NIST HANDBOOK 150-2E

National Voluntary Laboratory Accreditation Program

Calibration Laboratories

Technical Guide for Optical Radiation Measurements

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Preface

The Calibration Laboratories Accreditation Program was developed by the National Voluntary Laboratory Accreditation Program (NVLAP) at NIST as a result of interest from private industry and at the request of the National Conference of Standards Laboratories. The goal of the program is to provide a means by which calibration laboratories can be assessed for competency. This voluntary program is not designed to serve as a means of imposing specific calibration procedures or minimum uncertainties on applicant laboratories; instead, the program allows for all scientifically valid calibration schemes and requires that laboratories derive and document their measurement uncertainties.

To accomplish this goal, NVLAP employs technical experts, on a contract basis, to serve as assessors in each of the following eight fields of physical metrology calibration:

- electromagnetic dc/low frequency,
- electromagnetic rf/microwave frequency,
- time and frequency,
- ionizing radiation,
- optical radiation,
- dimensional,
- mechanical, and
- thermodynamics.

NIST Handbooks 150-2A through 150-2H are technical guides for the accreditation of calibration laboratories, with each handbook corresponding to one of the eight fields of physical metrology calibration. They are intended for information and use by:

- NVLAP technical experts in assessing laboratories,
- staff of accredited laboratories,
- those laboratories seeking accreditation,
- other laboratory accreditation systems,
- users of laboratory services, and
- others needing information on the requirements and guidelines for accreditation under the NVLAP Calibration Laboratories Accreditation Program.

NOTE The Calibration Laboratories Accreditation Program has been expanded to cover chemical calibration for the providers of proficiency testing and certifiers of spectrophotometric NTRMs. (See NIST Handbooks 150-19 and 150-21.) Other NVLAP handbooks in the chemical calibration area are expected in the future.

The assessor uses NIST Handbook 150, *NVLAP Procedures and General Requirements*, and the appropriate guides (NIST Handbooks 150-2A through 150-2H) to validate that a laboratory is capable of performing calibrations within the laboratory's stated uncertainties. These technical guides and other relevant technical information support assessors in their assessments of laboratories. Along with inspecting the facilities, documentation, equipment, and personnel, the assessor can witness a calibration, have an item recalibrated, and/or examine the results of measurement assurance programs and round-robins to collect objective evidence.

NIST Handbooks 150-2A through 150-2H supplement NIST Handbook 150, which contains Title 15 of the U.S. Code of Federal Regulations (CFR) Part 285 plus all general NVLAP procedures, criteria, and policies. The criteria in NIST Handbook 150 originally encompassed the requirements of ISO/IEC Guide 25:1990 and the relevant requirements of ISO 9002 (ANSI/ASQC Q92-1987). These handbook criteria have been updated to incorporate the requirements of ISO/IEC 17025:1999. The entire series of Handbooks 150-2A through 150-2H comprises information specific to the Calibration Laboratories Program and neither adds to nor detracts from requirements contained in NIST Handbook 150.

Any questions or comments on this handbook should be submitted to the National Voluntary Laboratory Accreditation Program, National Institute of Standards and Technology, 100 Bureau Drive, Stop 2140, Gaithersburg, MD 20899-2140; phone (301) 975-4016; fax (301) 926-2884; e-mail NVLAP@nist.gov.

Acknowledgments

NIST Handbook 150-2 was first available as a draft covering all eight fields of physical metrology calibration in one volume. It has been separated into eight handbooks to allow easier updating and electronic downloading from the NVLAP web site. The preparation of these documents has been a joint effort, with input from representatives of other government agencies, laboratories, and the private sector. Acknowledgment of their efforts is in order; however, the listing of individual names is impractical. The submissions by individuals and companies offering suggestions for improvement to this document were also very welcome, as were the contributions of those who attended the public workshops.

We thank all the NIST measurement divisions for their work in writing or contributing to the individual handbooks. Listed below are those from the NIST measurement divisions who deserve special thanks for input to Handbook 150-2E, *Technical Guide for Optical Radiation Measurements*:

> Dr. Ted Early and Dr. Maria Nadal (Spectrophotometry), Charles E. Gibson (Radiance Temperature, Spectral Radiance and Spectral Irradiance), Sally S. Bruce and Thomas C. Larason (Spectral Responsivity), Dr. Yoshihiro Ohno (Photometry), and Thomas R. Scott (Laser Power and Energy and Optical Fiber Power). Editing and Coordination: Sally S. Bruce and Dr. Keith Lykke.

