Generally the length is transferred from the NBS master blocks by a systematized intercomparison sequence using mechanical comparators. The intercomparison sequence and a description of the statistics for measurement assurance for the process are described in the references below. Single or multiple wavelength interferometric measurements are also available at special request.

Square or rectangular gage blocks of lengths up to 20 inches are routinely calibrated and the lengths reported in English or metric units. For blocks longer than 20 inches the Dimensional Metrology Group should be contacted in advance to discuss alternative measurement techniques. A reasonable estimate for the accuracy of the calibration is 2 microinches (0.05 micrometer) for blocks under 2 inches, and decreasing accuracy with length to 20 microinches for the 20-inch blocks.

There is available a Gage Block Measurement Assurance Program (MAP) for users who wish the highest possible accuracy of transfer of the length standard. This program has a number of variations and the cost depends on the variation selected. The program is described in NBS Monograph 163, "Measurement Assurance for Gage Blocks."

Line standards of 1 meter or less are measured on an instrument called a line scale interferometer. It is used to measure the distance between suitable lines on a flat surface. The instrument employs a fixed photoelectric microscope to determine the position of the scale lines, a linearly mobile carriage in the focal plane of the microscope to carry the scales, two interferometers (one commercial unit and one NBS-made Michelson) that can be used separately or in tandem to measure carriage displacement, and a temperature-controlled housing enclosing the whole apparatus.

The maximum length of line standards that can be measured is 1 meter, and the maximum width of any part of the piece being calibrated cannot exceed 150 millimeters. The accuracy of the calibration depends significantly on the shape and optical properties of the line, the background, and the geometric flatness of the artifact being calibrated. If the lines have straight edges, are 2 to 10 micrometers wide, there is good contrast between the line and the background, and the reference surface of the artifact is flat, then the accuracy of the calibration will be near optimum. Uncertainties as low as 0.006 micrometer have been achieved on short intervals and on 1-meter lengths uncertainties of 0.1 micrometer can be achieved. Current overall system accuracy is limited by imprecise knowledge of the refractive index of air to normal operating conditions.

The calibration of surveying tapes (and oil gaging tapes) is carried out in the Long Length Calibration Laboratory. This laboratory houses two permanent working standards; a laser interferometer and a 50-meter (200-foot) stainless steel bench. Measurements are performed for the most part using the laser system which 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 an independent environmental control system can vary the chamber temperature from 15 to 40 °C for special tests.

Normal calibration of tapes will be made with the tape under tension and supported on a horizontal-flat surface in a laboratory controlled to 20 °C. Unless otherwise requested, the total length and each 15-meter or 50-foot 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 to an accuracy of 2 parts per million. Calibrations made with respect to the stainless steel bench are normally reported to an accuracy of 10 parts per million.

Leveling rods are currently calibrated using two methods. One method involves the comparison of the rod to a 3-meter standard at the one, two, and three-meter intervals. A second system provides measurement at multiple intervals and automatic report generation. This system incorporates a 7-meter one-dimensional measuring machine, a motorized carriage, a photoelectric microscope and a helium-neon laser interferometer interfaced to a large minicomputer. Measurements can be made on virtually any type of linear scale or leveling rod with scribed, engraved or painted graduations.

The random error of measuring high quality leveling rods is plus or minus 6 micrometers for new rods and plus or minus 12 micrometers for used rods at the one standard deviation level. The systematic errors are largely un-evaluated, and to account for their existence the total error being reported by NBS at present is plus or minus 50 micrometers for new rods. The length of intervals will be reported at 20 °C unless otherwise requested. The report can be supplied in either written or computer-readable form.

NBS can provide measurement services for sieves--i.e., tests for conformity to ASTM specifications--if arrangements are made in advance.

Documentation

Measurement Assurance for Gage Blocks, C. Croarkin, J. Beers, and C. Tucker, Natl. Bur. Stand. (U.S.), Monogr. 163, 75 pages (Feb. 1979).

Measurement Assurance Program--A Case Study: Length Measurements. Part 1. Long Gage Blocks (5 in to 20 in), P. E. Pontius, Natl. Bur. Stand. (U.S.), Monogr. 149, 75 pages (Nov. 1975).

Gage Block Flatness and Parallelism Measurement, J. S. Beers and C. D. Tucker, Natl. Bur. Stand. (U.S.), NBSIR 73-239, 12 pages (Aug. 1973). Order from NTIS as PB273962.

Intercomparison Procedures for Gage Blocks Using Electromechanical Comparators, J. S. Beers and C. D. Tucker, Natl. Bur. Stand. (U.S.), NBSIR 76-979, 23 pages (Jan. 1976). Order from NTIS as PB248992.

A Gage Block Measurement Process Using Single Wavelength Interferometry, J. S. Beers, Natl. Bur. Stand. (U.S.), Monogr. 152, 34 pages (Dec. 1975).

Preparations for Gage Block Comparison Measurements, C. D. Tucker, Natl. Bur. Stand. (U.S.), NBSIR 74-523, 14 pages (July 1974). Order from NTIS as COM 75-11126.

Contact Deformation in Gage Block Comparisons, J. S. Beers and J. E. Taylor, Natl. Bur. Stand. (U.S.), Tech. Note 962, 46 pages (May 1978).

Interferometric Measurement of Length Scales at the National Bureau of Standards, J. S. Beers and K. B. Lee, Precision Engineering, 4, No. 4, 205-214 (Oct. 1982).

An Automatic Fringe Counting Interferometer for Use in the Calibration of Line Scales, H. D. Cook and L. A. Marzetta, J. Res. Natl. Bur. Stand. (U.S.), 65C, 129 (1961).

Training Programs

There are currently no training programs available in the length metrology area because of its very highly specialized nature. The NBS Dimensional Metrology Group is, however, open to discussions regarding workshops and Research Associate programs for those companies interested in learning this technology. These programs have been conducted in the past and proved to be a very successful means of transferring this complex technology.

Future Directions

For some years now the gage block data acquisition and report generation has been highly automated for the mechanical intercomparisons. This automation was done using a central minicomputer system. At this time this older system is being modified so that the laboratory will be automated by a stand-alone microcomputer system. Upon the completion of this task a report will be generated and the next research thrust will be in the direction of developing the experimental methods and acquiring data to enhance the accuracy of interferometric measurements of gage blocks.

The interferometric system used in measuring line standards is currently being upgraded to provide higher accuracies and faster calibrations. In particular it is being fitted with a new carriage servo system based around two milliarc-second autocollimators which will be used in the servo loop to control angular motion of the carriage. Also being added to the instrument in the next few years will be a new interferometer system which derives the laser frequency from the iodine stabilized helium-neon laser and provides for very precise on-line compensation for changes in air refractive index. A new document is in preparation which will describe the complete measurement algorithm used for the measurement of several common types of length scale.

The Long Length Laboratory is in the process of being partially automated using a laboratory microcomputer interfaced to the laser interferometer and temperature-measurement systems. Some research is also being performed into the calibration of remote length-measuring devices, and this calibration may soon be available on a special test basis. A publication is planned, that will describe the whole system, and will be issued in 1985. The calibration reports are currently computer-generated, however, and provide the user with considerable information regarding the calibration procedure.

Future work on leveling rods will be to undertake a thorough study of all systematic error sources in their measurement, with overall goals of (a) eliminating as many sources as possible, (b) reducing the overall uncertainty of the calibrations, and (c) hardening the database on which the error estimate rests. A report summarizing the results of this study will be prepared.

Contact Person at NBS

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Automated Production Technology Division
301-921-2216

LENGTH AND DIAMETER DIMENSIONAL METROLOGY (1.4)

Description of Services

NBS provides a calibration service for the measurement of the diameter of thread and gear wires by intercomparison to NBS Master wires. The diameter is transferred from known Master wires using a systematized intercomparison sequence with a mechanical comparator.

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 thread wires extreme care should be taken to prevent corrosion, and all wires should be properly greased and their bottles rigidly contained inside an appropriate packing case.

Thread measuring wires for 60-degree and 29-degree threads are tested for compliance with the latest specifications in commercial use. Special thread measuring wires for unusual sizes and for threads finer than 80 tpi are measured as a special test in a manner consistent with current commercial practice. Gear measuring wires in the 1.92"/P, 1.728"/P, 1.44"/P, and 1.68"/P series are tested for compliance with the latest specifications in commercial use and the mean diameter reported. Accuracies are reported to a 3-sigma confidence level of 10 microinches for English wires and 0.25 micrometer for metric wires. The NBS has a wide variety of state-of-the-art metrology equipment and can provide other test and calibration services associated with dimensional quality control as special tests. Listed below are some of the capabilities available for special tests. Arrangements for these tests should be made in advance.

(a) 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. The machine has a working volume of 48 x 24 x 12 inches and can detect a length difference of 0.013 micrometer. Reference to the international standard of length is through interferometers. Uncertainties in the calibrations are variable.

(b) End standards having spherical, flat, or pointed ends can be measured. End standards up to 20 feet in length can be calibrated to high accuracy. Lengths are reported with 2.5-lb measuring force unless otherwise requested.

(c) Step gages having flat, parallel faces along a common center line are calibrated as special tests.

(d) Internal and external diameter standards, such as plug and ring gages, are accepted for measuring.

(e) Spherical diameter standards, such as balls used in precision bearings and master balls used as transfer diameter standards, are calibrated using a laser-based mechanical comparator.

Documentation

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

Measurement Assurance for Gage Blocks, C. Croarkin, J. Beers, and C. Tucker, Natl. Bur. Stand. (U.S.), Monogr. 163, 75 pages (Feb. 1979).

Intercomparison Procedures for Gage Blocks Using Electromechanical Comparators, J. S. Beers and C. D. Tucker, Natl. Bur. Stand. (U.S.), NBSIR 76-979, 23 pages (Jan. 1976). Order from NTIS as PB248992.

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

American National Standard B1.2, available from ANSI Headquarters, New York, New York.

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

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

Designs for the Calibration of Small Groups of Standards in the Presence of Instrumental Drift, J. M. Cameron and G. E. Hieles, Natl. Bur. Stand. (U.S.), Tech. Note 844 (Aug. 1974).

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

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

Unified Three-Dimensional Program - Two Useful Non-Contacting Probes, J. A. Simpson, Natl. Bur. Stand. (U.S.), Report 10597 (1971).

Training Programs

No formal training programs are currently available. However, special cases for training are treated on a case-by-case basis.

Future Directions

The thread wire calibration laboratory will undergo a modification of the data acquisition procedure. The system will be switched from the central minicomputer, which is now obsolete, to a local laboratory microcomputer. Efforts are also being made to procure new measuring instrumentation which will allow laser measurement of the wires and reduce the number of Masters currently required. NBS plans to maintain state-of-the-art measurement capability in all dimensional geometric measurements relevant to mechanical manufacturing and quality control. These services will be expanding in the future by the procurement of new measuring machines and the development of new measurement technology.

Contact Person at NBS

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COMPLEX STANDARDS OF LENGTH AND DIAMETER (1.5)

Description of Services

NBS provides calibration and certification services for API threaded plug and ring gages, casing, tubing and line pipe plug and ring gages as well as sucker rod gages.

NBS is the custodian of the American Petroleum Institute (API) Grand Master rotary thread gages. These Grand Master gages are maintained and have been recalibrated in our laboratory for more than 40 years. They can be considered an international artifact since all API Regional Master Gages throughout the world are referenced to NBS. Foreign product manufacturers can have their Reference Master Gages calibrated and certified by NBS or by one of the following national standard laboratories:

National Physical Laboratory, Teddington, England
National Research Laboratory of Metrology, Tokyo, Japan
National Standards Laboratory, Chippendale, N.S.W., Australia
Physikalisch Technische Bundesanstalt, Braunschweig, Germany
Laboratoire National d'Essais, Paris, France

Parameters measured for plug gages are:

- Length of plug
- Taper
- Pitch diameter
- Major diameter
- Thread lead
- Load 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

These calibrations are based on a three standard deviation confidence level and are accurate to plus or minus 0.0003 inch.

Micrometer calipers, vernier calipers, plain snap gages, micrometer screws, dial micrometers, and other similar devices are accepted for calibration under special circumstances. Precision penetration needles and cones are also tested for compliance to ASTM specifications. Arrangements for services in these areas should be made in advance.

Documentation

Threaded plug and ring gage calibrations are currently limited to those gages conforming to current API specifications. API Regional Masters and Reference Master thread gages are tested as required by API Standards 5B, 7, and 11B. These specifications and tests are well documented in API publications available from the American Petroleum Institute, 211 North Erbay, Suite 1700, Dallas, TX 75201. Further documentation of the current measuring system is not required.

Training Programs

Formal training programs are not available for API gage calibration. In the past, however, NBS has made itself available for individual training of those technicians required by gage manufacturers for their gage quality control. These technicians spend approximately two weeks at NBS learning our measurement methodologies. Individual arrangements should be made by contacting NBS.

Future Directions

A major effort in the API calibration area will focus on the transfer of measurements made on present instrumentation to a new computer-controlled high-accuracy coordinate measuring machine. The transfer of measurements and calibration report preparation to this automated system are expected to be complete in late 1985.

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FLATNESS, STRAIGHTNESS, AND ROUNDNESS (1.6)

Description of Services

NBS provides services for optical reference planes and roundness measurements as special tests, since such services are not performed frequently enough to merit maintenance of a full scale calibration laboratory. Arrangements for these services should be made in advance. Optical reference planes (such as flats) and surface plates are calibrated optically or mechanically. Roundness measurements on parts and gages are made and the results may be reported graphically.

Documentation

A Survey of the Stability of Optical Flats, C. P. Reeve and R. C. Veale, Natl. Bur. Stand. (U.S.), NBSIR 73-232, 27 pages (June 1973). Order from NTIS as PB273947.

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, 40 pages (Dec. 1975). Order from NTIS as PB253113.

Training Programs

No formal training program is available, however, special requests for individualized training are treated on a case-by-case basis.

Future Directions

NBS plans to maintain state-of-the-art measurement capability in all dimensional geometric measurements relevant to mechanical manufacturing and quality control.

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ANGULAR (1.7)

Description of Services

NBS provides calibration services for all standard sizes of angle gage blocks. Blocks with angles ranging from 1 arc-second to 45 degrees are routinely handled, however, optical squares and other standards can also be accommodated. Accuracy at the 3-sigma level is approximately 0.1 arc-second, however, this value varies with the condition of the gaging surface on the standard. The measurement of the angle of angle blocks is made by direct comparison to NBS Master angle blocks using a dual-autocollimator system. Current autocollimators have resolution to 0.01 arc-second and electronic readout. The blocks are enclosed in a special chamber during intercomparison to minimize air currents, and the laboratory is maintained at 20 degrees Celsius to within plus or minus 0.1 degree. The intercomparison sequence has been systematized.

Angular standards of various types, including polygons, wedges, and the like, are calibrated by comparison or interferometry. Precision rotary and indexing tables, autocollimating telescopes, and angle-generating equipment and transducers are calibrated at specific angular settings. These services, however, are provided as special tests and arrangements must be made in advance by the customer.

Documentation

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The Calibration of Indexing Tables by Subdivision, C. P. Reeve, Natl. Bur. Stand. (U.S.), NBSIR 75-750, 38 pages (July 1975). Order from NTIS as PB249934.

Training Programs

No formal training programs in angle block calibration exist. Requests for specialized one-on-one training will be considered on a case-by-case basis.

Future Directions

The NBS angle block calibration facility is now partially automated. The system will be modified for direct on-line data acquisition and report generation using a laboratory microcomputer. Further experiments for determining the errors caused by surface out-of-flatness and angular tilt in the non-sensitive direction are under consideration.

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SURFACE TEXTURE (1.8)

Description of Services

NBS provides measurement services in three categories: Instrument calibration specimens (with regular geometric profiles); roughness comparison (and other types of roughness specimens); and step height specimens.

The property of surface roughness in the 10 μm R_a range and below and heights up to 25 μm are measured by means of a minicomputer/stylus instrument system. Using an interferometrically measured step, the system is calibrated on each value of magnification employed during a measurement.

In measurements of roughness, surface profiles are taken according to the American National Standard B46.1-1978 using a 0.76 mm cutoff length, and a traversing length of 3.8 mm. A number of other statistical parameters and functions may be calculated from the stored profile data including the rms roughness, average slope, average wavelength, skewness, amplitude density function, autocorrelation function, and power spectral density.

In step height measurements, a straight line is fitted by the method of least squares to each side of the profile of the step and the height is calculated from the position of these two lines.

The NBS calibration uncertainty for step height or R_a depends on a number of factors, the most important being the step or R_a value itself. The uncertainties range from approximately .3 μm at a step height of 25 μm to .003 μm. Comparable uncertainties are achieved for measurements of r_a.

Documentation

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Three-Dimensional Stylus Profilometry, E. C. Teague, F. E. Scire, S. M. Baker and S. W. Jensen, Wear, 83, 1-12 (1982).

FASTMENU: A Set of FORTRAN Programs for Analyzing Surface Texture, T. V. Vorburger, Natl. Bur. Stand. (U.S.), NBSIR 83-2703 (July 1982).

Training Programs

None.

Future Directions

None specified.

Contact Person at NBS

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IMAGE OPTICS AND PHOTOGRAPHY (1.9)

Description of Services

Microscopy resolution test charts conforming to ISO Standard 3334, NMA Standard MS104-1972, and MIL-M-9868D, are available through the NBS Office of Standard Reference Materials (SRM 1010a). Diffuse transmission density is measured in accordance with ANSI Standard PH2.19-1976. Calibrated step tablets for photographic calibrations are available through the NBS Office of Standard Reference Materials as SRM 1008.

45°/0° absolute visual reflection density is measured in accordance with ANSI Standard PH2.17-1977. Calibrated step tablets are available through the Office of Standard Reference Materials as SRM 2061.

In special cases, measurements may be made by arrangement. Tablets submitted for calibration must be free of scratches, fingerprints, abrasions, and foreign matter and must have steps of uniform density. Tablets not suitable as standards will not be accepted by NBS for calibration.

Documentation

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Training Programs

None.

Future Directions

None specified.

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ACOUSTIC MEASUREMENTS (2.1)

Description of Services

NBS provides calibration services for special microphones, acoustic emission transducers, ultrasonic transducers and ultrasonic reference blocks. Pressure calibrations 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. Pressure calibrations are reported in terms of open-circuit voltage per unit sound pressure applied uniformly to the diaphragm. The open-circuit voltage at the electrical terminals of a microphone may be influenced by stray capacitances evident at these terminals. For type-L microphones, these capacitances are defined by the geometrical configuration of the ground shield. If the ground shield dimensions are not adhered to in making use of the response levels reported by NBS, errors may result. Pressure calibrations of type-L microphones exhibit typical uncertainties of approximately 0.1 dB or less at frequencies from 50 Hz to 8 kHz, 0.2 dB or less at frequencies from 8 kHz to 20 kHz.

Since American National Standards Institute publications S1.10.1966 (R1976) and S1.12.1967 (R1977) were issued, certain types of half-inch diameter precision microphones have attained widespread use. Therefore, NBS has developed procedures for determining the pressure response levels of half-inch microphones by comparison with NBS type-L standard microphones, which in turn are calibrated periodically by the reciprocity technique.

The free-field response levels of certain type-L microphones (e.g. Western Electric type 640AA condenser microphones or equivalent) can be computed from pressure response levels reported by NBS. However, certain precautions must be taken and there is some degradation in accuracy. Therefore, for the most demanding free-field measurement requirements NBS offers a calibration service for determining the free-field response levels for half-inch microphones. The calibrations are made at normal incidence over the frequency range of 2.5 kHz to 20 kHz. They are reported in terms of open-circuit voltage per unit sound pressure 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 uncertainty in this calibration is approximately 0.15 dB at each frequency within the range of 2.5 kHz to 20 kHz. For the most precise free-field measurements, it is recommended that the customer contact the person listed for recommendations prior to submitting the microphone to NBS for calibration.

Special acoustical measurement services are available by special arrangement. These services may include extended frequency ranges, additional data points and calibration of certain piston phones and acoustic calibrators. NBS 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, has been carefully controlled during design and construction.

The NBS acoustic emission transducer calibration provides the voltage output of a transducer per unit of motion (displacement or velocity) of the mounting surface as a function of frequency. The calibration is based upon the normal component of motion which would occur in the absence of the transducer. The method of the test is as follows: a step function of "point" force is generated on the surface of a large steel block by breaking a glass capillary.

The transducer under test and the NBS standard capacitive transducer are located on this same surface and are equidistant from the source. Both transducers experience the motion of the seismic surface pulse generated by the step function force. The transient voltage outputs from both transducers are recorded and analyzed for frequency content. The frequency response of the transducer under test is obtained by dividing the spectral amplitude from the transducer under test by that from the standard transducer, frequency by frequency. The calibration is absolute, since the sensitivity of the standard transducer is known.