Additional thanks go to those who actively participated in the Technical Guide Workshop held November 1993 and to those who served as points of contact within fields of calibration. They include: Georgia L. Harris, Norman B. Belecki, Dr. Theodore D. Doiron, Robert M. Judish, Thomas C. Larason, Sally S. Bruce, and Dr. Donald B. Sullivan. A special thanks is owed to James L. Cigler for work in developing the content and format of this guide, and to Vanda White for her editorial expertise in making this a readable document.

Above all, we wish to thank Jon M. Crickenberger, the editor of the first three drafts of this document, for literally hundreds of hours of his work in creating this guide. It was he who tasked the contributors to produce the technical content, assembled the results of their efforts into a consistent format, and provided the general commentary. Without Jon's dedicated effort to this monumental task, this guide would never have been published.

NVLAP has edited the individual handbooks and made changes resulting from comments by individuals to earlier draft versions. This editing has been to a different extent for each parameter. Every effort was made to include all pertinent information relevant to an ISO/IEC 17025-derived technical guide.

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Summary

This guide presents the general technical requirements (i.e., on-site assessment and proficiency testing) of the laboratory accreditation program for calibration laboratories along with specific technical criteria and guidance applicable to optical radiation measurement. These technical guidelines are presented to indicate how the NVLAP criteria may be applied.

Any calibration laboratory (including commercial, manufacturer, university, or federal, state, or local government laboratory) engaged in calibration in optical radiation frequency measurements listed in this handbook may apply for NVLAP accreditation. Accreditation will be granted to a laboratory that complies with the criteria for accreditation as defined in NIST Handbook 150. Accreditation does not guarantee laboratory performance – it is a finding of laboratory competence.

Fields of calibration covered: Specific calibration parameters and related stimulus and measurement devices in areas of optical radiation.

Scope of accreditation: Calibration parameter(s), range, and uncertainty level. Types of measuring and test equipment. Quality assurance system for measuring and test equipment.

Period of accreditation: One year, renewable annually.

On-site assessment: Visit by an assessor(s) to determine compliance with the NVLAP criteria before initial accreditation, in the first renewal year, and every two years thereafter. Preassessment and monitoring visits as required. All calibration parameters or general areas of calibration within the specific scope of accreditation requested will be assessed.

Assessors: Selected from technical experts with experience in the appropriate areas of calibration and quality systems assessment.

Proficiency testing (measurement assurance): Each laboratory is required to demonstrate its capability to successfully perform calibrations as part of on-site assessment or by documented successful completion of an approved Measurement Assurance Program (MAP) or round-robin correlation. Proficiency testing may be required for initial accreditation, or where other evidence of measurement assurance is not evident, and may be conducted annually thereafter. Advance notice and instructions are given before proficiency testing is scheduled.

Fees: Payments are required as listed on the NVLAP fee schedule, including the initial application fee, administrative/technical support fee, on-site assessment fee, and proficiency testing fee.

1 General information

1.1 Purpose

The purpose of this handbook is to amplify the general requirements for accreditation by NVLAP of calibration laboratories in the area of optical radiation measurements covered by the Calibration Laboratories Program. It complements and supplements the NVLAP programmatic procedures and general requirements found in NIST Handbook 150, *NVLAP Procedures and General Requirements*. The interpretive comments and additional guidelines contained in this handbook make the general NVLAP criteria specifically applicable to the Calibration Laboratories Program.

This handbook does not contain the general requirements for accreditation, which are listed in NIST Handbook 150, but rather provides guidelines for good calibration laboratory practices, which may be useful in achieving accreditation.

1.2 Organization of handbook

The handbook is organized in two sections. The first section provides additional explanations to the general procedures and requirements contained in NIST Handbook 150. The second section provides details and guidance very specific for optical radiation calibration laboratories.

1.3 Description of Calibration Laboratories Accreditation Program

On May 18, 1992, as a result of the petition and public notice process, the Director of the National Institute of Standards and Technology published in the *Federal Register* a notice of intent to develop the Calibration Laboratories Accreditation Program under the procedures of the National Voluntary Laboratory Accreditation Program . On June 2, 1994, the procedures and general requirements under which NVLAP operates, Title 15, Part 285 of the U.S. Code of Federal Regulations (CFR), were revised to:

a) expand the procedures beyond testing laboratories to include accreditation of calibration laboratories,

b) update the procedures to ensure compatibility with generally accepted conformity assurance and conformity assessment concepts,

c) incorporate international changes, especially with relevant International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) documents (e.g., ISO/IEC Guides 25 (now ISO/IEC 17025:1999), 38, 43, and 58, and the ISO 9000 series), and

d) facilitate and promote acceptance of the calibration and test results between countries to avoid barriers to trade.

Calibration laboratory accreditation is offered in eight fields of physical metrology calibration covering a wide variety of parameters and includes accreditation in multifunction measuring and test equipment calibrations. Specific requirements and criteria have been established for determining laboratory qualifications for accreditation following prescribed NVLAP procedures. The criteria address quality systems, staff, facilities and equipment, test and calibration methods and procedures, manuals, records, and calibration/certification reports.

On September 18, 1992, a public workshop was held at NIST Gaithersburg and attended by a mix of private sector and government personnel. The workshop reviewed a draft handbook, which included general requirements, as well as very specific technical requirements for dc voltage calibrations at all levels. As a result of the workshop, the draft handbook was revised to take the form of a Calibration Laboratories Program Handbook, which included the general requirements for laboratories (using ISO/IEC Guide 25 as a basis), and eight companion Technical Guides covering the specific requirements for each field of calibration offered for accreditation.

On May 18, 1993, a public workshop on the revised draft program handbook was held at NIST Boulder and attended by more than 60 industry and government personnel. Comments from this workshop, as well as responses to a survey/checklist mailing, were used to prepare the final draft of the handbook, now entitled *NVLAP Procedures and General Requirements* (NIST Handbook 150), published in March 1994. [A revised NIST Handbook 150 incorporating ISO/IEC 17025:1999 is dated 2001.]

A public workshop for the Calibration Laboratories Technical Guides was held at NIST Gaithersburg, on November 22 through 24, 1993. More than 60 industry and government personnel attended and provided comments on the draft version of the Technical Guide for each of eight fields of calibration. As a result, the eight Technical Guides were incorporated into a draft Handbook 150-2, *Calibration Laboratories Technical Guide*, covering the fields being offered for accreditation. [In 2000, Handbook 150-2 (draft) was divided into eight handbooks, one for each calibration area.]

The need for technical experts to serve as assessors was advertised, and the first group of assessors was selected and trained during a four-day session held from November 16 through 19, 1993, in Gaithersburg, using materials developed by NVLAP.

The Calibration Laboratories Accreditation Program officially began accepting applications when notification was given in the *Federal Register* dated May 11, 1994. Applications are accepted and processed in accordance with procedures found in NIST Handbook 150.

1.4 References

1.4.1 The following documents are referenced in this handbook.

a) NIST Handbook 150, *NVLAP Procedures and General Requirements*; available from:

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National Institute of Standards and Technology
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Gaithersburg, MD 20899-2140

Phone: (301) 975-4016
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E-mail: nvlap@nist.gov
NVLAP Web site: http://www.nist.gov/nvlap

b) ISO/IEC/BIPM (BIPM is the Bureau International des Poids et Mesures, the International Bureau of Weights and Measures) *Guide to the Expression of Uncertainty in Measurement* (GUM), 1993.

c) ISO/IEC 17025: 1999: *General requirements for the competence of testing and calibration laboratories.*

d) ISO/IEC Guide 43: 1997, *Proficiency testing by interlaboratory comparisons, Part 1 and Part 2.*

e) ISO/IEC/BIPM *International Vocabulary of Basic and General Terms in Metrology* (VIM), 1993.

ISO documents **b)** through **e)** are available from:

Global Engineering Documents (paper copies)
Order phone: (800) 854-7179

American National Standards Institute (ANSI) (electronic copies)
Electronic Standards Store
ANSI web site: http://www.ansi.org

f) NIST Technical Note 1297, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*. Available on-line at http://physics.nist.gov/Document/tn1297.pdf.

g) EA-2/03, EA Interlaboratory Comparison (previously EAL-P7), Mar. 1996. Available on-line at http://www.european-accreditation.org/.

h) ANSI/NCSL Z540-1-1994, *Calibration Laboratories and Measuring and Test Equipment—General Requirements.*

i) ANSI/NCSL Z540-2-1997, *U.S. Guide to the Expression of Uncertainty in Measurement.*

j) NCSL Recommended Practice RP-7: *Laboratory Design*, 1993.