Results of the calibration are obtained as magnitude and phase of the sensitivity of the transducer under test at discrete frequencies, f_n = 9765.625n (Hz), where n = 1,2,3. . . The customer is provided with the results in the form of graphs and magnitude and phase. These are piecewise linear functions constructed through the data points. Within the valid range of 0.1 MHz to 1 MHz, the uncertainty is approximately 10%. At the option of the customer, the results will be given with respect to normal displacement or velocity of the mounting surface, and also at the option of the customer, the results will be on a linear magnitude scale or on a decibel scale.

Measurements of total ultrasonic forward power radiated into a water load are offered for the purpose of characterizing ultrasonic systems and transducers. Ultrasonic systems are characterized by measurement of output under operating conditions specified by the customer. Transducers for which the continuous-wave electrical input voltage can be accurately and reproducibly 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 of output power spanning an appropriate range of power. Equipment is available for the measurement of both continuous-wave and pulsed ultrasonic power.

Continuous-wave ultrasonic power is measured using a modulated-radiation force balance. Output power is determined from the force required to arrest the motion of a conical target which diverts the output beam of the transducer under test into a bank of absorbers. Because the rf input voltage to the transducer is amplitude-modulated, the motion of the target is oscillatory and sensitive ac techniques can be used for null detection. The nulling force is generated by an independently calibrated electromagnetic device for which absolute transfer characteristics are known under static conditions. Absolute power can thus be measured at spot frequencies between 1 MHz and 20 MHz. The overall uncertainty varies from 2.2% at 1 MHz to 7.6% at 20 MHz. These estimates of uncertainty apply to measurements made at power levels ranging from a few milliwatts to a few watts; the minimum detectable power is about 10 microwatts while high-power measurements are limited by the onset of cavitation in the water load. Swept-frequency measurements of relative transducer output can be made by recording the error signal of the unbalanced detector. Although the results do not constitute absolute measurements, swept-frequency tests have been found useful in the assessment of overall transducer performance and the determination of frequencies suitable for absolute measurements. Transducers of diameter no greater than 45 mm can be tested in this apparatus.

Pulsed ultrasonic power is measured using a special designed calorimeter. With pulsed excitation, only ultrasonic systems comprising a transducer and an electrical driver can be tested. Transducers by themselves cannot be independently characterized with pulsed drive waveforms since the electrical input signals cannot at present be adequately measured or characterized. Power levels ranging from 1 mW to several watts at frequencies between 1 MHz and 15 MHz can be measured with an overall uncertainty less than (7% + 0.2 mW). Transducers with diameters as great as 26 mm can be accommodated. Measurements of continuous-wave power are also possible with the calorimeter. The length of its response time precludes swept-frequency tests.

Additional services offered include consultation, customized testing, and the lending of air-backed transducers for the purpose of transferring power measurements. Quartz transducers characterized by radiation conductance and thus suited for the reproduction of arbitrary power levels are available for frequencies of 2 MHz, 3 MHz and 5 MHz and can be specially calibrated for operation at odd overtones. Lithium niobate transducers with built-in circuitry allowing the field user to reproduce prearranged power levels while measuring only dc voltage are available for use at frequencies below 20 MHz approximated by odd multiples of 0.5 MHz.

The ultrasonic response of 7075 aluminum alloy reference blocks of 0.50 inch and greater metal path distances is determined relative to an NBS interim reference standard. The immersion, pulse, echo, longitudinal wave, 5 MHz quartz transducer testing system defined in the ASTM E-127 calibration document is used with some procedural modifications. An NBS developed procedure is used where the interim reference standards are calibrated along with the customer's blocks.

System precision and stability over time are provided by the set of check standard blocks with flat-bottom hole sizes of 3, 5, and 8/64 inch diameter. Standard deviation data, representing random errors associated with the NBS system, are provided for the respective block and hole sizes. The plus or minus two standard deviation uncertainty levels range from about 3 to 10 percent of block response, depending on the block and hole sizes of the respective check standards. A comparison of the customer's block value to the data base of all blocks measured by NBS is also available.

Response following the procedures of the ASTM Recommended Practice E-127 can also be determined. In addition, the response of some blocks with metal path distances less than 0.50 inch can be obtained by special arrangement. Where special services are required, it is recommended that the customer contact the person listed at the end of this section for recommendations and to discuss any special requirements.

Documentation

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Surface-Wave Displacement: Absolute Measurements Using a Capacitive Transducer, F. R. Breckenridge and M. Greenspan, J. Acoust. Soc. Am., 69, No. 4, 1177-1185 (Apr. 1981).

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Ultrasonic Transducer Characterization at the NBS, E. R. Miller and D. G. Eitzen, IEEE Trans. Sonics and Ultrasonics, SU-26, No. 1, 28-37 (Jan. 1979).

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Training Programs

None.

Future Directions

None specified.

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VIBRATION MEASUREMENTS (2.2)

Description of Services

NBS calibrations of vibration exciters and pickups are performed by comparison with the response characteristics of NBS standards or by absolute measurements. The measurand is 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. In the case of an accelerometer, the U.S. practice has been to express the output in millivolts, and the input, in units of g, the standard acceleration of free fall. The acceleration sensitivity is then given in mV/g. Other units are sometimes used, for example, the calibration of piezoelectric and piezoresistive accelerometers without signal conditioners is stated in picocoulombs per g (pC/g).

The calibration of an accelerometer is given as the sensitivity of the transducer at the discrete frequencies at which the measurements are made and is reported in tabular form. Because sensitivity is a phasor quantity, representable as a complex number, a complete calibration consists of a measurement of both magnitude and phase of the sensitivity. Only the magnitude of the sensitivity is usually reported. However, the phase component can be furnished on request.

The NBS also offers several standardized vibration calibration services designed to meet the needs of the users. Calibrations are furnished at frequencies from 2 Hz to 13,000 Hz and accelerations from 0.2 g to 10 g, depending on frequency. Calibrations at other frequencies and accelerations can be furnished by pre-arrangement.

The NBS vibration standards have been calibrated by reciprocity and interferometric techniques, two independent and absolute methods. Their calibration is periodically checked using both techniques. The use of these standards in the calibration of stable transducers furnish calibration data with a typical uncertainty of from one to three percent over the frequency range.

Documentation

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Training Programs

None.

Future Directions

None specified.

Contact Person at NBS

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Description of Services

The NBS provides calibration services for a wide variety of humidity-measuring instruments. Calibrations are performed by subjecting the instrument under test to atmospheres of known moisture content produced by the NBS two-pressure humidity generator. The instruments and ranges of calibration are listed below.

Dew-Point Hygrometers: Dew-point hygrometers can be calibrated over the dew/frost-point range of 80 to -80 °C.

Electric Hygrometers: 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 percent relative humidity over the temperature range -55 to 80 °C.

Psychrometers: A limited number of types of wet-dry bulb hygrometer (aspirated psychrometers) can be calibrated at NBS. The contact person should be consulted for the special features of the psychrometer which are necessary before the instrument can be calibrated at NBS.

Coulometric Hygrometers: Coulometric 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 measure the electrolysis current. The range of calibration is 1 to 31,000 ppm (parts per million) by volume.

Pneumatic Bridge Hygrometers: Pneumatic bridge hygrometers are instruments which 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 (gram water vapor/gram dry air) is 0.0005 to 0.015.

Documentation

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Training Programs

None.

Future Directions

Efforts are underway to automate the acquisition of the generator's pressure and temperature data and the indication data from the instrument under test where possible. Certain of the control functions of the generator will also be automated to reduce the amount of labor currently needed to perform a calibration. In addition to the automation of the generator, the pressure instruments used in the generator will be replaced since maintenance at the required level of performance is becoming necessary. Comparison of the generator's gas stream with the primary standard gravimetric hygrometer is planned to begin in the next two years. This is an extremely laborious task and is expected to take approximately one year to complete. The gravimetric hygrometer is not currently operational and must be to do the comparison.

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CALIBRATION OF FORCE TRANSDUCERS AND FORCE MEASUREMENT SYSTEMS (2.5)

Description of Services

NBS provides calibration services for force measuring devices by applying known forces, either tension or compression, to the elastic device and recording the sensed deformation. Practically all of the devices calibrated are either providing 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. An electrical output is usually provided from load cells to indicate the deformation caused by the application of a force. The calibration report gives the measured electrical output or measured deformation of a known applied force. When the calibration calls for reading and electrical output, the output can be measured by either a readout device furnished by the customer, in which case the sensor and the readout device are calibrated as a unit and the calibration is only valid when they are used together; or the output is measured directly and the calibration is given in terms of the electrical output of the sensor directly.

Tension or compression calibrations in the range of 10 lbf to 1,000,000 lbf are performed using deadweight machines. NBS has six such deadweight machines with maximum capacities of 500; 6,100; 25,300; 112,000; 300,000; and 1,000,000 lbf. The three larger machines allow the force applied to the unit being calibrated to be incremented or decremented without having to go to zero load between force applications. When using the three smaller machines it is necessary to go to zero load before the load is changed. The estimated uncertainty of the vertical component of the applied force is 20 parts per million.

Comparison calibrations in the range of 10,000,000 lbf to 12,000,000 lbf are performed in a universal testing machine. In this case, the system being calibrated is loaded in series with one or more load cells that have been previously calibrated in a deadweight machine.

NBS is prepared to perform special tests and calibrations in some cases. These should be discussed with NBS before any such tests or calibrations are ordered.

Documentation

Uncertainties Associated with Proving Ring Calibration, T. E. Hockersmith and H. H. Ku, Preprint No. 12.3-2-64: ISA Conference, Oct. 12-15, 1964.

Absolute Value of g at the National Bureau of Standards, D. R. Tate, Natl. Bur. Stand. (U.S.), Monogr. 107, 24 pages (June 1968).

Gravity Measurements and the Standards Laboratory, D. R. Tate, Natl. Bur. Stand. (U.S.), Tech. Note 491, 10 pages (Aug. 1969).

Studies of Calibration Procedures for Load Cells and Proving Rings as Weighing Devices, G. B. Anderson and R. C. Raybold, Natl. Bur. Stand. (U.S.), Tech. Note 436, 22 pages (Jan. 1969).

Universal Testing Machine of 12-Million-lbf Capacity at the National Bureau of Standards, A. F. Kirstein, Natl. Bur. Stand. (U.S.), Spec. Publ. 355, 14 pages (Sept. 1971).

A Study of the National Force Measurement System, D. E. Marlowe, Natl. Bur. Stand. (U.S.), NBSIR 75-929, 40 pages (June 1975).

Interlaboratory Comparison of Force Calibrations Using ASTM Method E74-74. Phase I, R. W. Peterson and R. L. Bloss, Natl. Bur. Stand. (U.S.), NBSIR 76-1145, 35 pages (Aug. 1976).

Characterizing the Creep Response of Load Cells, R. A. Mitchell and S. M. Baker, VDI-Berichte (312), 43-48 (1978).

Force Sensor-Machine Interaction, R. A. Mitchell and P. E. Pontius, Proceedings of the 27th International Instrumentation Symposium (ISA), Indianapolis, IN, Instrumentation in the Aerospace Industry, 27, 225-232 (1981).

Inherent Problems in Force Measurements, P. E. Pontius and R. A. Mitchell, Exper. Mech., 22, No. 3 (Mar. 1982).

Training Programs

None.

Future Directions

None specified.

Contact Person at NBS

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FLUID QUANTITY AND FLOW RATE METERS (2.7)

Description of Services

NBS provides calibration services for flow meter systems which include a flow meter and pertinent adjacent tubing and readout equipment.

Flow meter systems having demonstrated precision and temporal stability commensurate with the quality of the calibrations are accepted for calibration. Calibration tests usually include five different flow rates, although additional rates can be included on request. At each flow rate, 10 observations are made.

Facilities are maintained for flow rate (volumetric and mass) measurements for fluids, using water, air, and a stable hydrocarbon as test fluids. The ranges of flow rates used in calibrations are: 1-10,000 gal/min for water; up to 150 cubic ft/min for air in the small gas flow facility, and 150-3000 cubic ft/min for air in the large gas flow facility; and up to 200 gal/min for hydrocarbons.

Documentation

Introduction to Liquid Flow Metering and Calibration of Liquid Flowmeters, L. O. Olsen, Natl. Bur. Stand. (U.S.), Tech. Note 831, 60 pages (June 1974).

Flow Measurement: Procedures and Facilities at the National Bureau of Standards, F. W. Ruegg and M. R. Shafer, (Proc. Symp. Flow Measurement, San Francisco, CA, Jan. 19-22, 1970). Chapter in ASHRAE (Amer. Soc. Heat Refrig. Air-Cond. Eng.), Bull. Flow Measurement Part 1, SF70-7, 1-8 (1972).

Practical Considerations for Gas Flow Measurement, M. R. Schafer, Jr. and D. W. Baker, Proc. 3rd Annual Precision Measurement Association Metrology Conf., National Bureau of Standards, Gaithersburg, MD, June 17-18, 1970, 1, 187-227 (Precision Measurements Association, Burbank, CA, 1970).

Gas Flow Measurement by Collection Time and Density in a Constant Volume, L. Olsen and G. Baumgarten, Symposium on Flow, Its Measurement and Control in Science and Industry, ISA, 1, Part 3, 1287 (1972).

Evaluation of a Low Flow Generator and Calibrator as a Flow Measurement Standard, G. Baumgarten, Natl. Bur. Stand. (U.S.), Technical Report 10921 (1972).

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, 66 pages (Aug. 1976). Order from NTIS as PB258250.

A Laboratory Study of Turbine Meter Uncertainty, G. E. Mattingly, P. E. Pontius, H. H. Allion, and E. F. Moore, Natl. Bur. Stand. (U.S.), Spec. Publ. 484 (Oct. 1977).

Training Programs

None.

Future Directions

The key parameters measured in each device calibration are the transit time, volume (stroke), pressure, and temperature. Improvements are planned for each parameter measurement which will enhance the capability to perform the calibration measurements and, where possible, automate the calibration measurements and decrease the uncertainty in the measured variables.

Pressure Measurement - All pressure measurement will be changed to use transducers which may be interfaced to the microprocessor system used for data acquisition and control of the test. Direct ties to the pressure standard will be maintained using dead weight testing devices which have been calibrated by the pressure group. Response characteristics of each transducer will be kept in a database to provide a history of its performance.

Temperature Measurement - Contact thermometry used for determination of gas temperatures either in the collection volumes, displacers, or in the gas stream passing through the meter, will be characterized using a platinum resistance thermometer which has a history of calibration by the temperature group. Either thermocouples or resistance thermometers will be used in the initial automation and documentation of the laboratory. Since contacting methods measure the temperature at a point, the question of average temperature of the gas contained in the displaced volume is one of concern. An acoustic thermometry approach will be explored to obtain an improved measurement of the average gas temperature in the displacers.

Volume Measurement - To improve the measurement of the volume of gas displaced, a laser interferometric technique will be used to measure the stroke of the displacer. This technique will be used with each of the five mercury-sealed piston provers and with the bell gasometers. The device is easily moved from one system to the other by moving the laser head and using multiple sets of interferometer optics. The Hewlett-Packard laser interferometer will be used with corner cubes as the reflectors. Each piston/bell will have a cube attached with the laser/interferometer block held stationary. Measurement of the diameter of the cylinders and of the bells will be done using established length metrology techniques. For the bell gasometers the outer diameter will be measured using strapping tapes. The volume of oil displaced by the bell material will be determined volumetrically. The inner diameter of each cylinder will be measured using an air gauging technique. Both methods will be tied to length standards.

Time Measurement - Time interval measurement will be done by modification of a counter register of the laser interferometer system. A 100 KHz clock will be used to drive the counter during the time interval of the displacer movement. This frequency will be compared directly with the standard frequency available on the NBS site. This technique allows the simultaneous triggering of the counter registers used for the displacement measurement and the timing measurement.

Calibration measurements on high range flow meters are based on the use of a set of working standards which are flow nozzles operated under critical conditions, i.e., at sonic velocity in the throat of the nozzle. Determination of the mass flowrate through these nozzles is based upon measured discharge coefficients. Measurement of the discharge coefficient for each nozzle over the range of throat Reynolds numbers used has been done in PVT experiments in which the gas flowing through the nozzle is diverted into the collection tank of the loop for a measured period of time. At this time the collection tank is of unknown volume since the piping associated with it has been modified, adding additional contained volume. Efforts are underway to redetermine the collection tank volume. Automation of the data acquisition system associated with this flow measurement facility is underway.

Plans are underway to upgrade the calibration service for hydrocarbon flow meters by improving laboratory capabilities through the use of new technology using positive displacement, piston/cylinder devices (commonly called piston provers) which promise considerably improved accuracy in the characterization of flow metering devices.

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AERODYNAMICS (2.9)

Description of Services

NBS provides calibrations of air speed measuring instruments. Measurements are performed in two high quality wind tunnels covering the air speed range of 4-4900 meters per minute (0.1-180 mph).

The low velocity wind tunnel has a test section with dimensions 0.9 meter by 0.9 meter and covers an air speed range of 4-540 meters per minute (0.1-20 mph). The velocity standard in this wind tunnel is a laser velocimeter.

The high velocity wind tunnel has two test sections. The first of these has dimensions of 1.5 meters by 2.1 meters and covers an air speed range of 2-46 meters per second (4-100 mph). The second test section has dimensions of 1.2 meters by 1.5 meters and covers an air speed range of 4-82 meters per second (9-180 mph).

Air density values in the tunnels are computed from pressure and temperature measurements in the tunnel's settling chamber. These measurements are made using a recently refurbished mercury barometer and thermistors.

Documentation

Experimental Investigation of Drag on a Compliant Surface, J. M. McMichael, P. S. Klebanoff, and N. E. Mease, Viscous Flow Drag Reduction, edited by Gary R. Hough, 72 of Progress in Astronautics and Aeronautics, 1980.

Low Velocity Performance of a Ball Bearing Vane Anemometer, L. P. Purtell, Natl. Bur. Stand. (U.S.), NBSIR 78-1485, 19 pages (June 1978). Order from NTIS.

A Low-Velocity Airflow Calibration and Research Facility, L. P. Putrell and P. S. Klebanoff, Natl. Bur. Stand. (U.S.), Tech. Note 989, 18 pages (Mar. 1979). Order from NTIS. Also available from Supt. of Documents, Washington, DC, SD Stock No. SN003-003-02038-9.

Low Velocity Performance of Anemometers, L. P. Purtell, Natl. Bur. Stand. (U.S.), NBSIR 79-1759, 168 pages (May 1979). Request from Bureau of Mines.

Low Velocity Performance of a Magnetic Pick-Up Vane Anemometer, L. P. Purtrell, Natl. Bur. Stand. (U.S.), NBSIR 79-1566, 34 pages (Dec. 1978). Request from Bureau of Mines.

Training Programs

None.

Future Directions

Efforts are underway to develop a full set of documentation for the measured parameters to infer the uncertainty in the calibration measurements themselves. The mercury barometer used for pressure measurements will be compared with the standard maintained by the NBS Pressure Group utilizing a transfer standard available from that group. The currently used thermometers will be discarded and platinum resistance elements or new thermocouples will be substituted. These will have been calibrated against a standard PRT as are those used for gas flow measurements.

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RESISTANCE MEASUREMENTS (3.1)

Description of Services

This service provides for calibrations of primary standard resistors in the range from 0.0001 ohms to 1 teraohm, high-current standards of resistance (shunts) up to 0.1 ohms, and resistance measurements assurance program (MAP) transfers. One-ohm resistance standards of the Thomas type are calibrated directly against the five NBS Thomas resistors used to maintain the legal ohm. All others are calibrated by comparison with NBS working standards of the same nominal value, except at the two ends of the scale, where ten to one ratios may be employed. These working standards are calibrated in terms of the primary group of Thomas resistors through the use of resistance networks especially designed to attain 10:1 and 100:1 ratios with accuracies better than 0.01 ppm.

Shunts are calibrated by comparison with special low-valued standards resistors designed to maximize heat dissipation and kept in stirred, temperature-controlled oil. Currents of up to 1000 ampers may be handled directly.

Resistance MAP transfers are generally carried out at one of three levels: one ohm, ten-thousand ohms, or ten to one hundred megahoms. In the first two cases, commercial standard resistors (generally four) are used as transport standards; in the latter case, use is made of NBS-constructed resistors based on tested thin-film resistors. These services are intended to provide traceability at the highest attainable accuracies and therefore involve a high degree of interaction between NBS and client personnel.

Documentation

Automated NBS 1-Ohm Measurement System, K. R. Baker and R. F. Dziuba, IEEE Transactions on Instrumentation and Measurement, IM-32, No. 1, 154 (Mar. 1982).