NCSL documents **h)** through **j)** available from:

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Boulder, CO 80301-1026
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Fax: (303) 440-3384
E-mail: info@ncslinternational.org
Web site: http://www.ncslinternational.org

k) C. D. Ehrlich and S. D. Raspberry, "Metrological Timelines in Traceability," Jour. Res. NIST, Vol. 103, No. 1, Jan-Feb, 1998.

l) C. Croarkin, Measurement Assurance Programs, Part II: Development and Implementation, NBS Special Publication 676-II (U.S. Government Printing Office, Washington, DC, 1985).

1.4.2 Additional references specific to optical radiation measurements are listed in Sections 2.3 through 2.9.

1.5 Definitions

Definitions found in NIST Handbook 150 apply, but may be interpreted differently or stated differently, when necessary to amplify or clarify the meaning of specific words or phrases as they apply to specific technical criteria.

1.5.1 Proficiency Testing: Determination of laboratory performance by means of comparing and evaluating calibrations or tests on the same or similar items or materials by two or more laboratories in accordance with predetèrmined conditions. For the NVLAP Calibration Laboratories Accreditation Program, this entails using a transport standard as a measurement artifact, sending it to applicant laboratories to be measured, and then comparing the applicant's results to those of a reference laboratory on the same artifact.

1.5.2 Traceability: Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties. [VIM:1993, 6.10]

A single measurement intercomparison is sufficient to establish uncertainty relationships only over a limited time interval (see reference 1.4.1.(k)); internal measurement assurance (see reference 1.4.1(l)), using control (check) standards, is required to fully demonstrate that uncertainties remain within stated levels over time. For the purposes of demonstrating traceability for NVLAP accreditation, a laboratory must demonstrate not only that there is an unbroken chain of comparisons to national standards, but also that this chain is supported by appropriate uncertainties, measurement assurance, continuous standard maintenance, proper calibration procedures, and handling of standards. In this way, traceability is related to these other areas of calibration.

1.6 NVLAP documentation

1.6.1 Accreditation documents

Laboratories granted NVLAP accreditation are provided with two documents: Scope of Accreditation and Certificate of Accreditation.

The Scope of Accreditation lists the "Best Uncertainty" that an accredited laboratory can provide for a given range or nominal value within a given parameter of measurement. This "Best Uncertainty" is an statement of the smallest uncertainty that a laboratory has been assessed as capable of providing for that particular range or nominal value. The actual reported value of uncertainty for any particular measurement service that the accredited laboratory provides under its scope may vary depending on such contributors as the statistics of the test and uncertainties associated with the device under test.

1.6.2 Fields of calibration/parameters selection list

The Calibration Laboratories program encompasses eight fields of physical metrology calibration, with multiple parameters under each field. Each field is covered by a separate handbook (NIST Handbooks 150-2A through 150-2H). (Fields of accreditation under Chemical Calibration are covered by separate handbooks.) Depending on the extent of its calibration capabilities, a laboratory may seek accreditation to all or only selected fields and parameters within the scope of the program. The fields of calibration and their related parameters are given on the Fields of Calibration and Parameters Selection List, which is provided to a laboratory seeking accreditation as part of the NVLAP application package for the program. Additional fields of calibration and/or parameters may be added to the Calibration Laboratories program upon request of customer laboratories and/or if decided by NVLAP to be in the best interest of the Calibration Laboratories program.

The laboratory is requested to indicate on the Fields of Calibration/Parameters Selection List the parameter(s) for which accreditation is desired, along with appropriate ranges and uncertainties. There is also provision for an applicant laboratory to request accreditation for parameters not currently listed on the Selection List, or for accreditation of the quality system employed for assuring Measurement and Test Equipment (M & TE) used in support of product certification. Request for accreditation of quality assurance systems for M & TE will be treated as a separate field of calibration for the purpose of setting appropriate fees. Once a laboratory meets all the requirements for accreditation for the Fields of Calibration/Parameters Selection List, this information will become the basis for the Scope of Accreditation document.

1.6.3 Checklists

Checklists enable assessors to document the assessment of the laboratory against the NVLAP requirements found in NIST Handbook 150. The NVLAP Calibration Laboratories Accreditation Program incorporates the NVLAP General Operations Checklist. The questions are applicable to evaluating a laboratory's ability to operate a calibration program, and address factors such as the laboratory's organization, management, and quality system in addition to its calibration competency.

The NVLAP General Operations Checklist is numbered to correspond to the requirements in NIST Handbook 150. Comment sheets are used by the assessor to explain deficiencies noted on the checklist. Additionally, the assessor may use the sheets to make comments on aspects of the laboratory's performance other than deficiencies.

1.7 Assessing and evaluating a laboratory

1.7.1 On-site assessment

1.7.1.1 The NVLAP lead assessor will schedule with the laboratory the date for on-site evaluation, and will request the quality manual and documented quality and calibration procedures in advance of the visit to reduce time spent at the laboratory; such materials will be returned by the assessor. NVLAP and the assessor will protect the confidentiality of the materials and information provided. The laboratory should be prepared to conduct routine calibrations, have equipment in good working order, and be ready for examination according to the guidance contained in this handbook, the requirements identified in NIST Handbook 150, and the laboratory's quality manual. The assessor will need time and work space to complete assessment documentation while at the laboratory, and will discuss these needs at the opening meeting of the on-site assessment.

1.7.1.2 NVLAP technical assessors are provided with the NVLAP General Operations Checklist to help ensure the completeness, objectivity, and uniformity of the on-site assessment.

1.7.1.3 When accreditation has been requested for a considerable number of fields of calibration and parameters, the assessment may range from observing calibrations in progress, requiring repeat measurements on completed calibrations, to listening to laboratory staff describe the calibration process. The depth into which the assessor performs the assessment depends on the number of fields of calibration and associated parameters for which accreditation is requested and the time required to perform a given calibration.

1.7.1.4 The assessor, or the assessment team, does the following during a typical on-site assessment:

a) Conducts an entry briefing with the laboratory manager to explain the purpose of the on-site visit and to discuss the schedule for the day(s). At the discretion of the laboratory manager, other staff may attend the briefing.

b) Reviews quality system manual, equipment and maintenance records, record-keeping procedures, laboratory calibration reports, and personnel competency records. At least one laboratory staff member must be available to answer questions; however, the assessor may wish to review the documents alone. The assessor(s) dòes not usually ask to take any laboratory documents with him/her, and previously supplied documents will be returned.

c) Physically examines equipment and facilities, observes the demonstration of selected procedures by appropriate personnel assigned to perform calibrations, and interviews the personnel. The demonstrations must include preparation for calibration of devices, and the setup and use of measuring and test equipment, standards and systems.

d) Holds an exit briefing with the laboratory manager and staff to discuss the assessment findings. Deficiencies are discussed and resolutions may be mutually agreed upon. Items that must be addressed before accreditation can be granted are emphasized, and outstanding deficiencies require response to NVLAP within 30 days. Items that have been corrected during the on-site and any recommendations are specially noted.

e) Completes an On-site Assessment Report, as part of the exit briefing, summarizing the findings. The assessor(s) attaches copies of the completed checklists to this report during the exit briefing. The report is signed by the lead assessor and the laboratory's Authorized Representative to acknowledge the discussion. This signature does not necessarily indicate agreement; challenge(s) may be made through NVLAP. A copy is given to the representative for retention. All observations made by the NVLAP assessor are held in the strictest confidence.

1.7.2 Proficiency testing

1.7.2.1 Background

Once the quality system review and on-site assessment steps have been satisfactorily completed, it is necessary to gather another set of data points to aid in deciding whether or not the applicant laboratory is competent to perform calibrations within the fields of interest to the uncertainties claimed. In the eight fields of calibration covered by Handbooks 150-2A through 150-2H, there are approximately 85 parameters of interest. Under most parameters there are several subsets, referred to as ranges. For example, in the Electromagnetic DC/Low Frequency field, the dc resistance parameter can range from .001 Ω to the teraohm, TΩ (1×10^{12}) level in decade values. In view of the many possible ranges, proficiency testing could be conducted in thousands of areas. NVLAP reserves the right to test by sampling in any area; hence, applicant laboratories must be prepared, with reasonable notice, to demonstrate proficiency in any of a number of parameters.

1.7.2.2 Proficiency testing vs. measurement assurance

There is an important difference between proficiency testing and measurement assurance. The objective of proficiency testing is to determine through a measurement process that the laboratory's measurement compares favorably with the measurement of the audit laboratory (NIST or one designated by NVLAP), taking into account the relative uncertainties assigned by both the applicant and audit laboratories. NVLAP employs the same principle used by the European Cooperation for Accreditation and described in EA-2/03 covering international measurement audits. Note that the objective is not to determine and certify the total uncertainty of the applicant laboratory, as is done in a Measurement Assurance Program (MAP) with NIST, but to verify (through the assessment process) that the uncertainty claimed by the applicant laboratory is reasonable, and then to test that the measurement result obtained through the proficiency test is acceptable.