Determination of the Fine-Structure Constant Using GaAs-Al (x) Ga (1-x) as Heterstructures, D. C. Tusui, A. C. Gossard, B. F. Field, M. E. Cage, and R. F. Dziuba, Phys. Rev. Ltrs., 48, 3 (1982).

Measurement of the Quantized Hall Steps in Silicon at the PPM Level, R. J. Wagner, C. F. Lavin, M. E. Cage, R. F. Dziuba, and B. F. Field, Surface Science, 113, 10 (1982).

An Integrated System for the Precision Calibration of Four-Terminal Standard Resistors, T. E. Wells and E. F. Gard, IEEE Transactions on Instrumentation and Measurement, IM 20, No. 4, 253 (Nov. 1971).

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

Measurement of Multimegohm Resistors, A. H. Scott, J. Res. Natl. Bur. Stand. (U.S.), 50, No. 3 (Mar. 1953).

Precision Resistors and Their Measurement, J. L. Thomas, Natl. Bur. Stand. (U.S.), Circular 470 (Oct. 1948).

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

Training Programs

None.

Future Directions

Effort is being put forth to develop techniques to permit companies to run a reverse MAP - i.e., to minimize NBS involvement in data processing and, if posible, permit companies to use their own transport standards and NBS calibration services as the basis for quality-control in the resistance area. A large effort is being made to reduce uncertainties and turnaround time via automation. The system for calibrating Thomas-type resistors was automated recently, resulting in a three-fold improvement in precision. The same techniques are being applied to the calibration of 0.1 to 100 ohm standards. A capacitance discharge system for calibrating resistors above a terahom will be completed in the next year. The development of an unbalanced bridge technique for the calibration of resistors in the range from 10 ohms to one megohm will take place over the next two years. Calibrations of resistors with greater magnitudes than one teraohm will be reinstated upon completion of the new automated capacitance discharge system.

Another major activity is that of establishing a resistance standard based on atomic physics via the quantized Hall effect discovered by von Klitzing in 1980. This activity has three aspects: the characterization of the effect itself as manifested in MOSFET's and gallium arsenide heterostructures, the development of improved methods to measure the resistances involved at very low power levels, and the improvement of scaling techniques to link the Hall resistances (6453.2 and 12906.4 ohms) to the legal unit, maintained at the one-ohm level. It is expected that in three to five years this effect will be used both nationally and internationally as the preferred method of maintaining the ohm, freeing this area of resistance metrology from dependence on artifact standards and their material-linked properties.

Upon completion of the automation projects and the adoption of a quantized Hall effect primary resistance standard, efforts will be redirected to the areas of improving both transport and working resistance standards; developing seminars, courses, and publications to teach resistance measurement technology to the metrology community; and address techniques for making resistance measurements under adverse conditions.

Planned documentation with target dates are as follows:

Compendium of resistance measurement papers jointly with NCSL and IEEE.	Dec. 1984
Operational and quality control procedures document.	June 1985
Error analysis document.	June 1985

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PRECISION APPARATUS (3.2)

Description of Services

This service covers Hamon resistance transfer devices, and inductive voltage dividers at 400, 1000, 10000 Hz and Silsbee-type primary voltage ratio standards from 1.5 to 1500 volts dc. Hamon devices are calibrated by comparing their series and parallel-mode resistances with those of NBS-constructed devices on a one-to-one basis. This tests the parallel to series transfiguration error of the device. Inductive voltage dividers are calibrated by comparison with a two-stage, three-decade transformer of known ratios. Silsbee standards are done by one-to-one comparison with a primary voltbox, which is self-calibrated by design.

Documentation

American National Standard for Decade Transformer Dividers (Voltage Type), ANSI C100, 1-1972 (Jan. 1972).

Instructions for the Use of the NBS Reference Inductive Divider, Wilbur C. Sze, National Bureau of Standards, Unpublished (1970).

Two-Stage, Guarded Inductive Voltage Divider for Use at 100 kHz, D. H. Hamon and T. L. Zaf, ISA Transactions, 9, 3 (1970).

Comparator for Calibration of Inductive Voltage Dividers from 1 to 10 kHz, W. C. Sze, ISA Transactions, 6, 4 (1967).

Training Programs

None.

Future Directions

There will be little activity other than the maintenance of the calibration facility, or spin-offs from the development work in the impendance area.

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IMPEDANCE MEASUREMENTS (3.3)

Description of Services

This service covers the calibrations of standard capacitors and inductors in the audio-frequency range. Capacitors of the air (0.001 to 1000 pF), fused-silica (10 and 100 pF), and silvered-mica (1 to 1000 μF) type can be measured at frequencies between 66-2/3 and 10,000 Hz. Inductors having nominal values between 0.01 mH and 10 H can be measured at the same frequencies.

Documentation

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

Transportable 1000 pF Standard, G. M. Free and J. J. Morrow, Natl. Bur. Stand. (U.S.), Tech. Note 1162 (1982).

New Measurements of the Absolute Farad and Ohm, R. D. Cutkosky, IEEE Trans. Instrum. Meas., IM-23, No. 4, 305 (Dec. 1974).

Applications of Coaxial Chokes to A-C Bridge Circuits, D. N. Homan, J. Res. Natl. Bur. Stand. (U.S.), 72C, No. 2 (June 1968).

Improved Ten-Picofarad Fused Silica Dielectic Capacitor, R. D. Cutkosky and H. L. Lee, J. Res. Natl. Bur. Stand. (U.S.), 69C, No. 3 (Sept. 1965).

Calibration of Inductance Standards in the Maxwell-Wein Bridge Circuit, T. L. Zapf, J. Res. Natl. Bur. Stand. (U.S.), 65C, No. 3 (Sept. 1961).

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

Training Programs

None.

Future Directions

The major efforts in this area are directed to the improvement of the quality of calibrations by replacing worn out or obsolete apparatus and by improving quality-control procedures. In particular, a replacement for the Maxwell-Wien bridge used to calibrate standard inductors has been developed and is under test. The replacement bridge will cover a broader frequency range, up to 100 kHz, than the present bridge, and can be used for ac resistance measurements if proper standards are developed. Replacement of the Type II capacitance bridge is planned also. An automated substitute bridge is expected to be developed in about three to four years' time. Improved quality-control techniques to be instituted will inclue a more effective system of check standards and a scheme for comparing the ratios in the Type II bridge with those of the transformer used as the standard in the inductive voltage divider set-up. Efforts are also underway to resume the currently suspended capacitance MAP with new transport standards for 1 μF at frequencies from 400 to 1000 Hz.

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VOLTAGE MEASUREMENTS (3.4)

Description of Services

This service provides for the calibration of standards of direct voltage (saturated and unsaturated standards cells at 1.02 V and Zener diode-based electronic standards from 6.5 to 10 V) and voltage MAP services. The volt is maintained by monitoring the emf's of a group of six saturated standard cells in an oven on a monthly basis using the ac Josephson effect and a specialized measurement system to perform the required scaling (from $\sim$ 10 mV to 1.02 V). Customer cells are calibrated by comparing their emf's with those of working groups of standard cells on a one-to-one basis using low-level potentiometers and nanovoltmeters. Electronic standards with output voltages in the ranges from six to ten volts are measured relative to a group of standard cells using an automated system.

Documentation

Volt Transfer Program Instructions, revised in 1983, unpublished.

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, No. 4, 282-286 (Dec. 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, 155-166 (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).

Training Programs

A week-long seminar on MAP techniques for voltage measurements is being held twice yearly at various locations. Statistical concepts, quality-control techniques, and standard cell metrology principles are presented.

Future Directions

The major current activity is that of automating the standard cell calibration facility. The measurements on transport standards required for the MAP are made using an automated system. All other measurements are made manually. Recent work has shown the feasibility of using high-accuracy digital multimeters as standard cell comparators with resolution of ten nanovolts or better. This resolution readily suffices for calibration of nearly all standard cell enclosures. Moreover, the use of such instruments precludes accidental damage to the cells because of the high input impendance of the meters. These multimeters are easily operated under the control of desktop computers under the control of the IEEE 488 instrumentation bus. Preliminary design for such measurement systems has been completed and a prototype is being built for evaluation. A second major effort is the development of a MAP transfer service at the ten-volt level using Zener-diode based standards. A system has been constructed to make measurements at the 0.2 ppm level of precision to evaluate components. A suitable transport standard is likely to be developed by October 1985 and testing will follow. Upon completion of the automation work and the institution of MAP services at the ten-volt level, attention will be focused on providing support for voltage levels up to 1000 volts dc. Scaling apparatus developed to support volt-ratio MAP activities last decade will be rejuvinated to provide the basis for development of a MAP service for high voltages needed to support new, high-accuracy 7 and 8 digit multimeters. Transport standards capable of measuring or supplying such voltages with accuracy of 5 ppm or better will need to be developed. Measurement techniques to determine the effects of noise, faulty grounds, common-mode signals, etc., will be needed. Techniques to determine optimum test point sets for various types of meters will be studied to minimize the effort required to characterize a multimeter or measuring system.

Planned documentation includes a manual on voltage operating and quality control procedures (Sept. 1984) and an overview publication on voltage measurements (Jan. 1985).

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ELECTRICAL INSTRUMENTS (3.5)

Description of Services

This service covers the calibration of thermal voltage and current converters, ac shunts, and primary thermo-elements used to make measurements of alternating current and voltage in terms of direct current standards of voltage and resistance. These are carefully compared with similar NBS devices which have been calibrated using the NBS primary set of multijunction thermo-elements as a defining standard. The frequency range covered is from 2 Hz to 1 MHz, with higher frequencies being covered by the Electromagnetic Technology Division in Boulder. Voltages as high as 1000 volts are covered, but only up to 50 kHz.

Documentation

The Practical Uses of AC-DC Transfer Instruments, E. S. Williams, Natl. Bur. Stand. (U.S.), Tech. Note 1166 (Nov. 1982).

A Thermoelement Comparator for Automatic AC-DC Difference Measurements, E. S. Williams, IEEE Trans. Instrum. Meas. IM-29, No. 4, 405 (Dec. 1980).

An Investigation of Multijunction Thermal Converters, F. L. Hermach and D. R. Flach, IEEE Trans. Instrum. Meas., IM-25, No. 4, 524 (Dec. 1976).

Thermal Voltage Converters and Comparators for Accurate AC Voltage Measurements, E. S. Williams, J. Res. Natl. Bur. Stand. (U.S.), 75C (Dec. 1971).

Training Programs

None.

Future Directions

The major activities in the electrical instruments area are those of reevaluating the primary, secondary, and working standards; investigating the properties of new solid-state thermo-elements, and automating the calibration set-ups. The first is nearly complete. Data will be collected over the next year to permit a statistical evaluation of the results. A new, automated system has been constructed to compare solid-state with conventional thermal converters in order to measure their frequency response more accurately. The evaluation of these devices is expected to take a year or more. A new system for automated calibrations is under consideration. Several measurement approaches are being looked at and the development of a practical system will be complete in a year to eighteen months. This will relieve the backlog of calibrations experienced in this area for the past three years.

There are two major areas which will be addressed in the future. The first is that of the development of a MAP-type service for alternating current and voltage measurements. Currently available equipment could be used as the basis for a MAP service for ac-dc difference measurements. While this is a required constituent of the process of making measurements of alternating quantities, it is by no means the only constituent. It is quite possible for a laboratory to make good ac-dc difference measurements but have serious problems with measurements of current and voltage. Accordingly, transport standards which are either sources or measurement systems need to be devised and checked before it is possible to say anything about a lab's capability in this area. The second major area is that of developing the next generation of ac-dc standards and comparison apparatus. The present primary standards, multijunction thermo-elements, are limited in both signal and frequency range. New technology will be explored for the feasibility of producing standards at the part in ten-million level of accuracy.

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DC-AC VOLTAGE, CURRENT, AND POWER MEASUREMENTS (3.6)

Description of Services

Calibrations are made on devices that are of high quality for use as reference standards. These include voltage and current transformers, voltage dividers, high voltage resistors and capacitors, and watthour meters.

NBS provides 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. Results of these tests are reported with an uncertainty of ± 0.03% for ratio and ± 0.3 mrad for phase angle. Calibrations of these voltage transformers are done routinely only at 60 Hz. Measurements are made with one side of both the primary and secondary windings connected to ground. Current transformers, with a rated secondary current of 5 A, can be calibrated at 0.5, 1, 2, 3, 4, or 5 A. These tests are carried out at 50, 60, and 400 Hz. For measurements of 50 or 60 Hz, the results are generally reported with an uncertainty of ± 0.01% in ratio and ± 100 μrad in phase angle. For measurements at 400 Hz, the reported uncertainty is ± 0.03% in ratio and ± 300 μrad in phase angle.

A calibration service is maintained at NBS to specify the dc voltage ratio of resistive dividers. This calibration service is available for applied voltages from 10 to 150 kV. The calibrations are performed with a measurement system which has an uncertainty of ± 0.01% of the voltage ratio. To assure adequate sensitivity at the lowest applied voltage levels, calibrations are performed only on dividers with ratios of 100,000:1 or smaller. The calibration service is also restricted to dividers with a low-resistance element of 10,000 ohms or less.

AC high-voltage dividers are calibrated at 60 Hz for applied voltages between 10 and 100 kV rms. There are high voltage dividers which perform satisfactorily as standards under dc voltages but which cannot be considered standards when excited by 60-Hz voltages. The design of an ac divider requires special care beyond that of a dc divider. In particular, ac dividers 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. Calibrations are performed with a measurement system which has an uncertainty of ± 0.05% in the determination of the ratio and ± 0.5 milliradian in the determination of the phase angle. The calibration of dividers used to measure the high voltage in diagnostic x-ray units consists of three measurements. These are the measurements of the variation of the ratio with a change in the frequency of the applied voltage in the frequency range from dc to 10,000 Hz; a determination of the ratio under direct voltage at 25 kV; and a measurement of any voltage induced variation of the ratio in the voltage range from 20 to 70 kVp. If the device under test is designed to operate continuously under full rated voltage, this last test is done at three dc voltages between 20 and 70 kV. If it cannot operate continuously, a preselected number of half cycles of 60-Hz voltage ranging in magnitude from 20 to 70 kVp are applied. These calibrations are performed with an uncertainty of ± 0.1% of the indicated value of the dc ratio at 25 kV, an uncertainty of ± 1% of the indicated value of the frequency dependence and it is generally reported that the ratio varied by less than ± 1% as the applied voltage is varied over the full range. Ratios of resistive, capacitive, or mixed-voltage dividers are determined under pulsed high-voltage conditions. Determinations employ specially designed pulse dividers and calibrated Kerr cells as reference standards. 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 to 300 kV as requested and up to 500 kV with certain pulse shapes. The typical uncertainty is ± 3% of the voltage ratio.

A calibration service is maintained for resistors designed for dc high-voltage applications. This service is designed for nearly corona-free resistors designed for dc operation between 10 and 150 kV. A calibration service is also maintained for capacitors designed for 60-Hz operations, especially at voltages above 100 V. Typical uncertainties for a calibration are ± 100 ppm of the capacitance, and ± 1% of the dissipation factor $\pm 1 \times 10^{-5}$. Routine calibrations are limited to devices with a dissipation factor of 0.011 or smaller and which are operated at sufficient voltage that at least 40 μA pass through the device under test.

Calibration services are available for portable watthour meters of the rotating and electronic types. The test conditions must be specified by the customer. These include the current (0.5 to 50 A), voltage (± 10 V around 120, 240, and 480 V), 50 or 60 Hz, and power factor of 1.0, 0.5 leading, or 0.5 lagging. The duration of a calibration run is about 100 seconds for a power factor of 1.0 and about 200 seconds for a power factor of 0.5. The reported values of the percentage registration generally have uncertainties of ± 0.05% of the indicated value. A Measurement Assurance Program for electric energy is also available to evaluate energy measuring equipment. An NBS-owned, transport standard, watthour meter is shipped to the customer and a tie is made to the U.S. national energy unit without the downtime encountered when the customer's standards are shipped to and calibrated by NBS. In addition, and more important to those who calibrate standard watthour meters, the MAP standard can be used by customers to evaluate their measurement process in a convenient and cost effective way.

Documentation

A Wide Range High-Voltage Capacitance Bridge With One ppm Accuracy, O. Petersons and W. E. Anderson, IEEE Trans. Instrum. Meas., IM-24, No. 4, 336-344 (Dec. 1975).

An Electronic Ratio Error Set for Current Transformer Calibrations, R. L. Kahler, IEEE Trans. Instrum. Meas., IM-28, No. 2, 162-164 (June 1979).

A Wide Range Current Comparator System for Calibrating Current Transformers, T. M. Souders, IEEE Trans. Power Appar. Syst., PAS-90, No. 1, 318-324 (Jan.-Feb. 1971).

Wide-Band Two-Stage Current Transformers of High Accuracy, T. M. Souders, IEEE Trans. Instrum. Meas., IM-21, No. 4, 340-345 (Nov. 1972).

X-CAL - A Calibration System for Electrical Measurement Devices Used With Diagnostic X-Ray Units, R. H. McKnight and R. E. Hebner, Natl. Bur. Stand. (U.S.), NBSIR 79-2072, 74 pages (June 1980).

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, 97 pages (Nov. 1979).

Calibration of High-Voltage Pulse Measurement Systems Based on the Kerr Effect, Natl. Bur. Stand. (U.S.), NBSIR 77-1317, 33 pages (Sept. 1977).

Special Shielded Resistor for High-Voltage Measurements, J. H. Park, J. Res. Natl. Bur. Stand. (U.S.), 66C, No. 1, 19-24 (Jan.-Mar. 1962).

A Calibration Service for Wattmeters and Watthour Meters, J. D. Ramboz and R. C. McAuliff, Natl. Bur. Stand. (U.S.), Tech. Note 1179, 111 pages (July 1983).

A Measurement Assurance Program for Electric Energy, N. M. Oldham, Natl. Bur. Stand. (U.S.), Tech. Note 930, 17 pages (Sept. 1976).

Sampling Techniques for Electric Power Measurement, R. S. Turgel, Natl. Bur. Stand. (U.S.), Tech. Note 870, 31 pages (June 1975).

Transfer of the Kilowatthour, S. R. Houghton, IEEE Trans. Power Appar. Syst., PAS-94, No. 4, 1232-1240 (July-Aug. 1975).

A Current Comparator System to Establish the Unit of Electrical Energy at 60 Hz, K. J. Lentner, IEEE Trans. Instrum. Meas., IM-23, No. 4, 334-336 (Dec. 1974).

Training Programs

There is no formal schedule of educational seminars, but over the last few years NBS has sponsored one or two seminars per year on selected topics in electrical measurements. Potential participants can have their names added to the mailing lists for these seminars by contacting the person listed at the end of this section.

Future Directions

NBS will develop a capability to evaluate shunts and current transformers used to measure welding currents. This application requires the measurement of current pulses with amplitudes up to 100 kA and durations of tens to hundreds of milliseconds. Development of a bridge for calibrating shunts down to 0.1 mΩ and up to frequencies of 100 kHz is progressing slowly with the present funding level. Long range plans also include support of dc current measurements from 5 to 2000 A as a step toward developing support for dc revenue metering in high voltage dc systems.

NBS' present capabilities for power and energy calibration are restricted to power frequencies, 50 to 400 Hz, with a routine uncertainty of ± 0.05%. Under special conditions, we are able to achieve uncertainties in the range ± 0.01 to ± 0.02%. These capabilities are for unity and 0.5 power factor, but no measurements at zero power factor. Present plans are to gradually upgrade this facility during the next 5 years. The goal is to develop a largely automated facility having the following characteristics:

Frequency	:	40 Hz to 10 kHz	Waveforms:	sinusoidal and distorted
Voltage	:	10 to 240 V	Quantities:	power, energy, VAR, power factor, voltage, and current
Current	:	10 mA to 10 A	Accuracy:	± 0.01% to ± 0.05% routine, ± 50 ppm special
Power Factor	:	all, zero to unity, positive and negative		

<u>Contact Person at NBS</u>

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WATTMETER AND AC VOLTAGE MEASUREMENTS (3.8)

Description of Services

Calibrations of portable ac-dc wattmeters are provided at voltages ranging from 110 to 130 V, 220 to 260 V, and 440 to 520 V; at currents from 0.5 to 50 A; and at frequencies up to 60 Hz. The duration of a test run is about 100 seconds and the reported corrections (in watts) generally have uncertainties of ± 0.05% of the full scale range. A calibration service is also available for ac voltage standards and rms voltmeters in the 0.1 to 10 Hz range. The ac voltmeters can be calibrated at frequencies of 10, 5, 2, 1, 0.5, 0.2, and 0.1 Hz at any voltage level between 0.5 mV and 7 mV while voltage sources can be calibrated at any frequency in the 10 to 0.1 Hz range and are usually tested near the full-scale level of the voltmeter ranges (2, 5, 10, 20, 50 mV, and 0.1, 0.2, 0.5, 1, 2, 5 V).

Documentation

A Calibration Service for Wattmeters and Watthour Meters, J. D. Ramboz and R. C. McAuliff, Natl. Bur. Stand. (U.S.), Tech. Note 1179, 111 pages (July 1983).

An rms Digital Voltmeter/Calibrator for Very-Low Frequencies, H. K. Schoenwetter, IEEE Trans. Instrum. Meas., IM-27, No. 3, 259-268 (Sept. 1978).

AC Voltage Calibrations for the 0.1 Hz to 10 Hz Frequency Range, H. K. Schoenwetter, Natl. Bur. Stand. (U.S.), Tech. Note 1182, 56 pages (Sept. 1983). (This reference provides a complete description of the calibration service.)

Training Programs

There is no formal schedule of educational seminars, but over the last few years NBS has sponsored one or two seminars per year on selected topics in electrical measurements. Potential participants can have their names added to the mailing lists for these seminars by contacting the person listed at the end of this section.

Future Directions

A system capable of calibrating alternating voltage sources or voltmeters in the ± 10 ppm accuracy range (1 to 1000 V and up to 100 kHz) is being developed. This system can also characterize the ac-dc difference of thermal voltage converters. A second more portable system is being developed for calibrating dc/ac voltmeters in the ± 5/± 50 ppm accuracy range which may ultimately cover frequencies up to 1 MHz. The primary application is calibration of programmable sources and automated test equipment.

Contact Person at NBS

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DATA CONVERTER MEASUREMENTS (3.9)

Description of Services

NBS maintains a calibration service for high resolution (12-18 bit) analog-to-digital (ADC) and digital-to-analog (DAC) converters. Measurements are made on the linearity, differential linearity, offset, gain, and equivalent runs of the data converters. To be compatible with the NBS data converter test set, test units must conform to the following general specifications:

- Nominal resolution from 12- to 18-bits;
- Conversion rate of at least 10 kHz;
- Binary coding format, including binary sign-magnitude, offset binary, 2's complement, 1's complement, and complemented versions of these;
- TTL compatibility;
- Voltage ranges of 0-5 V, ± 5 V, 0-10 V, ± 10 V; and
- Maximum error including offset and gain, not to exceed 500 ppm.

In general, it is the customer's responsibility to mount integrated circuit, hybrid, or modular test converters on suitable test boards, providing all required trimmer circuits, voltage references, input or output amplifiers, recommended power supply decoupling capacitors, and connectors for interfacing to the input/output lines. Fully self-contained converters need only be fitted with the necessary interfacing connectors.

Documentation

A Calibrated Service Analog-to-Digital and Digital-to-Analog Converters, T. M. Souders, D. R. Flach, and B. A. Bell, Natl. Bur. Stand. (U.S.), Tech. Note 1145, 66 pages (July 1981). (This reference provides a complete description of the calibration service.)

A 20-Bit + Sign Relay Switched D/A Converter, T. M. Souders and D. R. Flach, Natl. Bur. Stand. (U.S.), Tech. Note 1105, 16 pages (Oct. 1979). (This describes the reference standard used in the calibration service.)

A Technique for Measuring the Equivalent rms Input Noise of A/D Converters, T. M. Souders and J. A. Lechner, IEEE Trans. Instrum. Meas., IM-29 (Dec. 1980).

A High-Speed Low-Noise 18-Bit Digital-to-Analog Converter, H. K. Schoenwetter, IEEE Trans. Instrum. Meas., IM-27 (Dec. 1978).

An Automated Test Set for the Dynamic Characterization of A/D Converters, T. M. Souders, D. R. Flach, and T. C. Wong, IEEE Trans. Instrum. Meas., IM-32 (Mar. 1983).

Training Programs

There is no formal schedule of educational seminars, but over the last few years NBS has sponsored one or two seminars per year on selected topics in electrical measurements. Potential participants can have their names added to the mailing lists for these seminars by contacting the Electrosystems Division at the address given below.

Future Directions

NBS has recently developed the capability to measure the dynamic response of ADCs to well defined, programmable input voltage characteristic of typical input signals. Until further analysis of systematic and random errors of the test procedure is completed and until additional operating experience is obtained these dynamic measurements will only be offered as a special test.

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ATTENUATION (4.1)

Description of Services

NBS provides calibration services for attenuation and phase shift measurement listed below:

Attenuation Measurement of Coaxial Attenuators

(a) Fixed and Variable Attenuators

Coaxial fixed and variable attenuators are measured on the NBS modified automatic network analyzer (ANA) over the frequency range 0.1 to 18 GHz.

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

In addition to measurements performed on the ANA, measurements at a fixed frequency of 30 MHz are available referenced to the NBS waveguide below cutoff standard at this frequency.

Coaxial attenuators are normally measured in a system having a characteristic impedance of 50 Ω. Limits of uncertainty depend upon the VSWR of the individual attenuator, quality of the attenuator and connectors, and the magnitude of the attentuation. Typical systematic uncertainties range from 0.03 to 0.05 dB/10 of attenuation.

(b) Attenuation Measurements at 30 MHz

Incremental attenuation. Incremental attenuation is the change in attenuation of an adjustable attenuator between a reference setting (usually zero) and any other setting. The same restraints on system conditions apply as for attenuation. The term "differential attenuation" is sometimes applied.

Measurements on waveguide-below-cutoff (piston) attenuators are performed at 30 MHz. These attenuators are normally quite stable and seldom need recalibration unless damaged or mechanically worn. Since any laboratory can perform independent checks to determine continuing repeatability and linearity of attenuation, periodic NBS recalibrations are not recommended. This recommendation, in part, is also because more damage can be suffered in transit than in daily use. In any measurement, the maximum power delivered to the test attenuator will not exceed 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 leakage. Limits of uncertainty depend upon the quality of the attenuator and connectors, as well as upon the VSWR of the attenuator, and the magnitude of attenuation. Typical systematic uncertainties range from 0.003 to 0.005 dB/10 dB of attenuation.

(c) Attenuation Measurements Below 10 MHz

Special tests may be performed over the frequency range 30 kHz to 10 MHz using the voltage ratio measurement technique. These tests are limited to attenuators with GR 874 connectors and to 10 dB maximum.

(d) Standard Transmission Lines

The characteristic impedance, Z_o, and the equivalent electrical length of air-dielectric coaxial transmission lines are calculated from measurements of the physical dimension of the line and estimates of the electrical conductivity of the line. The physical dimensions are measured with precision air gages.

The electrical parameters vary slightly with frequency because of the finite conductivity of the material. The calibration report includes a table of electrical parameters calculated at different frequencies for a typical value of conductivity. The actual conductivity of the line material is not determined.

(e) Rectangular Waveguide Variable Attenuators

Variable waveguide (usually rotary vane) attenuators are calibrated in various frequency bands by the IF-substitution technique referenced to 30 MHz, direct rf substitution, or on the NBS modified ANA, as appropriate.

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

The uncertainty is a function of resettability and input VSWR of the waveguide ports. Devices submitted should be in the best possible condition to justify calibration and ensure long-term stability of measured values. Typical systematic uncertainties range from 0.03 to 0.05 dB/10 dB of attenuation.

Documentation

Applications of Waveguide and Circuit Theory to the Development of Accurate Microwave Measurement Methods and Standards, R. W. Beatty, Natl. Bur. Stand. (U.S.), Monogr. 137, 218 pages, (Aug. 1973).

Basic Theory of Waveguide Junctions and Introductory Microwave Network Analysis, D. M. Kearns and R. W. Beatty, Pergamon Press Intl. Series of Monographs in Electromagnetic Waves, 13, 59-63 (1967).

Effects of Connectors and and Adapters on Accurate Attenuation Measurements at Microwave Frequencies, R. W. Beatty, IEEE Trans. Instrum., 13, 272-284 (Dec. 1964).

Insertion Loss Concepts, R. W. Beatty, Proc. IEEE, 52(6), 663-671 (June 1964).

Rf Attenuation, D. Russell, Proc. IEEE, 55(6), 942-959 (June 1967).

IEEE Standard 474-1973, Specifications and Test Methods for Fixed and Variable Attenuators, dc to 40 GHz.

Training Programs

None.

Future Directions

Presently, routine calibrations are provided only for linear, reciprocal, one-port and two-port networks and then only over limited frequency and parameter ranges. It is planned to greatly extend the coverage in the near future providing all S-parameter measurement at most frequencies from 100 kHz to 100 GHz, and for $|S_{12}|$ up to approximately 60 dB.

Plans call for providing attenuation measurements of special three-port devices at 1.25 MHz. A measurement system is being 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.

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Description of Services

Measurement services are generally available for microwave and low-directivity antennas from 30 Hz to 75 GHz. Antenna measurements are conducted as special tests owing to the great variability in antenna design, performance, and use.

Accurate measurement of microwave antenna gain, pattern, and polarization are generally available from about 750 MHz to about 75 GHz. 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. Extrapolation range measurements offered primarily for determining the absolute on-axis gain and polarization of standard gain horns which are, in turn, used as reference standards in determining the gain and polarization of other antennas by the gain comparison technique. Above 1 GHz, the accuracies are typically ± 0.05 dB/dB for polarization axial ratio measurements. Gain, pattern, and polarization parameters are calculated from Near-Field Scanning Measurements in which amplitude and phase measurements are taken over a surface close to the test antenna. The absolute gain can be determined to within about ± 0.15 dB, the polarization axial ratio to within about ± 0.10 dB/dB, and side lobe levels can be obtained down to -50 or -60 dB.

Non-direction antenna measurements for radiated field strength measurements are available as indicated in the following table:

Field Parameter	Type of Measurement Facility	Frequency Range	Radiating Antenna Source
H(near zone)	Wood building	30 Hz - 50 MHz	Loop (20 cm)
E(vertical)	Open site (ground screen)	10 kHz - 30 MHz	Short monopole
E(vertical)	Open site (ground screen)	30 - 300 MHz	$\lambda/4$ monopole
E(horizontal)	Open site	30 - 300 MHz	Receiving $\lambda/2$ dipole
Power density	Anechoic chamber	200 - 500 MHz	Open-end wave guide
		0.5 - 18 GHz	Pyramidal horn

Measurement services are also offered for antenna systems, field strength measurement devices, and both electric (E) and magnetic (H) field probes and meters.

Documentation

Accurate Measurement of Antenna Gain and Polarization at Reduced Distances by an Extrapolation Technique, A. C. Newell, R. C. Baird, P. F. Wacker, IEEE Trans. Antennas Propagat., AP-27, No. 4, 418-431 (July 1973).

Determination of Both Polarization and Power Gain of Antennas by a Generalized 3-Antenna Measurement Method, A. C. Newell and D. M. Kerns, Electronics Letters, 7, No. 7, 68-70 (Feb. 1971).

Correction of Near-Field Antenna Measurements Made With an Arbitrary but Known Measuring Antenna, D. M. Kerns, Electronics Letters, 6, No. 11, 346-347 (May 1970).

New Method of Gain Measurement Using Two Identical Antennas, D. M. Kerns, Electronics Letters, 6, No. 11, 348-349 (May 1970).

Plane-Wave Scattering-Matrix Theory of Antennas and Antenna-Antenna Interactions: Formulation and Applications, D. M. Kerns, J. Res. Natl. Bur. Stand. (U.S.), 806 (Math. Sci.), No. 1, 5051 (Jan.-Mar. 1976).

Plane-Wave Scattering-Matrix Theory of Antennas and Antenna-Antenna Interactions, D. M. Kerns, Natl. Bur. Stand. (U.S.), Monogr. 162 (June 1981).

Upper-Bound Errors in Far-Field Antenna Parameters Determined from Planar Near-Field Measurements, A. D. Yaghjian, Natl. Bur. Stand. (U.S.), Tech. Note 667 (Oct. 1975).

The Near-Zone Magnetic Field of a Small Circular Loop Antenna, F. M. Greene, J. Res. Natl. Bur. Stand. (U.S.), 71C (Eng. and Instr.), No. 4 (Oct.-Dec. 1967).

Calibration Principles and Procedures for Field Strength Meters (30 Hz to 1 GHz), H. E. Taggart and J. L. Workman, Natl. Bur. Stand. (U.S.), Tech. Note 370 (Mar. 1969).

NBS Field Strength Standards and Measurements (30 MHz to 1000 MHz), F. M. Greene, Proc. IEEE, 55, 970-981 (June 1967).

Field Strength Above 1 GHz: Measurement Procedures for Standard Antennas, R. R. Bowman, Proc. IEEE, 55, 981-990 (June 1967).

Electromagnetic Waves and Radiating Systems, E. C. Jordan, Prentice-Hall, Inc. (1950).

Antennas Theory and Practice, S. A. Schelkunoff and H. T. Fritz, John Wiley and Sons, Inc. (1952).

Generation of Standard EM Field Using TEM Transmission Cells, M. L. Crawford, IEEE Trans. Electromag. Compat., EMC-16, No. 4, 189-195 (Nov. 1974).

Design and Calibration of the NBS Isotropic Electric Field Monitor (EFM-5), 0.2-1000 MHz, E. B. Larsen and F. X. Ries, Natl. Bur. Stand. (U.S.), Tech. Note 1033 (Mar. 1981).

Training Programs

A variety of consultation and advisory services are available upon request. Included are cooperative measurement programs, wherein a customer may bring an item to NBS for measurement and actually participate in the measurements 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, NBS measurement techniques.

Future Directions

Work is in progress to enable NBS to respond to the measurement problems associated with electromagnetic interference and radiation hazards.

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IMPEDANCE OR ADMITTANCE (4.3)

Description of Services

Calibration services provided in this category are for passive devices over the frequency range from 10 kHz to 95 GHz. Highest accuracy is obtained only for standards equipped with precision coaxial connectors or waveguide flanges. Standards submitted for calibration should be in good repair and, except for very minor cleaning of connector surfaces, should require no precalibration maintenance. NBS does not provide repair services so that items received which require maintenance will be returned to the sender and a handling fee will be charged.

o Capacitance, Two-Terminal, Low-Loss

In the frequency range from 30 kHz to 250 MHz, capacitance calibrations to a minimum uncertainty of ± 0.1 percent are available from 1 pF to 1 μF depending upon frequency. The upper capacitance limit for calibration decreases as the frequency increases and is 50 pF at 5 MHz and above. At 1 MHz a special high accuracy service is available for capacitors with nominal values of 50, 100, 200, 500, and 1000 pF provided they are equipped with 14 mm coaxial connectors.

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

o Capacitance, Three-Terminal, Low-Loss

Services are available at 100 kHz and 1 MHz for capacitors having values of 10, 100, and 1000 pF. Calibration uncertainty is typically ± 0.02 percent for all frequencies and values except for 1000 pF at 1 MHz where the uncertainty is nominally ± 0.04 percent.

Fixed value reference standards are maintained by NBS for values of 10, 100, 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 an accuracy of ± 0.10 percent, 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.

o Inductors, Two-Terminal, High-Q

In the frequency range from 10 kHz to 250 MHz, inductance calibrations to a minimum uncertainty of ± 0.1 percent are available from 0.01 μH to

1 H. The upper inductance limit for calibration decreases as the frequency increases and is 1 μH at 250 MHz. Service is available only for aircore inductors or inductors whose value is independent of current.

o Resistors, Two-Terminal, Low-Q

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

o Q-Standards

Standards for Q-measurements are maintained at NBS. These are high-Q inductors equipped with banana plug connectors at a spacing of 1 inch on centers. These standards have inductance values of 0.25, 2.5, 25, 250, 2500, and 25,000 μH, and effective Q-values from 100 to approximately 600. These serve as working standards for calibration of Q-standards of a similar type. Calibration frequencies range from 50 kHz to 45 MHz. 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.

o Coaxial Terminations, Reflection Coefficient

Services are available for complex impedance, reflection coefficient, and voltage standing wave ratio (VSWR). Measurements on coaxial devices in the frequency range 0.1 to 18 GHz are made on the NBS modified Automatic Network Analyzer (ANA). The calibration services usually apply to determining the reflection coefficient or VSWR of standard terminations and mismatches.

o Waveguide Terminations, Reflection Coefficient

Waveguide terminations are measured in a reflectometer system relative to a quarter-guide wavelength short circuit and a precision transmission line. Some measurements in waveguide bands below 18 GHz can be performed on the NBS modified Automatic Network Analyzer (ANA) while all of those above 18 GHz are performed on manual fixed-frequency systems. Waveguide terminations are usually quite stable and need not be resubmitted unless tests performed by the user indicate a shift in values.

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.

Documentation

Lumped Parameter

The Measurement of Lumped Parameter Impedance: A Metrology Guide, R. N. Jones, Natl. Bur. Stand. (U.S.), Monogr. 141, 211 pages (June 1974).

Impedance of Lumped Circuits, L. E. Huntley, R. N. Jones, Proc. IEEE, 55(6), 900-911 (June 1967).

A Technique for Extrapolating the 1 kc Values of Secondary Capacitance Standards to Higher Frequencies, R. N. Jones, Natl. Bur. Stand. (U.S.), Tech. Note 201, 15 pages (Nov. 1963).

A Precision High Frequency Calibration Facility for Coaxial Capacitance Standards, R. N. Jones and J. E. Huntley, Natl. Bur. Stand. (U.S.), Tech. Note 386, 27 pages (Mar. 1970).

Evaluation of Three-Terminal and Four-Terminal Pair Capacitors at High Frequencies, R. N. Jones, Natl. Bur. Stand. (U.S.), Tech. Note 1024, 15 pages (Sept. 1980).

Standards for the Calibration of Q-Meters, 50 kHz to 45 MHz, R. N. Jones, J. Res. Natl. Bur. Stand. (U.S.), 58C (Eng. and Instr.), 4, 243-248 (Oct.-Dec. 1964).

Coaxial

An NBS Developed Automatic Network Analyzer, W. Little, et al., Conference on Precision Electromagnetic Measurements, June 28 - July 1, 1976, Boulder, Colorado, Digest, p. 130-133.

Waveguide

A Guide to the Use of the Modified Reflectometer Technique of VSWR Measurement, W. J. Anson, J. Res. Natl. Bur. Stand. (U.S.), 65C (Eng. and Instr.), 4, 217-223 (Oct.-Dec. 1961). (The measurement technique utilized in reflection measurements is described in this paper.)

Millimeter Attenuation and Reflection Coefficient Measurement System, B. C. Yates and W. Larson, Natl. Bur. Stand. (U.S.), Tech. Note 619 (1972).

Training Programs

No training programs currently available.

Future Plans

The introduction of automatic digital impedance and admittance meters has produced many requests concerning methods and standards for calibrating them. It is evident that instruments of this type will eventually replace the traditionally manually balanced impedance bridges because in addition to speed and versatility, they have demonstrated very good accuracy capabilities. At this time no calibration services are available either for the meters themselves or for any standards specifically designed for use with them. However, work directed to this problem has been initiated with some success in the calibration of those types having the four-terminal-pair type interface for the connection of the unknown impedance. A generalized calibration procedure has been successfully demonstrated wherein the instrument together with an adaptor to a two-terminal (one-port) connector can be evaluated as an integrated measurement system. Correction factors are determined which will correct the displayed readings to be in agreement with preselected two-terminal calibration standards. Plans are to pursue this technique to a point where it can be made available to the measurement community. Publication of an NBS Technical Note and perhaps the offering of a training seminar are under consideration.

NBS plans to transfer all coaxial, most waveguide, and some lumped circuit impedance measurements to dual six-port ANAs as they are completed.

Contact Person at NBS

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LASER POWER AND ENERGY (4.4)

Description of Services

The laser power and energy measurement services include several Measurement Assurance Programs (MAPs). These MAPs are implemented by means of transfer standards which have been evaluated and characterized relative to the national standards (three types of isoperibol type calorimeters). One of these transfer standards, evaluated for the specific wavelength and power (energy) range of laser radiation, is forwarded to each MAP participant twice per year. The participant is asked to calibrate the transfer standard in accordance with his normal procedures, or in accordance with procedures sent with the instrument. The data is then sent to NBS where an analysis is performed. The range of wavelengths and powers are as follows:

514.5 nm		10 to 660 mW
632.8 nm		1 mW
632.8 nm		30 and 100 μW
647.1 nm		10 to 200 mW
1.06 μm		10 mW to 1 W
1.06 μm	(Q-switched)	100 mJ to 10 J
10.6 μm		5 to 50 W

The uncertainty of these calibrations is about 1 to 5 percent at the 99 percent level of confidence depending on the power (or energy) and wavelength at which the calibration is performed.

The laser power and energy measurement services also include a limited number of calibrations of laser power and energy meters. These calibrations are carried out as special test calibrations in which customer-owned instruments are sent to NBS for measurement. These special tests include services to measure 1.064-μm laser pulses from 10^{-8} to 10^{-4} watts peak power and 10^{-16} to 10^{-11} joules and 10.6-μm nanosecond pulses using a TEA laser in the 0.1-joule energy range.