It is not the intention nor the mission of NVLAP to conduct MAPs or to otherwise provide traceability for laboratories. Laboratories obtain these services from the NIST measurement divisions. NVLAP assesses the implementation, application, and documentation of MAPs by laboratories. NVLAP accreditation encourages the use of MAPs by the calibration laboratory community, and MAP results produce objective evidence that NVLAP assessors look for as part of the assessment process.

1.7.2.3 Requirements

NVLAP's proficiency testing program uses a sampling approach. All applicant laboratories are required to complete an annual proficiency test in one parameter under each field of calibration for which it has applied to be accredited. For the purposes of the NVLAP Calibration Laboratories Accreditation Program, the results of the proficiency test are considered as objective evidence, along with the on-site visit, of a laboratory's ability to perform competent calibrations. Proficiency testing is conducted annually using different parameters in each field; however, those laboratories accredited in only one parameter within a field are retested in the same parameter.

1.7.2.4 Uncertainty determination

The applicant laboratory is required to perform a measurement or series of measurements on an artifact using the same calibration method, apparatus, and personnel that it uses to calibrate customers' equipment. The laboratory must be able to identify and quantify all sources of uncertainty that affect the measurement. The laboratory should attach an overall uncertainty to the measurement by combining all uncertainty contributions, in their type A and type B components, in the root-sum-squared method as described in the *Guide to the Expression of Uncertainty in Measurement* (see 1.4.1 (b)). The confidence limit used should be k = 2, which is equivalent to a 95% confidence probability.

1.7.2.5 Pass/fail criteria

The performance of the proficiency test is judged by calculating the error of the measurement, normalized with respect to the uncertainty of the measurement, using the following equation:

$$E_{normal} = \left| (Value_{lab} - Value_{ref}) / (Uncertainty_{ref}^2 + Uncertainty_{lab}^2)^{1/2} \right|$$

where

E_{normal} = normalized error of the applicant laboratory
$Value_{lab}$ = the value as measured by the applicant laboratory
$Value_{ref}$ = the value as measured by the reference laboratory
$Uncertainty_{ref}$ = the uncertainty of the reference laboratory
$Uncertainty_{lab}$ = the uncertainty of the applicant laboratory

To pass the proficiency test, the applicant laboratory must have a value for E_{normal} less than 1 (i.e., $E_{normal} < 1$). The results may be plotted graphically, with lines representing the limits of uncertainty of the measurements. The anonymity of each applicant laboratory will always be preserved.

1.7.2.6 Scheduling and handling

Proficiency testing is scheduled by NVLAP-designated reference laboratories. These sites are NIST laboratories or NVLAP-accredited laboratories that have been found to have the ability to perform the required proficiency tests to an uncertainty level appropriate for the laboratories they evaluate. The proficiency test is scheduled independently and not to correspond with the on-site visit. Applicant laboratories are notified in advance as to the approximate arrival time of the measurement artifact. Instructions for performing the test, reporting the results, communicating with the reference laboratory, and shipping are included along with the artifact as part of the proficiency test package. Applicant laboratories are instructed to perform all required measurements within a reasonable time and are told where to ship the artifacts once the testing has been completed.

1.7.2.7 Notification of results

NVLAP notifies each laboratory of its own results in a proficiency test. If a laboratory has been evaluated prior to the completion of the proficiency test, the status of that laboratory's accreditation is contingent upon successful completion of proficiency testing. The laboratory's accreditation status may be changed to reflect a partial accreditation, or may be completely suspended pending demonstration of the laboratory's ability to successfully complete the proficiency test at a later date.

1.7.3 Traceability

1.7.3.1 Establishing traceability

Laboratories must establish an unbroken chain of comparisons leading to the appropriate international or national standard, such that the uncertainties of the comparisons support the level of uncertainty that the laboratory gives to its customers. Generally speaking, the uncertainties of the comparisons increase as they move from a higher (international or national level) to a lower level standard. This uncertainty chain is the evidence of traceability and must be documented accordingly. Traceability does not simply mean having standards calibrated at the national laboratory, but must consider how a measurement, with its corresponding uncertainty, is transferred from the national level to the calibration laboratory's customers.