Documentation

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Precision Measurement and Calibration, H. Ku, Natl. Bur. Stand. (U.S.), Spec. Publ. 300 (Feb. 1969).

Documentation of the NBS C, K, and Q Laser Calibration Systems, W. E. Case, Natl. Bur. Stand. (U.S.), NBSIR 82-1676 (Sept. 1982).

A System for Measuring the Characteristics of High Peak Power Detectors of Pulsed CO Radiation, P. A. Simpson, Natl. Bur. Stand. (U.S.), Tech. Note 1023 (Sept. 1980).

A System for Measuring Energy and Peak Power of Low-Level 1.064-μm Laser Pulses, A. A. Sanders and A. L. Rasmussen, Natl. Bur. Stand. (U.S.), Tech. Note 1058 (Oct. 1982).

Training Programs

None.

Future Directions

Expand the C series calibration system to include laser power measurements at several wavelengths in the range 0.8 to 0.9 μm and at 1.3 μm and the K series MAP program to include laser power measurements up to 300 watts.

Contact Person at NBS

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NOISE TEMPERATURE MEASUREMENTS (4.6)

Description of Services

Calibration or special test services for the measurement of noise sources (generators) are offered in limited frequency coverage from 30 MHz to 94 GHz; the type of service offered being determined by the frequency. In some frequency regions only spot frequency measurements are available while in others measurements are available over a band. 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 waveguide flanges are required. Complete operating instructions and special electronic connectors should be supplied, and pertinent operating conditions (voltages, circuits, etc.) specified for the noise source to be measured. The limits of uncertainty vary with noise temperature, reflection coefficient, and source and connector stability, but typically lie between 1% and 3% of the noise temperature.

Documentation

Noise Standards, Measurements, and Receiver Noise Definitions, C. K. S. Miller, W. C. Daywitt, and M. G. Arthur, IEEE Proc., 55, No. 6, 865-877 (June 1967). (This reference describes noise standards, basic principles of noise measurements, and concepts of noise factor and noise temperature.)

Measurement of Effective Temperature in Microwave Noise Sources, J. S. Wells, W. C. Daywitt, and C. K. S. Miller, IEEE Trans. Instrum. Meas., IX-13, No. 1, 17-28 (Mar. 1964). (This reference describes the method of measurement and error analysis.)

Precision Measurement of Antenna System Noise Using Radio Stars, D. F. Wait, IEEE Trans. on I&M, IM-32, No. 1 (Mar. 1983).

Training Programs

Noise measurement seminars are held on an irregular basis on the basis of perceived need. For example, the most recent seminar held in Boulder, CO, provided both theoretical and practical instruction on precision noise measurements, including topics such as reference noise sources; noise measuring systems; characterizing and measuring noise in passive components, amplifiers, and satellite earth terminals; noise concepts and measures, such as noise power, noise equivalent flux, and the ratio of system gain to system noise temperature G/T.

Future Directions

Plans call for the development and provision of noise temperature measurement services for new frequency ranges to follow the needs of the communication and other relevant industries, and of defense requirements. The NBS automated radiometer, a form of total-power radiometer requiring noise sources at two reference temperatures, will serve as the basis for a considerable portion of the planned extensions in frequency coverage.

Contact Person at NBS

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PHASE SHIFT (4.7)

Description of Services

Specific phase shift services listed below 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. Often a measurement technique can be suggested that will permit the customer to perform calibrations in-house with appropriate reference to other NBS-supported standards so that consultation by telephone is recommended as an initial action.

(a) Coaxial Devices

Fixed and variable coaxial two ports are measured on the NBS modified Automatic Network Analyzer (ANA) over the frequency range 0.1 to 18 GHz. In addition, measurements can be performed with reference to a precision variable air line at 30 MHz. Items to be calibrated must be fitted with connectors having a known plane of reference such as the sexless precision connectors, or Type N connectors meeting Mil C 39012. The phase angle measured is $\psi + 360\ n$, where n is the integer. The value of n is not determined.

Limits of uncertainty are

30 MHz	0 - 360°	0.1 - 0.5°
0.1 - 18 GHz	0 - 360°	0.5°

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

(b) Waveguide Devices

In a rectangular waveguide the measurement services are limited to phase shift difference at frequencies below 18 GHz. Measurements are made on continuously variable waveguide phase shifters with the zero value of the scale as the normal reference position. Since 360 mechanical degrees of rotation represent 720 electrical degrees, attention should be given to the relationship between dial indication and actual mechanical position of the rotating vane assembly. The uncertainty is approximately the same as for coaxial devices.

(c) Baseband Pulse Parameters

NBS offers special test services for several baseband pulse parameters. These are broken down into four categories: impulse generator spectrum amplitude, fast repetitive baseband pulse parameters, network impulse response, and pulse time delay.

The following list indicates the limitations of the service for measuring the broadband spectrum amplitude output from impulse generators:

Parameter	Limits
Frequency range	5 MHz to 6 GHz
Frequency spacing	Δf = 5,10,20,50, or 100 MHz
Maximum impulse amplitude without attenuators	± 400 mV
Maximum impulse amplitude with external attenuators	± 1.2 mV
Spectrum amplitude	-15 dBμV/MHz $<[S(f)-S_o]>$ + 5 dBμV/MHz
Load impedance	50.0 Ω
Trigger pulse magnitude	$>$ 200 mV
Trigger pulse transition time	$<$ 5 ns
Trigger to impulse delay	$75\ \text{ns}<t_t<100\ \text{ns}$
Trigger to impulse jitter	$<$ 20 ps

The measurement capabilities for fast repetitive baseband pulses include pulse amplitude (± 500 mV), pulse rise time and fall time (10 ps to 1 μs), and pulse duration (10 ps to 1 μs). The customer's device must generate a repetitive pulse with repetition rate between 100 Hz and 1 GHz.

Network impulse response measurements on coaxial networks, using pulse techniques, provide data over a 100 kHz to 12.5 GHz frequency range, and 0 to 40 dB loss or gain range. A wide variety of connectors can be accommodated. The approximate limits of uncertainty are ± 2% for all parameters.

NBS offers a special test for pulse time delay from 200 ps 1 μs. Customer's device must utilize precision coaxial connectors for both delay ports and, if possible, a driving pulse generator should be provided.

Documentation

Evaluation of a Microwave Phase Measurement System, D. A. Ellerbruch, J. Res. Natl. Bur. Stand. (U.S.), 69C (Eng. and Inst.), 1, 55-65 (Jan.-Mar. 1965).

Impulse Generator Spectrum Amplitude Measurement Techniques, J. R. Andrews, IEEE Trans. Instrum. Meas., 25, No. 4, 280 (Dec. 1976).

Spectrum Amplitude Definition, Generation, and Measurement, J. R. Andrews and M. G. Arthur, Natl. Bur. Stand. (U.S.), Tech. Note 699 (Oct. 1977).

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IEEE Standard Pulse Terms and Definitions, IEEE Std. 194-1977, and IEEE Standard on Pulse Measurement and Analysis by Objective Techniques, IEEE Std. 181-1977, IEEE, New York (July 1977).

Time Domain Automatic Network Analyzer for Measurement of RF and Microwave Components, W. L. Gans and J. R. Andrews, Natl. Bur. Stand. (U.S.), Tech. Note 672 (Sept. 1975).

Present Capabilities of the NBS Automatic Pulse Measurement System, W. L. Gans, IEEE Trans. Instrum. Meas., IM-25, 384-388 (Dec. 1976).

Pulsed Wavemeter Timing Reference for Sampling Oscilloscope Calibration, J. R. Andrews and W. L. Gans, IEEE Trans. Instrum. Meas., IM-24, 82 (Mar. 1975).

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Deconvolution of Time Domain Waveforms in the Presence of Noise, N. S. Nahman and M. E. Guillaume, Natl. Bur. Stand. (U.S.), Tech. Note 1047 (Oct. 1981).

The Measurement and Deconvolution of Time Jitter in Equivalent-Time Waveform Samplers, W. L. Gans, IEEE Trans. Inst. Meas., IM-32, No. 1, 126-133, (Mar. 1933).

Training Programs

No formal training activities are scheduled at present. Seminars such as the Seminar on Waveform Recorder Measurement Needs and Techniques for Evaluation/Calibration (Boulder, CO 1981) will be held as appropriate.

Future Directions

Plans call for measurement methods to continue to be developed in response to demonstrated needs of industrial and other clientele. Potentially relevant technological developments, such as the use of subpicosecond optical pulses and the electrooptic effect to sample electrical transients, will be monitored and applied as appropriate to solve pulse measurement problems.

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RADIO AND MICROWAVE WAVE POWER MEASUREMENTS (4.8)

Description of Services

Calibrations of coaxial peak pulse power meters from 0.001 to 5000 W at frequencies between 0.95 and 1.25 GHz are made with pulsed rf waves modulated by a baseband trapezoidal pulse. Limits of other basic parameters of the pulses are as follows:

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

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

Calibration services are also available for thermistor-type bolometer units having a nominal resistance of either 100 or 200 Ω at a bias current between 3.5 and 15 mA and thermoelectric (TE) power sensor-power meter units. Calibrations are performed at a nominal power level of 10 mW. Thermistor-type bolometer units have shown adequate stability over long periods of time (approximately 10 yr.) and warrant long recalibration intervals. Two- or three-year recalibration intervals are recommended once the stability of a bolometer unit has been verified. Thermoelectric power sensor power meter units must be linear witn power level to within 0.02 dB/10 dB on 10 mW range. Only bolometer units designed for low frequency operation will be calibrated below 100 MHz.

Documentation

A Refined X-Band Microwave Microcalorimeter, G. Engen, J. Res. Natl. Bur. Stand. (U.S.), 63C, 77-82 (1959).

WR-15 Microwave Calorimeter and Bolometer Unit, M. Harvey, Natl. Bur. Stand. (U.S.), Tech. Note 618 (May 1972).

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A Transfer Instrument for the Intercomparison of Microwave Power Meters, G. Engen, IRE Trans. Instrum., I9, 202-208 (Sept. 1960).

A Semiautomated Six Port for Measuring Millimeter-Wave Power and Complex Reflection Coefficient, M. Weidman, IEEE-MTT Trans. MTT-25(12) (Dec. 1977).

Performance Characteristics of an Automated Broad-Band Bolometer Unit Calibration System, E. Komarek, IEEE-MTT Trans. MTT-25(12) (Dec. 1977).

Application of an Arbitrary Six-Port Junction to Power Measurement Problems, G. Engen and C. Hoer, IEEE Trans. Instrum. Meas., IM-21, 470-474 (Nov. 1972).

Accurate Microwave High Power Measurements Using a Cascaded Coupler Method, K. E. Bramall, J. Res. Natl. Bur. Stand. (U.S.), 3 & 4, (Eng. and Instr.) 181-186 (July-Dec. 1971).

Bolometric Microwave Power Calibration Techniques at the National Bureau of Standards, R. R. Desch and R. E. Larson, IEEE Trans. Instrum. Meas., IM-12(1) (June 1963).

A Method of Determining the Mismatch Correction in Microwave Power Measurements, G. Engen, IEEE Trans. Instrum. Meas., IM-17(4) (Dec. 1968).

Theory of UHF and Microwave Measurements Using the Power Equation Concept, G. Engen, Natl. Bur. Stand. (U.S.), Tech. Note 637 (April 1973).

Training Programs

None available.

Future Directions

Service for power levels below 10 mW in coaxial and rectangular waveguides of frequencies from 10 MHz to 26.5 GHz will be available by the end of 1985. Extension of dynamic range using 3-port couplers is being investigated.

Contact Person at NBS

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VOLTAGE (4.9)

Description of Services

Calibration services are available for four types of electromagnetic voltage measuring devices: (1) Thermal Voltage Converters (TVCs), (2) Peak-to-Peak Detectors, (3) Voltage Comparators, and (4) rf Micro-potentiometers.

- Thermal Voltage Converters

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

Most converters have rf-dc differences within ± 0.1 percent of zero at 1 MHz and below. All converters having previous calibration history that are submitted for recalibration should be evaluated at 1 MHz and results compared to prior data. If the difference is negligible, no further calibrations are usually necessary below 1 MHz.

Services available for low-frequency TVCs without a built-in "T: connector are:

Frequency (MHz)	rf voltage range (V)	Estimated limits of uncertainty* (±%)
0.03	0.1 to 200	0.05
0.1	0.1 to 200	0.05
0.3	0.1 to 200	0.05
1	0.1 to 200	0.05
3	0.1 to 200	0.1
10	0.1 to 200	0.1
30	0.1 to 200	0.2
100	0.1 to 200	1.0

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

Services available for the high-frequency TVCs with a built-in "T" connector are:

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

Calibrations having ± 1 percent uncertainty are performed only on the new high frequency thermal voltage converters with a "T" connector incorporated in the converter housing. The measurement reference plane is at the Type "N" male output connector.

o Peak-to-Peak Detectors

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. A 50 kHz ac signal is applied instead of dc. The services available are:

Frequency (MHz)	Applied rf voltage for "0" detector output	Estimated limits of uncertainty (%)
0.1, 0.3, 1.0	1.2 V p-p	0.15
3, 10		0.20
30		0.30
50		0.60
100, 200, 300, 400, 500		1.10

o Rf Voltage Comparators

Special tests are performed on rf voltage comparators using TVCs and micropotentiometers from 100 kHz to 1 GHz at voltages ranging from 10 mV to 20 V. Several calibration options are available to the customer. Therefore, consultations by telephone or written correspondence is suggested before the comparator is submitted for calibration.

o Rf Micropotentiometers

Rf 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. As a special service, rf micropotentiometers with output voltages greater than 200 μV can be calibrated from 0.05 to 1000 MHz, with reduced limits of uncertainty varying from ± 0.2 percent to ± 2 percent. This uncertainty is dependent on frequency, output level and the rf-dc difference vs. frequency response.

Rf micropotentiometers having resistive elements greater than 10 mΩ, in combination with thermoelement housings between 5 and 100 mA, usually have rf-dc differences within ± 1 percent of zero at 5 MHz. Since the rf-dc difference approaches zero below 5 MHz, 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.

Documentation

NBS rf Voltage Comparator, L. D. Driver, F. X. Ries, G. Rebuldela, Natl. Bur. Stand. (U.S.), NBSIR 78-871, 12 pages (Dec. 1978).

Thermal Voltage Converters for Accurate Voltage Measurements to 30 Megacycles Per Second, F. L. Hermach and E. S. Williams, Reprint from Communication and Electronics, 6 pages (July 1960).

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, 121-138 (1952).

Accurate Radio Frequency Microvoltages, M. C. Selby, Communication and Electronics, 158-164 (May 1953).

High Frequency Microvolt Measurements, F. X. Ries and G. Rebuldela, ISA Preprint 37.2.63, 5 pages (Sept. 1963).

Training Programs

None.

Future Directions

The feasibility of using six-ports in performing TVCs and rf micropotentiometer calibrations will be investigated.

Contact Person at NBS

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Description of Services

NBS offers several around-the-clock time and frequency dissemination services to the general public. This is accomplished primarily via the radio broadcasts of stations WWV, WWVH, and WWVB and a time code disseminated from the GOES satellite system. WWV's signal is also offered by a telephone service, not toll-free, by dialing (303) 499-7111. A similar service from WWVH is available by dialing (808) 335-4363 in Hawaii.

Broadcasts from WWV and WWVH can be received on conventional shortwave receivers nearly anywhere in the world. Broadcast frequencies include 2.5, 5, 10, and 15 megahertz for both stations and 20 megahertz from WWV only. Accuracies within one millisecond can be obtained from these broadcasts if one corrects for the station's distance from the receiver. These services also provide standard frequencies, a BCD time code, astronomical time corrections, and certain public service announcements for other government agencies. The telephone service offers to individuals without receivers, the capability of obtaining NBS time and audio frequency signals. The caller can receive a time signal accurate to 30 milliseconds or better, about the maximum delay in cross-country telephone lines. WWVB offers a direct path signal of greater accuracy than WWV or WWVH, but a special 60-kilohertz low frequency receiver is required. WWVB's signal is a binary coded system, needing special decoding equipment. These broadcast services are coordinated with similar operations in other countries through active participation in the international CCIR organization.

NBS time and frequency signals covering about 40 percent of the earth have been relayed via geostationary satellite since 1975 in an experimental service. More than 8 years of experience has shown that such a system can offer continuous time and frequency reception that is much more dependable than ground-based AM and FM radio stations, is free from propagation anomalies, and has a better-than-100-microsecond accuracy.

An enhanced level of calibration activity has been encouraged since 1982. Those calibrations which require the special facilities of the National Bureau of Standards and those which require traceability to the national standards are actively welcomed.

Two new time and frequency measurement assurance services were started in 1983. They permit the user to obtain time and frequency traceable to the NBS with greater precision and less work than previously possible. The new services are suitable for users who require time transfer accuracies in the 3 nanosecond to 1 microsecond range or frequency calibration capability in the 1 part in 10^{11} to 1 part in 10^{14} range. However, even applications which do not require this level of precision may take advantage of these services because of their high degree of automation, simplicity of use, and a degree of support from NBS.

Time requirements at the 1 microsecond level and frequency calibration requirements at the part in 10^{11} to part in 10^{12} level can be satisfied using low frequency radio signals from broadcast stations such as WWVB or Loran-C. The NBS service consists of assisting the user to set up a low frequency receiver and data logger system which is the most appropriate for his needs and his location. A typical system would contain a receiver, microcomputer, disc units and printer-plotter. The user's responsibility is to provide dedicated phone line and modem so that his data can be compared with data recorded at NBS, thus providing assurance that the measurements are valid. The user will also receive a bulletin, either by telephone or by mail, which reports the performance of many of the accurate signal sources. To assist the user in getting the most out of this system NBS will provide specific training on the actual equipment involved in its Seminar on Frequency Measurements and Calibrations. This will assist the user in resolving system failures.

The second service, based upon the NBS designed GPS receiver, provides much higher precision time and frequency data and a greater degree of automation. The receiver which is located at the users facility communicates its data automatically to an NBS computer which stores the raw data, determines which data elements are suitable for time transfer calculations and provides an optimally filtered value for the time and frequency of the user's clock with respect to the NBS Atomic Time Scales. The user is given an account on one of the NBS computers through which he may access both the raw data and the results of the NBS analysis. Tests between receivers in California, Colorado, Wyoming, France, Germany, and Spain, have demonstrated an ability to perform time comparisons with a precision of 3 nanoseconds, and frequency comparisons with a precision of 1 part in 10^{14}.

In conjunction with its new time scale algorithms NBS has developed a time and frequency measurement system which is unsurpassed in many of its capabilities. This new system has vastly improved capability of calibrating any clock that might be sent to NBS. The full accuracy of the NBS time scale and primary frequency standard is readily available and measurements are made automatically every two hours on a clock being calibrated. These data are logged in the NBS time scale computer and the standards' characteristics and performance are readily documentable. Similarly, the person for whom the clock is being calibrated can be given an account in one of the NBS computers through which he may access the data in real time. This has proven to be very useful.

Precision oscillator frequency calibrations are available at nominal frequencies of 5.0, 10, 10.23 MHz with reference standard accuracy of the order of 1×10^{-13}. Precision oscillators may be characterized in two ways:

(a) TIME DOMAIN measurements of the stability, $\sigma_y(\tau)$ for signals of the above nominal frequency. When comparing the unknown precision oscillator with the NBS standard the measurement limit is $\sigma_y(\tau) \leq 2 \times 10^{-12}\tau^{-\frac{1}{2}}$ where τ is the sample time of the comparison in seconds. The long-term (1 day and longer) stability of the NBS frequency reference is nominally 1×10^{-14}.

(b) FREQUENCY DOMAIN measurements of phase noise, $S_\phi(f)$ for signals of the above nominal frequency. Hz measurements of the order of -150 db are possible for f = 1 Hz and -175 db for f = 1 kHz.

Documentation

Time and Frequency User's Manual, G. Kamas and S. L. Howe, editors, Natl. Bur. Stand. (U.S.), Spec. Publ. 559 (1979).

A New Frequency Measurement Service Offered by the National Bureau of Standards, G. Kamas and J. L. Jespersen, 37th Annual Frequency Control Symposium, in press.

Training Programs

Two separate frequency measurement seminars are available.

Seminar on Frequency Measurements and Calibrations

This is a new seminar that incorporates new material into the Time and Frequency User's Seminar given in previous years. It is intended for engineers and standards lab technicians involved in making frequency calibrations. The course will be taught at a practical level to satisfy those new in the field as well as more experienced users. Methods taught will use commercially-available equipment.

Topics covered:

- Crystal oscillator calibration
- Applications of frequency counters
- How to choose a frequency calibration source
- Care and use of frequency sources
- Using LORAN-C and WWVB for frequency calibrations
- Time and frequency measurement assurance services at NBS
- Organization of time and frequency in the U.S.
- NBS, USNO, and other publications

Although all of the above subjects will be covered, emphasis will be on making practical frequency calibrations and measurements.

Seminar on Frequency Standards and Clocks

This seminar is intended for program managers, planners, and systems engineers.

Topics covered:

- A history of time scales (background)
- National and international structure of time and frequency (background)
- Concepts, definitions, and measures of short-term frequency stability (theoretical)
- Techniques for measuring short-term frequency stability and noise in oscillators

- Review of performance of commercial frequency standards (what's available, specifications)
- Limitations of present-day atomic frequency standards
- The process of timekeeping (clock modeling)
- Time coordination: methods for comparison of time scales
- Propagation effects on radio transmissions
- Optical techniques and propagation effects

Future Directions

Research activities in the NBS Time and Frequency Division will lead to improved calibration services in the future. For example, through the basic research program on laser cooled mercury ions, NBS scientists hope to develop more stable clocks with a 100-fold improvement in accuracy anticipated.

Based on the experiences gained with the present offerings and from close contact with the NCSL and others, NBS expects to expand its calibration services being offered to the public.

Other publications forthcoming will include articles for the popular electronic trade press describing the new calibration services to both the electronics industry and the communications/TV engineering community.

Contact Person at NBS

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LABORATORY THERMOMETERS (7.1)

Description of Services

This service provides for the calibration of a variety of thermometers covering the range from -196 to +538 °C. The majority of the thermometers calibrated are liquid-in-glass, but other thermometers (thermistors, industrial platinum resistance thermometers, thermocouples) are calibrated as well. A limited number of special tests falling outside the formal structure of all the other temperature calibrations are performed at the request of the customer. The thermometers to be calibrated are placed in a constant temperature bath along with the NBS primary standard - a calibrated platinum resistance thermometer. The primary standard maintains calibrations traceable to the International Practical Temperature Scale (1968) with an accuracy of ≃ 5 mK at the lower range and ≃2 mK at the higher range. The thermometers are provided with a Report of Calibration or Report of Test which gives the calibration of the customer thermometer with comparable accuracy.

TYPE OF THERMOMETER (Total Immersion)	RANGE	UNCERTAINTY
Mercury liquid-in-glass (graduations: 1-2 °C)	0 to 300 °C 300 to 500 °C	±0.2 to ±0.3 °C ±0.5 to ±1.0 °C
Mercury liquid-in-glass (graduations: 0.1 - 0.2 °C)	0 to 100 °C	±0.03 to ±0.05 °C
Organic liquid-in-glass (graduations: 1 °C)	-200 to 0 °C	±0.2 to ±0.5 °C
Thermistor	According to customer request	

Documentation

Liquid-in-Glass Thermometry, Jacquelyn A. Wise, Natl. Bur. Stand. (U.S.), Monogr. 150, 30 pages (Jan. 1976).

Training Programs

Twice a year NBS offers a 5-day Precision Thermometry Seminar in which one day is devoted to liquid-in-glass thermometry. That day includes both lectures and "hands on" laboratory experience.

Future Directions

The demand for liquid-in-glass thermometer calibrations has been holding steady at about 800 calibrations per year. We do not anticipate a significant change in demand here, but we suspect that the demand for other laboratory thermometers (industrial resistance thermometers and thermistors) may increase. Calibration services at present staffing levels can meet these new demands if they amount to less than 50/year. If the demand increases beyond that point NBS may have to consider additional staff or a MAP program. No automation of L-I-G thermometers is contemplated, although automation of the Calibration Report is underway. New documentation is planned that will guide State calibration laboratories in establishing in situ temperature calibration facilities.

Contact Person at NBS

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THERMOCOUPLES AND THERMOCOUPLE MATERIALS (7.2)

Description of Services

Calibration services for all commonly used types of thermocouples are provided by NBS from -196 to +2100 °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 accuracy required. All three methods provide traceability to the IPTS-68. In the first method, thermocouples are calibrated by comparison with a standard thermocouple maintained at NBS. In the second method, thermocouples are calibrated by comparison with a standard platinum resistance thermometer. In the third method, thermocouples are calibrated at three defining temperatures on the IPTS - the freezing points of Zn, Ag, and Au, as well as at 630.74 °C. Below 0 °C the thermocouple calibration is carried out in a cryostat, while 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. An automatic data acquisition system has been developed to record the test data during calibrations performed by the comparison method (the first method described above). The calibration data are processed on a laboratory computer, and calibration tables giving values of the thermocouple emf at one degree intervals are provided for Types B, S, R, and T thermocouples.

THERMOCOUPLE TYPE	RANGE (°C)	UNCERTAINTY
S	0 to 1450 °C	±0.2 °C at freezing points ±0.3 °C (0 to 1100 °C) ±2 °C at 1450 °C
S & R	0 to 1450 °C	±0.5 °C (0 to 1100 °C) ±2 °C at 1450 °C
B	0 to 1750 °C	±0.5 °C (600 to 1100 °C) ±2 °C at 1450 °C ±3 °C at 1750 °C
E	-196 to 538 °C 0 to 1000 °C	±0.1 to ±0.2 °C ±1 °C
J	-196 to 538 °C 0 to 760 °C	±0.1 to ±0.2 °C ±1 °C
K	-196 to 538 °C 0 to 1100 °C	±0.1 to ±0.2 °C ±1 °C
T	-169 to 300 °C 0 to 400 °C	±0.1 to ±0.2 °C ±1 °C

Documentation

Thermocouple Reference Tables Based on the IPTS-68, R. L. Powell, W. J. Hall, C. H. Hyink, Jr., L. L. Sparks, G. W. Burns, M. G. Scroger, and H. H. Plumb, Natl. Bur. Stand. (U.S.), Monogr. 125, 410 pages (1974).

American National Standard, Temperature Measurement Thermocouples, ANSI-MC96.1-1982 (Instrument Society of America, Research Triangle Park, 1982).

ASTM Standard E230-77, Temperature-Electromotive Force (EMF) Tables for Thermocouples, 1983 Annual Book of ASTM Standards, 14.01, 271 (American Society for Testing and Materials, Philadelphia, 1983).

Accurate Thermocouple Thermometry, L. A. Guildner and G. W. Burns, High Temperatures - High Pressures, 11, 173 (1979).

Methods of Testing Thermocouples and Thermocouple Materials, W. F. Roeser and S. T. Lonbarger, Natl. Bur. Stand (U.S.), Circular 590, 13 pages (1958).

ASTM Standard E220-80, Standard Method for Calibration of Thermocouples by Comparison Techniques, 1983 Annual Book of ASTM Standards 14.01, 255 (American Society for Testing and Materials, Philadelphia, 1983).

International Electrotechnical Commission Standard, Thermocouples, Part 1: Reference Tables, IEC Publication 584-1 (Bureau Central de la Commission Electrotechnique Internationale, Geneva, 1977).

Manual on the Use of Thermocouples in Temperature Measurement, ASTM STP 470B, (American Society for Testing and Materials, Philadelphia, 1981).

Training Programs

Twice a year a 5-day Precision Thermometry Seminar is offered in which one day is devoted to thermocouples. Lectures and "hands on" laboratory simulations of calibration are included.

Future Directions

NBS will continue to provide routine calibration services for various types of thermocouples. We will continue to update and expand the present calibration services to meet the needs of our customers. We note that special, non-routine requests for special thermocouple tests, such as emf stability testing of thermocouples and thermocouple devices, have grown during the past two years. We intend to modify existing equipment when practical and develop new techniques as needed in order to satisfy as many future requests of this nature as possible. New documentation is planned which will provide temperature-emf reference tables for Ni-18% Mo/Ni-0.8% Co thermocouples and a description of a calibration method for expendable, immersion thermocouple devices.

Contact Person at NBS

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STANDARD PLATINUM RESISTANCE THERMOMETERS (7.3)

Description of Services

NBS provides calibration services for standard platinum resistance thermometers (SPRTs) from 13.81 to 903 K. Both long-stem and capsule-type SPRTs are calibrated providing direct access to the IPTS-68. Measurement Assurance Programs are provided at two different levels. At the highest level of accuracy, the MAP consists of sending three calibrated SPRTs to the participant's laboratory where they are measured and then returned to the NBS for recalibration. The results are compared and a report to the participant is issued. Where necessary, suggestions for improvements in measurement or documentation are made. The measurements at most of the laboratories agree with NBS to within ±5 mK. In the lower level of accuracy MAP, NBS is conducting an assessment of industrial laboratories at the 0.1 to 0.01 K level through the exchange of SPRTs.

The reproducibility of the calibration measurements of SPRTs is better than ±0.1 mK and the accuracy of overall calibration is ±1 mK. The triple point of water cells used for calibration of SPRTs are reproducible to 50 μK or better while the zinc and tin freezing point cells agree to within ±0.1 mK. The precision of comparison calibration of long-stem type SPRT in terms of the reference standard SPRTs at the oxygen boiling point (-183 °C) is better than ±0.1 mK. The stability of the reference SPRTs in this temperature range is also about ±0.1 mK. The NBS temperature scale in the range 13 to 90 K is based on stable reference standards SPRTs of the capsule type and has a precision of about ±0.1 mK down to about 20 K. Below 20 K, the precision degrades to about ±0.3 K as the SPRTs become less sensitive.

Documentation

Platinum Resistance Thermometry, J. L. Riddle, G. T. Furukawa, and H. H. Plumb, Natl. Bur. Stand. (U.S.), Monogr. 126, (Apr. 1973).

Reproducibility of Some Triple Point of Water Cells, G. T. Furukawa and W. R. Bigge, Temperature, Its Measurement and Control in Science and Industry, Vol. 5 (American Institute of Physics, New York, NY, 1982), 291-297.

Investigation of Freezing Temperatures of National Bureau of Standards Tin Standards, G. T. Furukawa, J. L. Riddle and W. R. Bigge, Vol. 4 of Temperature (Instrument Society of America, Pittsburgh, PA, 1972), Part 1, 247-263.

Comparison of Freezing Temperature of National Bureau of Standards SRM-740 Zinc Standards, G. T. Furukawa and J. L. Riddle, Comité Consultatif de Thermométrie, May 9-11, 1978, Sèvres, France.

The International Practical Temperature Scale of 1968 in the Region 13.81 K to 90.188 K as Maintained at the National Bureau of Standards, G. T. Furukawa, J. R. Riddle, and W. R. Bigge, J. Res. Natl. Bur. Stand. (U.S.), 77A, 309-332 (May-June 1973).

The International Practical Temperature Scale of 1968 in the Region 90.188 K to 903.89 K as Maintained at the National Bureau of Standards, G. T. Furukawa, J. L. Riddle, and W. R. Bigge, J. Res. Natl. Bur. Stand. (U.S.), 80A, 477-504 (May-June 1976).

Standard Reference Materials: Application of Some Metal SRM's as Thermometric Fixed Points, G. T. Furukawa, J. L. Riddle, W. R. Bigge and E. R. Pfeiffer, Natl. Bur. Stand. (U.S.), Spec. Publ. 260-77 (Aug. 1982).

A Measurement Assurance Program - Thermometer Calibration, G. T. Furukawa and W. R. Bigge, in Testing Laboratory Performance, Evaluation and Accreditation, Natl. Bur. Stand. (U.S.), Spec. Publ. 591, 137-145 (Aug. 1980).

Training Programs

Two days of the twice-annual Precision Thermometry Seminar are given to platinum resistance calibration. Instruction is provided on all aspects of this form of thermometry. Laboratory simulation of calibrations is also given.

Future Directions

Plans include the automation of the calibration service and inclusion of some check standards (additional fixed points) in the calibration procedure. Fixed points under examination include Krypton triple point (116 K), Xenon triple point (161 K), Mercury triple point (234 K), Indium freezing point (430 K), and Cadmium freezing point (594 K).

Access to a second temperature scale, the EPT - 76 is now provided by calibration of resistance thermometers from 0.5 to 30 K. The traceability to the scale is $\simeq 1$ mK over this range. The calibration service is fully automated and serves as a model for future automation of the IPTS-68 calibration. An NBS Special Publication describing the NBS EPT-76 and calibration procedure is expected in FY84.

Contact Person at NBS

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Description of Services

These calibration services provide access to the International Practical Temperature Scale of 1968 (IPTS-68) as realized by NBS for the temperature range 800 °C to 4200 °C. High precision monochrometric visual and automatic optical pyrometers are calibrated in the temperature range of 800 °C to 4200 °C. Uncertainties in routine testing vary from ±3° at 1064 °C, to ±8° at 2800 °C, to ±30° at 4200 °C. Ribbon filament lamps are calibrated using the NBS photoelectric pyrometer, and reports of brightness temperature at 655 nm versus direct current are issued. Uncertainties in routine testing vary from ±1.5° at 1064 °C to ±3° at 2300 °C. In FY-83, 15 tests ($20K) were performed.

The radiation thermometry portion of IPTS-68 is defined in terms of a fixed temperature for the freezing point of gold (1064.43 °C) and the Planck equation for the radiation of a blackbody source. In practice, temperature scales are realized by constructing 1) a gold point blackbody and 2) a variable temperature blackbody and then measuring spectral radiance ratio at a red wavelength (approximately 650 nm) in terms of the Planck equation. Gold point blackbodies are reproducible at ±0.02°, but the temperature assignment of the freezing point of gold is uncertain by about ±0.5°. The spectral radiance ratio measurements can be performed with an uncertainty of 0.2-.3%. Higher accuracies than available in the routine tests described above can be provided as spectral tests subject to the IPTS uncertainties noted. Calibrations at wavelengths other than 650 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. Absorbing glass filters used for range changing in optical pyrometers can also be calibrated as special tests.

Documentation

The publications listed below describe the theory and methods of optical pyrometry as well as the instrumentation and procedures NBS uses to provide routine calibrations.

The International Practical Temperature Scale of 1968, Amended Edition of 1975, Metrologia, 12, 7-17 (1976).

High-Accuracy Spectral Radiance Calibration of Tungsten-Strip Lamps, H. J. Kostkowski, D. E. Erminy, and A. T. Hattenburg, Advances in Geophysics, 14, 111-127 (1970).

Theory and Methods of Optical Pyrometry, H. J. Kostkowski and R. D. Lee, Natl. Bur. Stand. (U.S.), Monogr. 41 (Mar. 1962).

The NBS Photoelectric Pyrometer and Its Use in Realizing the International Practical Temperature Scale above 1063 °C, R. D. Lee, Metrologia, 2, No. 4, 150-162 (Oct. 1966).

Vacuum Tungsten Strip Lamps with Improved Stability as Radiance Temperature, T. J. Quinn and R. D. Lee, 5th Symposium on Temperature, 1971, Instrument Soc. Am. 395-411.

Training Programs

At the present time, no training programs are offered by NBS.

Future Directions

Two research projects are currently being pursued in pyrometry. A new, state-of-the-art, photoelectric pyrometer is being constructed. It will incorporate a multi-wavelength capability, redundant components (filters and lamps) for statistical control, on-line computer control and data reduction, built-in linearity checks for IPTS realizations and as a goal, will reduce uncertainties by about a factor of 10. The second project involves the recently invented optical fiber thermometer. This device bridges the ranges covered by contact thermometers (thermocouples and platinum resistance thermometers) and optical pyrometers. Preliminary experiments indicate that the optical fiber thermometer offers precisions of a few hundredths of a degree and thus it holds out the promise of substantially improved temperature measurements in the range 500 °C to 2000 °C. As the results of the pyrometry research program are incorporated in the routine calibration services, appropriate documentation will be prepared.

Contact Person at NBS

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Description of Services

These calibration services, provide basic radiometric and spectroradiometric standards for the national measurement system. Tungsten, ribbon filament lamps (30A/T24/13) are provided as lamp standards of spectral radiance. The lamps are calibrated at 33 wavelengths from 225 to 2400 nm, with a target area 0.6 mm wide by 0.8 mm high. Radiance temperature range from 2675 K at 225 nm to 2495 K at 650 nm to 1650 K at 2400 nm, with corresponding uncertainties ranging from 3% to 1% to .5%. Lamp standards of spectral irradiance are provided in two forms. Tungsten filament, 1000-watt quartz halogen type FEL lamps are calibrated at 26 wavelengths in the range 250 to 1600 nm. At the working distance of 50 cm, the lamps produce 0.2 W/cm^3 at 250 nm, 220 W/cm^3 at 900 nm and 115 W/cm^3 at 1600 nm, corresponding uncertainties range from 2.5% to 1%. Deuterium lamp standards of spectral irradiance are also provided calibrated at 16 wavelengths from 200 to 350 nm. At the working distance of 50 cm, the spectral irradiance produced by the lamp ranges from about 0.5/cm^3 at 200 nm to 0.2 W/cm^3 at 250 to 0.06 W/cm^3 at 350 nm. The deuterium lamps are intended primarily for the spectral region 200 to 250 nm. The approximate uncertainty relative to SI units is 6% at 200 nm and 3% at 250 nm. The approximate 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 to 300 nm each time the deuterium lamp is lighted to take advantage of the accuracy of the relative spectral distribution.

Absolute spectral responsivity calibrations can be obtained by leasing one of the NBS Detector Response Transfer and Intercomparison Packages (DRTIPs). This is a well-characterized radiometer that utilizes a silicon photodiode as the detector element. Its calibration is reported in units of A/W at a number of wavelengths in the 250-1064 nm range. A precision aperture is provided for calibrations in units of A cm^2/W. The duration of the lease is enough to allow for the transfer of the calibration to a laboratory's own in-house standards, and for the performance of specific diagnostic tests to check their capability in spectral response transfer measurements.

Spectroradiometric source calibrations are performed on the Facility for Automatic Spectral Calibrations (FASCAL). This fully automated instrument has the capability of performing spectral radiance measurements from 200 to 2500 nm, radiance temperature from 1050 K to 2800 K, and adjustable spectral bandpass down to 0.1 nm. Spectral irradiance measurement capability from 200 to 1600 nm at flux levels down to 0.1 W/cm^3 is also available in this instrument. For both spectral radiance and spectral 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.

At present the DRTIP calibration is based on electrical substitution radiometry using cw laser lines and several atomic emission lines as the monochromatic radiation sources for the characterization measurements. The absolute spectral response is reported at the 10 nm intervals from 250 to 960 nm, and at two discrete wavelengths outside this range (1014 and 1064 nm). At present the estimated uncertainty ranges from 1 to 6%, depending on the wavelength and the particular radiometers. The radiometers cover a range of detector current from 10^{3} to 10^{6} A (full scale). This corresponds to a radiant power range of about 10^{2} to 10^{5} W. The lowest resolvable power depends on the resolution of the voltmeter used to read the radiometers output (10 = full scale).

Due to the recent development of a simple and accurate technique (the silicon photodiode self-calibration procedure) one can measure directly the photon to electron conversion efficiency of a silicon photodiode. Greater accuracy is possible, but not offered as a routine service. This is because the user can easily repeat the self-calibration procedure in their own laboratory within an uncertainty of ±0.2% (400 to 700 µm) without the necessity of an NBS standard.

Facilities to perform radiometric calibrations in the infrared, 1 to 15 micrometers, are also available. Three facilities are available and their capabilities are summarized below. Infrared radiometry is very demanding and usually involves a substantial R&D component. Therefore such work is performed as special tests and is often very expensive ($10K to $20K).

Facility	1	2	3
Source	Ambient to 77 K, 10^{-4} torr	20 K, 10^{-8} torr	Ambient (dry chamber) to 77 K, 10^{-4} torr
Radiometer environment	Ambient	20 K, 10^{-8} torr	Ambient (dry chamber)
Detector	Thermopile or PbS (77 K)	Absolute	Commercial I.R. radiometer
Spectral range	1 to 15 micrometers	Total	3 to 10 micrometers
Spectral detail	Continuous (0.1 to 1 micrometer resolution)	None (total flux)	Discrete (narrow band filters)
Max. physical size of source	1x1x1 m	10x10x10 cm	20x20x20 cm
Sensitivity	0.01 degrees at 600 K	10^{-9} watts	0.02 degrees at 300 K
Source temperature	350 to 1300 K	150 to 600 K	225 to 450 K

Max. source aperture	About 25 mm	1 mm	about 25 mm
Measurement technique	Comparison to reference blackbodies	Absolute radiant power measurement	Comparison to reference
Goniometry	Yes	No	Yes
Approximate radiometric quantity	Spectral radiance (W m^{-2} sr^{-1} nm^{-2}) (W sr^{-1}) measured	Axial radiant intensity	Spectral radiance (W m^{-1} sr^{-1} nm^{-1})

Documentation

In addition to the documentation listed below, ad hoc write-ups are available from the Radiometric Physics Division of NBS describing the calibration procedure and uncertainty from 1) lamp standards of spectral radiance, 2) type FEL lamp standards of spectral irradiance, and 3) deuterium lamp standards of spectral irradiance.