1.7.3.2 Considerations in determining traceability

Without measurement assurance, one cannot be reasonably certain that the comparisons have been transferred properly to the laboratory's customers. The measurement process itself must be verified to be in control over time. Therefore, traceability is not a static concept that, once established, may be ignored, but it is dynamic. Process control exercised in each calibration provides the assurance that a valid transfer of the international or national standard has taken place. This assurance may be accomplished through the use of tools such as check standards and control charts. Also, the laboratory's primary standards must be maintained in such a way as to verify their integrity. Examples of this may be having more than one primary standard to use for intercomparisons, monitoring the primary standard with a check or working standard (looking for changes), and verifying a primary standard on a well-characterized measurement/calibration system. Using scientifically sound measurement procedures to transfer the primary standard value to the working level and the customer's item is essential to establishing traceability. If the procedure itself yields the wrong result, there is no way the laboratory can perform a calibration traceable to the international or national standard. Handling the laboratory's standards affects the measurement process, and therefore the ability to transfer the standard's value to the customer. Examples of handling problems are dirty or improperly cleaned standards, maintaining standards in an improper environment, not maintaining custody and security, and improper handling of standards during the measurement process.

1.7.3.3 Relationship to existing standards

The above discussion illustrates how traceability is dependent on many aspects of the measurement process and therefore must be considered in all phases of calibration. It is not just coincidental that the factors addressed above are main topics of concern in ISO/IEC 17025:1999.

1.7.4 Uncertainty

NVLAP recognizes the methodology for determining uncertainty as described in the *Guide to the Expression of Uncertainty in Measurement*, published by ISO. To be NVLAP-accredited, a laboratory must document the derivation of the uncertainties that it reports to its customers. These uncertainties will appear on the scope issued to each accredited laboratory to an accuracy appropriate to the standards, procedures, and measuring devices used.

2 Criteria for accreditation

2.1 Introduction

2.1.1 Applicant laboratories are assessed using the requirements in NIST Handbook 150, *NVLAP Procedures and General Requirements*. This guide, NIST Handbook 150-2E, was developed from a NIST measurement laboratory perspective and provides examples and guidelines, not requirements, to assessors and interested calibration laboratories on good laboratory practices and recommended standards. Therefore, the guide language reflects this philosophy through the use of "shoulds" instead of "shalls" (along with other less prescriptive language) when describing criteria. The requirements presented here are not absolute since specific requirements depend on the measurement uncertainty for which an applicant laboratory wishes to be accredited. This is a business decision for each laboratory and beyond the scope of NVLAP. Simply stated, to be accredited, an applicant laboratory must have a quality system and be able to prove (and document) that it is capable of doing what it says it does (i.e., correctly calibrate to a stated uncertainty) within the framework of NIST Handbook 150. Accreditation will be granted, and therefore may be referenced in calibration reports, etc., only for those specific parameters, ranges and uncertainties using calibration methods and procedures for which a laboratory has been evaluated. Calibrations performed by a laboratory using methods and procedures not considered appropriate for the level of measurements being made, and which have not been evaluated by the accreditation process, are outside the scope of accreditation and may not be referenced as "accredited" calibrations on calibration reports, etc.

2.1.2 Section 2.2 provides general interpretations of the NIST Handbook 150 criteria for optical radiation calibrations. Sections 2.3 through 2.9 provide specific calibration guidelines for optical radiation measurements and references to related standards and documents. This guide is dynamic in that new parameters may be added and existing criteria updated and improved.

2.2 General criteria for optical radiation calibrations

2.2.1 Scope

2.2.1.1 This section contains the technical criteria in accordance with which a laboratory should demonstrate that it operates, if it is to be recognized as competent to carry out optical radiation calibrations. The optical radiation calibrations currently included in the accreditation program are:

a) Radiance temperature

   1) Optical pyrometry/radiance temperature

b) Photometric measurements

   1) Luminous intensity and illuminance

   2) Luminous flux

   3) Spectral flux and light source color

   4) Luminance

   5) Color temperature

c) Spectrophotometric measurements

1) Regular transmittance

2) Specular reflectance

3) 6°/hemispherical reflectance factor

4) 45°/0° reflectance factor

5) Coefficient of luminous intensity for retroreflectance

d) Spectral radiance and spectral irradiance measurements

e) Spectral responsivity measurements

f) Laser power and energy

g) Optical fiber power.