High-Accuracy Spectral Radiance Calibration of Tungsten-Strip Lamps, H. J. Kostkowski, D. E. Erminy, and A. T. Hattenburg, Advances in Geophysics, 14, 111-127 (1970).

The International Practical Temperature Scale of 1968, Metrologia, 5, 35-44 (1969).

Corrections in Optical Pyrometry and Photometry for the Refractive Index of Air, W. R. Blevin, Metrologia, 8, 146-147 (1972).

The 1973 NBS Scale of Spectral Irradiance, R. D. Saunders and J. B. Shumaker, Natl. Bur. Stand. (U.S.), Tech. Note 594-13 (U.S. Government Printing Office, Washington, DC, 1977).

Spectral Irradiance Standard for the Ultraviolet: The Deuterium Lamp, R. D. Saunders, W. R. Ott, and J. M. Bridges, Appl. Opt., 17, 593-600 (1978).

The NBS Detector Response Transfer and Intercomparison Package: The Instrumentation, M. A. Lind, E. F. Zalewski, and J. B. Fowler, Natl. Bur. Stand. (U.S.), Tech. Note 950 (U.S. Government Printing Office, Washington, DC, 1977).

Proc. of the Electro-Opt. and Laser Conf., M. A. Lind, (Industrial and Scientific Conference Management, Chicago, IL, 1976), p. 55.

Fundamental Principles of Absolute Radiometry and the Philosophy of this NBS Program (1968 to 1971), J. Geist, Natl. Bur. Stand. (U.S.), Tech. Note 594-1 (U.S. Government Printing Office, Washington, DC, 1972).

Spectral Radiometry: A New Approach Based on Electro-Optics, J. Geist, M. A. Lind, A. R. Schaefer, and E. F. Zalewski, Natl. Bur. Stand. (U.S.), Tech. Note 954 (U. S. Government Printing Office, Washington, DC, 1977).

Silicon Photodiode Absolute Spectral Response Self-Calibration, E. F. Zalewski and J. Geist, Appl. Opt., 19, 1214 (1980).

Spectral Response Self-Calibration and Interpolation of Silicon Photodiodes, J. Geist, E. F. Zalewski, and A. R. Schaefer, Appl. Opt. 20, 3795 (1980).

Silicon Photodiode Absolute Spectral Response - Self-Calibration Using a Filtered Tungsten Source, C. G. Hughes, III, Appl. Opt., 21, 2129 (1982).

Silicon Photodiode Device with 100% External Quantum Efficiency, E. F. Zalewski and C. R. Duda, Appl. Opt., 22, 2867 (1983).

Training Program

At the present time, no training programs are offered by NBS.

Future Directions

A program is now well underway to increase the efficiency of realization of the NBS scales of spectral radiance and spectral irradiance. It is envisioned that the techniques used to increase the efficiency of scale realizations will also allow extension of the spectral irradiance scale to 2500 nm.

In the area of detector spectral response, research on the physics of junction photodiodes is directed at extending the present self-calibration procedure into the UV and IR spectral regions. Collaborative efforts with scientists in Australia and at the University of Maryland have led to improved measurements of the quantum yield of silicon in the UV and a better understanding of the physics in this region. In the IR, a collaborative effort with the Purdue University Department of Electrical Engineering holds promise of producing, in the very near future, high quality germanium photodiodes capable of being self-calibrated out to about 1.4 μm.

In the longer wave infrared, a number of research proposals have been prepared to extend the wavelength range, increase the sensitivity of the NBS apparatus, and investigate the sources of systematic error. These proposals have been submitted to other government agencies. Progress is dependent on obtaining such outside support.

Two additional documents are in preparation, one will describe the realization of the NBS scale of spectral radiance and the other will describe the equipment and capabilities of FASCAL.

Contact Person at NBS

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NEAR AND VACUUM ULTRAVIOLET RADIOMETRIC STANDARDS (7.6)

Description of Services

NBS 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 services. The calibrations of these sources are traceable to a hydrogen arc whose radiance is calculable and which NBS maintains as a primary standard. The collection also includes tungsten strip lamps and tungsten halogen lamps whose calibrations are done by another group at NBS and are based on a blackbody rather than our hydrogen arc. Customer supplied sources are calibrated in both radiance and irradiance by comparing them with our 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 and the high wavelength limit the starting point of the range of another calibration group at NBS. 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 NBS arcs partially overlap the range of tungsten lamps, thus providing an independent check on calibrations.

Documentation

VUV Spectral Irradiance Calibrations: Method and Applications, Optics Letters, 5, 225 (1980).

Spectral Irradiance Standard for the Ultraviolet: The Deuterium Lamp, Appl. Opt., 17, 593 (1978).

Spectral Radiance Calibrations Between 165-300 nm: An Interlaboratory Comparison, Appl. Opt., 16, 1788 (1977).

VUV Radiometry. 3: The Argon Mini-Arc as a New Secondary Standard of Spectral Radiance, Appl. Opt., 16, 367 (1977).

NBS UV Radiometric Standards, Natl. Bur. Stand. (U.S.), Spec. Publ. 456, 107 (1976).

Training Programs

No formal training programs are available. However, occasionally users come to NBS with sources for calibration, but are unfamiliar with their sources. NBS has arranged for the user to spend time in the NBS laboratory to become familiar with their sources.

Future Directions

NBS will continue to investigate and develop new types of radiometric sources as well as providing calibrations for sources to be used in space experiments. Work on early models of portable low-powered (15w) re-excited dimer lamps has shown that these lamps make good standards of irradiance but are deficient as standards of radiance. Further work has shown that changes in the lamp design can also produce a satisfactory radiance standard. Lamps of advanced design incorporating NBS recommendations have been produced, and NBS calibrated one of them for use on the FOS (faint object spectrograph) space shuttle experiment.

Another radiometric source NBS has been investigating and will continue is an irradiance source of highly pure Lyman-α radiation which does not utilize a monochromator. A preliminary report on this source was presented at the October 1982 annual meeting of the Optical Society of America and a detailed manuscript is being prepared for publication.

NBS is presently involved in selecting and calibrating a deuterium lamp to be flown on the SUSIM (solar ultraviolet spectral irradiance monitor) space shuttle experiment as an in-flight calibration source.

Investigations are underway on a new source to provide radiometric calibrations in the 20 nm-200 nm range. This source is a pulsed plasma created by a focused laser beam striking a heavy metal target. A target chamber is in operation, and initial measurements have been made with a grazing incidence spectrograph.

Contact Person at NBS

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PHOTOMETRIC STANDARDS (7.7)

Description of Services

Calibration services in this area provide access to the photometric scales realized and maintained at NBS. Lamp standards of luminous intensity, luminous flux, and color temperature as described below are issued on a routine basis.

(a) Luminous intensity standards.

100-W (90-140 cd), 500-W (approximately 700 cd) and 1000-W (approximately 1400 cd) tungsten filament lamps with C-13B filaments in inside-frosted bulbs and medium bipost bases are supplied by NBS calibrated at either a set current or a specified color temperature in the range 2700-3000 K. Approximate uncertainties are 2 percent relative to the SI unit of luminous intensity and 1.5 percent relative to NBS standards.

(b) Luminous flux standards (geometrically total).

25-W vacuum tungsten lamps and 60-, 100-, 200-, and 500-W gas filled tungsten lamps submitted by customers are calibrated. Lamps must be base-up burning and rated at 120 V. Approximate uncertainties are 2.5 percent relative to SI units and 1.5 percent relative to NBS standards.

Luminous flux standards for miniature lamps producing 6-400 lm are calibrated with uncertainties of 3 percent.

(c) Color temperature standards.

Airway beacon 500 W medium bipost lamps are calibrated for color temperature in the range 2000-3000 K with an uncertainty of 10 degrees.

Documentation

Photometric Calibration Procedures, V. I. Burns and D. A. McSparron, Natl. Bur. Stand. (U.S.), Tech. Note 594-3 (U.S. Government Printing Office, Washington, DC, Nov. 1972).

Training Programs

At the present time, no training programs are offered by NBS.

Future Directions

In October 1979, an international redefinition of the photometric unit system was adopted. The new definition replaced the previous platinum point blackbody definition with a defined coupling constant to the radiometric watt. This allows a variety of technically competitive approaches to the realization of photometric scales. At present the NBS photometric scales are based on the NBS scale of spectral irradiance. Present photometric research centers on utilizing silicon self-calibration techniques and filter radiometry realize photometric scales. Future work will include an investigation of the possibility of replacing some of the present lamp standards with photopically corrected silicon cells and the radiometric characterization of new, spectrally-rich lamps.

Contact Person at NBS:

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SPECTROPHOTOMETRIC STANDARDS (7.8)

Description of Services

NBS provides standards of spectral transmittance for checking the photometric scale of spectrophotometers. These are either 30 mm polished glass disks or 51 mm polished glass squares, 2 to 3 mm thick, designated as cobalt blue, copper green, carbon yellow, and selenium orange (disks will be supplied unless otherwise specified). Information provided to user includes: (1) values of transmittance at 25 °C at certain wavelengths from 390 to 750 nm, (2) the estimated uncertainty of each value, and (3) the effect of temperature change on transmittance at each wavelength. Holmium oxide glass standards are available for checking the ultraviolet and visible wavelength calibrations of recording spectrophotometers having a bandpass less than 2 nm. These are made of polished Corning 3130 glass, 51 x 51 mm, 2.5 mm thick. A table of wavelengths of minimum transmittance is provided in the report to the user.

Measurements of spectral transmittance can be made for the wavelength region 0.19 to 2.5 µm. Measurements of absolute spectral reflectance factors, and spectral specular reflectance, can be made for the wavelength region 0.25 to 2.5 µm. However, arrangements for these measurements on submitted specimens must be made before shipment of specimens. The decision to perform the measurements and the instruments to be used will rest with NBS and refusal may be made after inspection of the specimens. Specimens not accepted for measurement will be returned. Accuracy and precision estimates will be given, dependent upon the optical characteristics of the submitted specimens.

Calibrated standards of didymium glass, for checking the wavelength scale of spectrophotometers from 400 to 750 nm, are available as SRMs 2009, 2010, 2013, and 2014.

Calibrated standards for diffuse spectra reflectance are available as SRMs 2015-16 (400-750 nm) and SRMs 2019-22 (250-2500 nm).

Calibrated standards for specular reflectance are available as SRMs 2003a (first surface mirror, 250-2500 nm) and SRMs 2023-25 (second surface mirror, 250-2500 nm).

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Training Programs

At the present time, no training programs are offered by NBS.

Future Directions

Studies and pilot runs on the Measurement Assurance Program (MAP) transport standards for retroreflection, transmission, and diffuse reflection have been completed. Plans are underway to establish MAP services.

A long wavelength infrared spectrophotometry project has been started to establish IR measurement capabilities from 2.5 to 25 μm on transmittance, diffuse reflectance and specular reflectance.

A new effort in fluorescence was initiated to establish measurement capability and issue standards in this area.

Research efforts to develop high optical density standards (up to optical density of 5.8) and to base calibration of master standards on the Inverse Fourth Apparatus (see above reference) is continuing.

<u>Contact Person at NBS</u>

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PRESSURE AND VACUUM MEASUREMENTS (7.9)

Description of Services

The NBS provides measurement services for the calibration of piston gages and transducers operating with gas in the range of 1.4 kPa to 4.2 MPa and with oil in the range of 700 kPa to 700 MPa. Calibrations are done by the cross-floating technique using NBS piston gages.

Type of Instrument	Range	Uncertainty
Gas-operated PG	1.4 kPa to 4 MPa	±50 ppm
Oil-operated PG	700 kPa to 280 MPa	±60 ppm
Oil-operated PG	40 to 400 MPa	±100 ppm
Oil-operated PG	70 to 700 MPa	±200 ppm

Service for the calibration of pressure and vacuum gages, includes capacitance-diaphragm gages, ball gages, and ionization gages ranging from 100 μPa to 0.1 MPa. Spinning rotor gages will also be accepted for special tests in this same range. In the range 1 Pa to 0.1 MPa the NBS Ultrasonic Interferometer Manometer is the standard against which other gages are calibrated. Its stability is 10^{-2} Pa plus 2 ppm of the reading, and its inaccuracy is presently limited to 100 ppm by the uncertainty in the speed of sound in the mercury used in the manometer. In the range of 100 μPa to 10^{-2} Pa an NBS facility using a known flow rate through a calculated conductance defines the pressure with an inaccuracy of 1%.

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Training Programs

Twice per year NBS offers a 2-day Precision Pressure Seminar on the operation and calibration of piston gages. An initial training course on spinning rotor gages and ion gage calibration will be held in the spring of 1984. As the calibration experience with these gages expands and their limits and potential are better understood, the extent of such courses will be expanded.

Future Directions

NBS is agressively assessing the accuracy of all piston gage calibrations with the view of reducing the inaccuracy and documenting it. This will take 3 years to complete the whole range. In FY 85 we expect to reduce the uncertainty in the gas-operated piston gage calibration service in the range below 4 MPa and to complete the documentation of such. In subsequent years we expect to reduce the uncertainty at higher pressures by the development and careful characterization of new primary pressure standards. Included in this program is the extension of the range of the gas calibration service at 25 MPa.

There is presently a gap in the calibration service between 10^{-2} to 1 Pa which will ultimately be closed by an oil interference manometer and a modified flow apparatus. An effort is currently underway to decrease the low pressure limit with a goal of reaching at least 10^{-7} Pa. Leak calibration facilities are also being developed that will range between 10^{-5} and 10^{-9} Pa m^3/sec or lower. New documentation is planned that will describe the results obtained in calibrating a conventional thiode-ionization gage, a high vacuum standard, and the update of the ultrasonic interference monometer.

Contact Person at NBS

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Description of Services

The NBS provides calibration services for natural standard neutron sources and neutron measuring devices, i.e., dosimeters and activation foils.

Neutron sources in the range from 5.0 x 10^5 to 5.0 x 10^9 neutrons/second may be calibrated to an accuracy of about ± 1.2% (one sigma) depending upon the amount and knowledge of construction of their encapsulations. Emission rates (neutrons/second) of neutron sources of unknown source strength are determined by the manganous Sulfate Bath Method. The neutron sources are calibrated by comparing their strengths to that of the NBS primary standard source, a Ra-Be photoneutron source known as NBS-1. The comparison of the source strengths is made by activating a manganese sulfate bath solution and continuously counting the induced, saturated manganese-56 radioactivity with a scintillation counter. The present emission rate of NBS-1, which is absolutely determined, is 1.246E+06 neutrons/second with an assigned uncertainty of ± 0.9% (one sigma).

A wide variety of neutron radiation detection instrumentation exists for the protection of personnel. NBS maintains a relatively wide variety of neutron fields for both research and calibration in the area of personnel dosimetry.

A thermal neutron beam is available at the thermal column of the NBS Research Reactor (NBSR) which can provide dose equivalent rates up to approximately 1 rem/hour over a 30 cm diameter circle.

Three monoenergetic epithermal neutron beams are available at the NBSR to determine neutron response as a function of energy:

2 KeV beam	Dose Equiv. = 4 mrem/hour
24 KeV beam	Dose Equiv. = 8 mrem/hour
144 KeV beam	Dose Equiv. = 70 mrem/hour

These epithermal neutron beams give primarily neutron doses with the gamma contributions being approximately 2 to 4%.

The neutron spectrum for a deuterium moderated Cf-252 is also available for calibration of personnel dosimetry instruments and the spectrum is very similar to that found inside containment of nuclear reactors. Available rates are 1.1 x 10^5 n/cm^2·s) or equivalently 3.0 rem/hour. Additionally, a pure Df 252 fission neutron spectrum is available with rates of 1.3 x 10^4 n/cm^2·s) or equivalently 1.6 rem/hour.

Materials dosimetry, such as that accomplished for surveillance of fast neutron fluence seen by the pressure vessel in an operating nuclear power plan, depends upon correct assay of the amount of isotopic radioactivity induced in radiometric dosimeters, such as foils or wires. NBS maintains Standard Fission Neutron Fields to supply calibration irradiations and Certified Fluence Standards. The NBS Cf-252 Fission Neutron Source (typical maximum fluence 1.0 x 10^{13} neutrons/cm^2 in 24 hours) and the U-235 Cavity Fission Neutron Source (typical maximum fluence 2.0 x 10^{15} neutrons/cm^2 in 24 hours) provide standard neutron field spectra. Known fluences are based upon known source strengths for the californium sources.

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Training Programs

None.

Future Directions

In the area of neutron source strength, measurement efforts will focus on two major areas:

(1) Improve Accuracy: Work on factors which dominate present accuracy limits. These are the uncertainty of 0.9% on the absolute calibration of NBS-1 and uncertainties involved with comparing the strength of sources whose emission rates differ by the factor of 5000.

(2) Facilities Upgrade: Improve performance of electronic and mechanical equipment. Emphasis is on improved Health Physics procedures to include new shielding and remote handling necessitated by increased requests for calibrations of sources in the higher ranges and automation of data acquisition and analysis.

In the area of neutron dosimetry calibrations and standards, plans are being made to:

(1) Develop and distribute selected isotopic dosimetry reactions as SRM certified fluence standards.

(2) Irradiate user's dosimetry foils to produce either certified fluence or certified-fission standards.

(3) Perform high accuracy (± 1% to ± 3%) integral cross section measurements of select dosimetry reactions in one or all of the NBS standard fields.

(4) Perform spectrometer calibrations in Cf-252 fields.

In the area of neutron source measurements, the most substantive documentation is over 15 years old and should be critically reviewed in light of more recent and precise measurements. For example, the consistency of NBS-1 absolute source strength with Cf-252 ν measurements could be studied or a reanalysis made of the uncertainty in the NBS-1 source strength. Plans are underway to prepare NBS reports on manganous sulfate bath facility and equipment for neutron source comparisons and on NBS-1 absolute source strength. Planned documentation in the personnel dosimetry area include "Procedures for Calibrating Neutron Personnel Dosimeters" and "Experimental Verification of the Neutron Spectrum for the NBS D_2 Moderated ^{252}Cf Sources." In the area of dosimetry calibrations and standards, a review paper on the state of development of thermal and fission neutron standard fields at NBS is planned.

Contact Person at NBS

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RADIOACTIVITY CALIBRATIONS (8.2)

Description of Calibration Services

Radioactivity calibration services are available from NBS as one part of a total program effort to disseminate accurate radionuclide activity and emission rate calibrations. In general, it is more efficient to produce a batch of standards - sometimes Standard Reference Materials (SRMs) - and encourage/recommend the measurement community to utilize them as part of a calibration program rather than measure individual samples submitted for calibration.

Radioactivity calibration services for some fifty radionuclides are available, including alpha-particle solid sources, beta-particle solutions and gamma-ray solutions. In addition, some sources may be calibrated under special arrangements on an "at cost" basis. In order to offer such a broad range of services, NBS must place stringent limitations on the physical and chemical form and activity range of sources which can be accepted. To ensure that these specifications are understood it is essential that there be good communication between the technical personnel at the user facility and those at NBS. A list of contacts at NBS for five different types of calibrations are provided at the end of this section. When planning to have a source calibrated, the user should discuss the following points with the contact at NBS:

- Type of calibration and units used for reporting results

  Often, more than one type of calibration is available for a given source. Units to be used in reporting the result and some estimate of the total uncertainty in the calibration should also be discussed.

- Source preparation, packaging, and shipment

  Two general requirements apply to all sources submitted for calibration: (1) All shipments must conform to applicable NRC and DOT regulations for packaging and transport, and (2) source description, including approximate activity, must be provided in advance. The NBS Health Physics Section must approve in advance all proposed calibrations, and sources may be refused if the necessary information is not available.

- Reports of calibration

  A typical NBS Report of Calibration is sent on completion of a radioactivity calibration service. If the user has particular requirements for documentation of the calibration, these should be discussed with the contact at NBS before the services are performed.

Alpha-particle sources may be calibrated using the NBS 2 $\pi\alpha$ proportional counter 0.8 $\pi\alpha$ defined-solid-angle counter. The former calibration is in terms of alpha-particle-emission rate into 2 π

steradians, while the latter is in terms of total activity. Thin alpha-particle sources less than 10 cm in diameter and with activities from 40 pCi to 300 nCi can be calibrated as to emission rate into the forward hemisphere with an uncertainty of about 1.5 percent. Similar sources less than 1.6 cm diameter with activities between 5 nCi and 300 nCi can be calibrated for activity with an uncertainty of about 1.0 percent.

Solutions of eight radionuclides emitting only beta particles, with activity concentrations of from 0.5 to 50 μCi/ml, can be measured with an uncertainty 1.5 to 3.0 percent. However, the infrequent demand for this service suggests that it be removed from the scheduled service.

Solutions of 26 radionuclides with half-lives greater than 15 days and 13 with half-lives less than 15 days can be measured in properly filled NBS ampoules with the calibrated NBS "4 π" gamma-ray ionization chambers. Uncertainties vary from 0.8 to 3.4 percent; activity limits are between 10 and 1500 μCi, depending on the radionuclide.

Sources which do not meet the specifications for the NBS scheduled calibrations may be calibrated on an "at cost" basis. In such instances a complete description of the source and the nature of the calibration must first be provided in writing to NBS. Such services are usually expensive because custom preparations and calibrations require additional labor for experimental design and measurements, and these expenses must be recovered. Often, it is more economical to have a commercial laboratory prepare a source which meets the specifications for a scheduled calibration, and have the source forwarded to NBS.

Calibration and measurement services can be provided for appropriate gaseous samples of tritium and carbon-14 as well as a number of gamma-ray-emitting noble-gas radionuclides. The preferred sample containers for the assay of gamma-ray emitters are 5 cm^3 ampoule or a flame-sealed 32.5 cm^3 sphere. It is desirable to have the material cryogenically transferred into the sphere, followed by flame sealing. If this is not possible, a "flow-through" container can be used. The activity level and the composition and pressure of the carrier gases are important considerations which should be discussed with the technical contact at NBS. Gamma-ray point sources (less than 1 cm diameter) and solution sources containing gamma-ray-emitting radionuclides may be assayed with calibrated Ge(Li) spectrometers.

Documentation

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Training Programs

There are currently no formalized training programs for radioactivity calibrations. However, the agencies who control the use of radionuclides in the U.S. have encouraged many suppliers of commercial standards and radiopharmaceuticals to utilize NBS calibration services as well as participate in unscheduled measurement tests. The regulatory agencies themselves are involved in measurement checks through interagency agreements with NBS. The calibration services and unscheduled tests provide one mechanism for traceability exercises which have evolved over the past decade for radioactivity measurements. With minimal NBS or other laboratory expense, a continuing check of the quality of measurements for a variety of radionuclides is possible.

Future Directions

"A Handbook of Radioactivity Measurements Procedures" is now being revised for republication as Report No. 58 of the National Council on Radiation Protection and Measurements. Valuable suggestions and data for all types of radioactivity measurements will be included. Special seminars on topics such as low-level-radioactivity or nuclear medicine measurements are being planned with the cooperation of national or international organizations. With the encouragement of the regulatory agencies, specific traceability requirements for commercial radioactivity standards are being developed.

Contact Persons at NBS

Service	NBS Contact	
General information	D. D. Hoppes Nuclear Radiation Division	301-921-2668
Alpha-particle solid sources	P. A. Mullen	301-921-2383
Beta-particle-emitting radionuclides in solution	B. M. Coursey	301-921-2383
Gamma-ray-emitting radionuclides in solution by "4π"γ ionization chamber	J. M. Calhoun	301-921-2383
Calibration of gaseous radionuclides	F. J. Schima M. P. Unterweger	301-921-2396
Calibration of gamma-ray-emitting radionuclides by gamma-ray spectrometry	A. T. Hirshfeld	301-921-2652

X-RAY AND GAMMA-RAY MEASURING INSTRUMENTS (8.3)

Description of Services

The NBS provides calibration services for x-ray and gamma-ray measuring instruments, passive dosimeters and x-ray penetrameters. X-ray calibration and irradiation is provided in 32 beam qualities, varying from 10 kV to 300 kV constant generating potential, with half-value layers from 0.03 mm Al to 23 mm Al $\approx$ 6 mm Cu. Gamma-ray calibration and irradiation is provided using cobalt-60 and cesium-137 beams. Calibration and irradiation can be provided at exposure rates appropriate to either radiation-protection or radiation-therapy applications.

X-ray measuring instruments are calibrated in terms of exposure in an x-ray beam at a point where the exposure rate has been determined by means of a standard free-air ionization chamber. In order to provide instrument calibrations over a wider range of x-ray energies, many combinations of generating potential and filtration are available.

Gamma-ray measuring instruments are calibrated in terms of exposure or absorbed dose at points in the collimated cobalt-60 and cesium-137 gamma-ray beams that have been standardized by means of graphite cavity chambers or a graphite calorimeter. Exposure rates and absorbed dose rates at the time of calibration are computed from the original beam standardization data and appropriate decay corrections.

Irradiation of passive dosimeters, for readout by the customer, are generally in terms of exposure; for passive dosimeters suitable for insertion in a phantom, irradiation in terms of absorbed dose can be provided by in-phantom irradiation using cobalt-60 gamma rays.

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

Documentation

Exposure Spectra from the NBS Vertical-Beam ^{60}Co Gamma-Ray Source, M. Ehrlich and C. G. Soares, Natl. Bur. Stand. (U.S.), NBSIR 76-1117 (1976).

Spectrometry of a ^{60}Co Gamma-Ray Beam Used for Instrument Calibration, M. Ehrlich, S. M. Seltzer, M. J. Bielefeld, and J. I. Trombka, Metrologia, 12, 169 (1976).

The Graphite Calorimeter as a Standard of Absorbed Dose for Cobalt-60 Gamma Radiation, J. S. Pruitt, S. R. Domen, and R. Loevinger, J. Res. Natl. Bur. Stand. (U.S.), 86, No. 5, 495-502 (1981).

The Photon-Fluence Scaling Theorem for Compton-Scattered Radiation, J. S. Pruitt and R. Loevinger, Medical Physics, 9, No. 2 (Mar.-Apr. 1982).

Uncertainty in the Delivery of Absorbed Dose, R. Loevinger and T. P. Loftus, Ionizing Radiation Metrology, International Course at Varenna, Italy, 1974, E. Casnati, ed., G-6, 459-473. Editrice Compositori, Bologna, 1977.

Medical Dosimetry Standards Program of the National Bureau of Standards, R. Loevinger. Proceedings of a Symposium on National and International Standardization in Radiation Dosimetry, Atlanta, GA, Dec. 5-9, 1977 (International Atomic Energy Agency, Vienna, 1978). (This article provides references for either publications on NBS exposure and absorbed-dose standards.)

<u>Training Programs</u>

None.

<u>Future Directions</u>

Efforts will focus on providing calibration and irradiation services in terms of water absorbed dose for gamma-ray beams of cobalt-60 and cesium-137.

<u>Contact Person at NBS</u>

Robert Loevinger
Radiation Physics Division
301-921-2364

Description of Services

Calibration services are provided for gamma-ray and beta-particle sources submitted to NBS subject to specified conditions. A summary of those conditions are listed below:

(a) Financial responsibility: Except for negligence by NBS personnel, NBS assumes no responsibility for loss or damage to the sources while in its possession.

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

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

(d) Packaging for shipment: Packages must be in compliance with the regulations of the Department of Transportation as detailed in CFR Title 49 and the regulations of the Nuclear Regulatory Commission as detailed in CFR, Title 10, Part 71. Copies of the Codes are available at the Government Printing Office, Washington, DC 20402.

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

(e) 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 including radium. In the case of other individuals, NRC regulations are applicable (radium is not licensed by the NRC). This certification may be by letter, by a suitable statement on the purchase order covering the calibration fee, or by a clear copy of the submitter's Possession License for the source.

Gamma-ray sources of cobalt-60, cesium-137, iridium-192, and iodine-125 are calibrated in terms of exposure rate at 1 m. Radium is calibrated in terms of mass of equivalent radium content measured relative to the National Radium Standard through comparison of the gamma radiation from the specimen and the standard. Calibration in terms of absorbed dose rate is provided for suitable encapsulated beta-particle sources; the dose rate to a low-atomic-number material (plastic) is determined by measurement with an extrapolation chamber.

Documentation

Medical Dosimetry Standards Program of the National Bureau of Standards, R. Loevinger. Proceedings of a Symposium on National and International Standardization in Radiation Dosimetry, Atlanta, GA, Dec. 5-9, 1977 (International Atomic Energy Agency, Vienna, 1978). (This article provides references for earlier publications on NBS exposure and absorbed-dose standards.)

Standardization of Iridium-192 Gamma-Ray Sources in Terms of Exposure, T. P. Loftus, J. Res. Natl. Bur. Stand. (U.S.), 85, No. 1, 19-25 (1980).

Training Programs

None.

Future Directions

Plans are to maintain state-of-the-art measurement capability to provide calibration services for gamma-ray and beta-particle sources.

Contact Person at NBS

Robert Loevinger
Radiation Physics Division
301-921-2364

DOSIMETRY OF HIGH-ENERGY ELECTRON BEAMS (8.5)

Description of Services

NBS provides dosimeters twice a year to users requesting assistance with absorbed-dose measurements in high-energy electron beams. The dosimeters consist of ferrous sulfate (Fricke) solution in radiation-resistant silica-glass spectrophotometer cells. The user irradiates all but one of the three furnished dosimeters to an absorbed dose between 50 and 80 Gy (5000 and 8000 rad) at electron energies between 5 and 50 MeV. After irradiation, the dosimeters are returned to NBS for spectrophotometric evaluation of the ferric-ion concentration in terms of absorbed dose in the phantom.

As a special service and by special arrangements, NBS provides calibration services for ionization chambers. An ionization chamber and electrometer combination, with the electrometer marked in terms of exposure or absorbed dose, is calibrated by providing a dimensionless correction factor for the electrometer scale. An ionization chamber submitted without an electrometer is calibrated in terms of exposure or absorbed dose per unit charge. Ionization chambers are tested, prior to calibration, for leakage, radiation-induced leakage, stabilization time, short-term stability, recombination loss, connection to the atmosphere, and guard-electrode insulation (if applicable). Chambers found unsuitable for calibration are returned with a statement of the reason for rejection.

Documentation

Uniformity of High-Energy Electron-Beam Calibrations, M. Ehrlich and P. J. Lamperti, Phys. Med. Biol. 14, 305-314 (1969).

Training Programs

None.

Future Directions

It is expected that additional facilities will be available to provide calibrations in electron and photon beams at energies up to 30 MeV.

Contact Person at NBS

Robert Loevinger
Radiation Physics Division
301-921-2364

DOSIMETRY FOR HIGH-DOSE APPLICATIONS (8.6)

Description of Services

NBS provides a variety of dosimeter calibration services to industrial radiation users of intense radiation fields, in particular, large gamma-ray sources and electron accelerators up to approximately 4 MeV. The services include the administering of known absorbed doses of ionized photons to customer-supplied dosimeters, supplying calibrated secondary-standard transfer 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, and measurement of detailed dose distributions in specific irradiation geometries and in selected absorbing materials. These dose distribution measurements can include dose profiles in heterogenous absorbers and at surfaces and interfaces of different substances. Such information is important in research leading to the commissioning of a radiation process, and in measurement assurance that provides quality control of a given radiation treatment.

Irradiation tests are available for customer-supplied dosimeters (such as solid radiochromic or liquid chemical types) or test samples that are sent to NBS, where they are packaged in appropriate material of thickness sufficient to approximate conditions of electron equilibrium. They are then irradiated in the NBS standard ^{60}Co calibration facility to specific agreed-upon absorbed dose values in the nominal "high-dose" range of 10-10^6 grays (10^3-10^8 rads). The dosimeters may either be read and evaluated by NBS or sent back to the customer for their analysis and evaluation. Each dosimeter should not exceed dimensions of 1 cm x 2 cm x 5 cm.

NBS can provide sets of calibrated radiochromic dosimeters packaged in appropriate equilibrium material (such as polystyrene or aluminum). 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 NBS to be read and evaluated. The absorbed dose range that is suitable for use with the radiochromic dosimeters is 1 to 600 kGy (0.1 to 60 Mrad) in water, silicon, aluminum, graphite, or certain plastics.

Spectrophotometric analysis of irradiated dosimeters may be done at several specific ultraviolet or visible optical wavelengths or as a spectral scan over an appropriate wavelength region of interest.

Documentation

A National Standardization Programme for High-Dose Measurements, W. L. McLaughlin, Technical Report No. 205, 17-32, IAEA, Vienna (1981).

Dosimetry for Industrial Radiation Processing, W. L. McLaughlin, J. C. Humphreys, and A. Miller, Natl. Bur. Stand. (U.S.), Spec. Publ. 609 (1981).

Dye Film Dosimetry for Radiation Processing, J. C. Humphreys and W. L. McLaughlin, IEEE Trans. Nucl. Sci., NS-28, No. 2, 1797-1801 (Apr. 1981).

The Measurement of Absorbed Dose and Dose Gradients, W. L. McLaughlin, Radiat. Phys. Chem., 15, 9-38 (1980).

Dosimetry Standards for Industrial Radiation Processing, W. L. McLaughlin, National and International Standardization of Radiation Dosimetry, 1, IAEA, Vienna (1978).

Training Programs

None.

Future Directions

Work is going on to develop better dosimetry capabilities for high-dose electron beams and for fast-pulse radiation sources. These efforts include real-time readout multifoil calorimeter systems and new radiochromic dosimeters usable over a wide dose range.

Contact Person at NBS

William L. McLaughlin
Radiation Physics Division
301-921-2201

NBS MEASUREMENT SEMINARS

The primary objective of the NBS conducted seminars is to provide advice and assistance on measurements and calibrations so that laboratories outside NBS can make measurements consistent with national standards as maintained by NBS. Participation is open to a limited number of persons from measurement and standards laboratories who meet appropriate prerequisites relating to education, work experience, and current professional activity.

Each seminar lasts from one to five days and its meetings are devoted to lectures, group discussions, and laboratory demonstrations. A course may be cancelled if registration is insufficient. However, in the past, requests for enrollment have nearly always exceeded the numbers that could be accommodated. Laboratory directors who wish to have members of their staff attend any of these courses are therefore urged to send, as soon as possible, a letter of application to the individual named in the course descriptions below. Applications should also be accompanied by a check, billing authorization, or purchase order for the stated fee.

Acceptance of qualified applicants, on the basis of first come, first served, other things being equal, will be made by letter not later than 4 weeks prior to the scheduled date of the course. Detailed information on schedules and housing will be available at that time. Those accepted will be expected to study the assigned reading material before coming to the course and should be prepared to discuss their own experiences with related problems.

o Quality Assurance of Chemical Measurements Seminar

Description: This two-day seminar is concerned with techniques to improve the precision and accuracy of analytical measurements such as those needed in the compositional analysis of materials, process control, and regulatory enforcement. It is designed for supervisors of analytical laboratories, experienced analytical chemists, and those responsible for the development and/or supervision of laboratory quality control programs. Topics discussed will include: general aspects of quality assurance; the role of Standard Reference Materials in quality assurance; statistical considerations used in the evaluation of data quality; and good laboratory practices for precise and accurate chemical measurements. In addition, each participant may elect to attend three two-hour clinics on good measurement practices, selected from the following areas: atomic absorption spectrometry; gas analysis; gas chromatography; gas chromatography-mass spectrometry; general analytical chemistry; ICP spectroscopy; ion chromatography; isotope dilution mass spectrometry; liquid chromatography; polarography-voltammetry; neutron activation analysis; spectrophotometry; statistical concepts; UV-IR organic spectroscopy; standard reference materials; and quality assurance program development. Applicants should indicate the three clinics of their choice when applying.

Arrangements: Attendance will be limited to 30. Fee: $300. Dates: To be announced. For further information contact: Dr. John K. Taylor, Center for Analytical Chemistry, A309 Chemistry Building, NBS, Washington, DC 20234. Telephone: 301-921-3497.

o Precision Thermometry Seminar

Description: The seminar will consist of integrated instruction in platinum resistance thermometry, liquid-in-glass thermometry, thermocouple thermometry, and thermistor thermometry to be given over a five day period. Material to be covered includes the International Practical Temperature Scale of 1968; its use in the laboratory; thermometers and instrumentation, including automatic data acquisition; the treatment of calibration data; and innovations in thermometry. Time will be split between lecture sessions and hands-on measurements in the laboratory. The seminar is especially intended for calibration laboratory personnel and others who wish to undertake precision temperature measurements. Applicants should possess undergraduate training in physics or engineering and should have some laboratory experience in metrology.

Arrangements: Attendance will be limited to 25. Fee: $300. Dates: October 15-19, 1984. For further information contact: Nancye E. McBryde or Robert J. Soulen, Temperature and Pressure Measurements and Standards Division, NBS, Washington, DC 20234. Telephone: 301-921-3315.

o Frequency Measurements and Calibrations Seminar

Description: This seminar is intended for engineers and standards lab technicians involved in frequency calibrations. The course will be taught at a practical level to satisfy those new to the field as well as more experienced users. Methods taught will use commercially-available equipment. Topics to be covered:

Crystal Oscillator Calibration
Applications of Frequency Counters
How to Choose a Frequency Calibration Source
Care and Use of Frequency Sources
Using LORAN-C and WWBV for Frequency Calibrations
Time and Frequency Measurement Assurance Services at NBS
Organization of Time and Frequency in the U.S.
NBS, USNO, and Other Publications

NOTE: Although all of the above subjects will be covered, emphasis will be on making practical frequency calibrations and measurements.

Fee: To be announced. Dates: To be announced. For further information contact: Mike Lombardi, Time and Frequency Division, NBS, Boulder, CO 80303. Telephone: 303-497-3212.

- Calibration and Use of Piston Gages Seminar

Description: The seminars are held to help industrial and other users attain the highest possible accuracy in pressure measurements with piston gages. The seminar is directed at engineers and senior technicians. The two-day seminar presents information on the theory of piston gages, elastic distortion, design and types, calibration of controlled clearance piston gages, calibration by cross-float, error analysis, computer programs, demonstration of cross-float, hydrostatic weighing and transducer calibrations. The seminar closes with a tour of the laboratory, and a discussion of research and development work in the field of pressure measurements.

Arrangements: Attendance will be limited to 10-15. Fee: $150. Dates: May 17-18, 1984 and November 15-16, 1984. For further information contact: Bernard E. Welch or Nancye E. McBryde, Temperature and Pressure Measurements and Standards Division, NBS, Washington, DC 20234. Telephone: 301-921-2121 or 3316.

- Frequency Standards and Clocks Seminar

Description: This seminar is intended for program managers, planners, and systems engineers. Topics to be covered:

A History of Time Scales
National and International Structure of Time and Frequency
Concepts, Definitions, and Measures of Short-Term Frequency Stability
Techniques for Measuring Short-Term Frequency Stability and Noise in Oscillators
Review of Performance of Commercial Frequency Standards
Limitations of Present-Day Atomic Frequency Standards
Possible Advances in Future Clocks and Frequency Standards
The Process of Timekeeping (Clocks Modeling)
Time Coordination: Methods for Comparison of Time Scales
Propagation Effects on Radio Transmissions
Optical Techniques and Propagation Effects

Fee: $370. Date: August 1984 (Tentative). For further information contact: Mike Lombardi, Time and Frequency Division, NBS, Boulder, CO 80303. Telephone: 303-497-3212.

- Electrical Measurements Assurance Programs Seminar

Description: This five-day intensive seminar on measurement quality assurance provides in-depth training for those involved in dc and low frequency electrical measurements. Participants will receive instruction on how to establish and maintain rigorous quality control programs in their own laboratories to ensure the accuracy of electrical measurements. The primary emphasis will be on quality control for dc voltage metrology; the techniques used are readily applicable to other electrical measurement areas.

Each class day will consist of lectures, to be followed by ample time for questions and answers and discussion of real measurement problems. Reference materials will be provided. This seminar is designed for technical personnel working in electrical measurements and it is not recommended for entry-level people unless they have a background in electrical engineering or physics. Some college level math is desirable, but attendees should, as a minimum, have a thorough knowledge of high school algebra.

The first morning session will be devoted to a discussion of "why have a measurement assurance program (MAP)," covering the costs and benefits of such a program, the implications for traceability, the impact on the operation of a calibration or standards lab, etc. Lab managers and/or supervisors of attendees are invited to join the group for this session. (Each attendee may invite one additional person to attend the Monday morning session at no additional cost.)

Arrangements: Plans are in progress for seminars in Minneapolis, Seattle, and Orlando. Attendance will be limited to 40. Fee: To be announced. Dates: To be announced. For further information contact: Dr. Arthur O. McCoubrey, Center for Basic Standards, Physics Building, Room B160, Washington, DC 20234. Telephone: 301-921-3301.

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report describes the current status of NBS's physical measurement services. It describes each of these services under five sections: Description; Documentation; Training Available; Future Directions; Contact Person at NBS. The services are keyed to the numerical classification of NBS Special Publication No. 250. This document will also serve as a source for the complete revision of NBS SP 250 in the near future.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

calibration, NBS services, services, status report

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