2.2.1.2 This material may be used as a guide by optical radiation calibration laboratories in the development and implementation of their quality systems.

2.2.2 Statistical process control

2.2.2.1 All sources of variability for the calibration should be monitored by calibrating the subsystems and through the use of check standards to ensure that the calibrations are carried out under controlled conditions. The laboratory should maintain some form of statistical process control (SPC) commensurate with the uncertainty levels of the calibration. The SPC control parameters should be based on measurements of check standards (or closure parameters) and the repeatability of multiple measurements. The frequency and number of process control checks should be appropriate for the number of calibrations, as well as the level of uncertainty and reliability claimed for the calibration.

2.2.2.2 The laboratory should have control artifacts which adequately span the measurement range of devices and samples normally calibrated by the laboratory. Every measured value of each control should be recorded and compared to its historical value to determine that the process is in control. The comparison may be made via a plotted control chart with appropriate control values, which should be updated at least annually using the most current data.

2.2.3 Accommodation and environment

2.2.3.1 The laboratory should provide facilities for the effective monitoring, control, and recording of environmental conditions. Attention should be paid to temperature, humidity, line voltage, dust, electromagnetic interference, and vibrations.

2.2.3.2 Unless otherwise specified, the laboratory temperature should be controlled to a nominal of 23 °C (± 2 °C is recommended), and the relative humidity should remain between 20 % and 60 %. The temperature and humidity of the laboratory environment should be monitored and recorded.

2.2.4 Equipment and reference materials

2.2.4.1 The laboratory should be furnished with all items of equipment for the correct performance of optical radiation calibrations.

2.2.4.2 The laboratory should have appropriately clean storage areas for storing reference materials.

2.2.5 Handling of calibration items

2.2.5.1 Calibration items should be inspected for damage and completeness when received and stored in an appropriately clean and safe place when not in use.

2.2.5.2 Detectors, sources, and reference materials should be cleaned when necessary.

2.2.6 Calibration methods

The laboratory should have documented calibration procedures to be followed for each type of calibration.

2.2.7 Records

2.2.7.1 All data associated with a measurement should be recorded, stored, and kept for a period of time as stated in the quality manual. If corrections are applied, the worksheets should show the measurement data, corrections, and final answers. The temperature, humidity, date, identification of test material and controls, and other pertinent process information should be included.

2.2.7.2 Information relating to the procedures, equipment, standards, results, and personnel involved for a particular calibration should be maintained for the period of time stated in the quality manual.

2.2.7.3 Records associated with a particular standard or control should be kept for the period of time stated in the quality manual.

2.2.8 Certificates and reports

2.2.8.1 The content of all certificates or reports of calibration must meet the requirements of NIST Handbook 150. SI units should be used unless otherwise required by the customer.

2.2.8.2 All certificates or reports of calibration should contain an uncertainty statement which is based upon scientifically determined data and which agrees with the laboratory's stated best uncertainty definition.

2.2.8.3 The uncertainty determination should follow the methods described in the ISO *Guide to the Expression of Uncertainty in Measurement* and be derived from a model of the measurement system which includes (as applicable) the uncertainties caused by:

a) Master artifact calibration

b) Long-term reproducibility of measurement system

c) Instrument geometry

    1) Alignment of the test material to the source

2) Distance of the test material to the source

3) Diameter of the source

d) Instrument wavelengths

e) Instrument linearity

f) Sample being tested

g) Other factors as appropriate (e.g., polarization, spectral bandpass, scattered light, etc.).

2.2.8.4 The uncertainty should be computed according to NIST Technical Note 1297, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results.*

2.2.8.5 The method used to fasten the calibration item on a fixture should be described in detail. In general, differences in fastening between calibration and use will introduce errors in calibration.

2.3 Radiance temperature

2.3.1 Scope

This section contains specific technical criteria which a laboratory should meet if it is to be recognized as competent to carry out radiance temperature calibrations.

2.3.2 References

a) Radiance Temperature Calibrations. C. E. Gibson, B. K. Tsia, and A.C. Parr, NIST Special Publication 250-43 (1998).

b) Temperature, Its Measurement and Control in Science and Industry, James F. Shooley, editor (American Institute of Physics, New York), Vol. 6, Part 1 (1992).

c) Temperature, Its Measurement and Control in Science and Industry, James F. Shooley, editor (American Institute of Physics, New York), Vol. 6, Part 2 (1992).

d) The International Temperature Scale of 1990, H. Preston-Thomas, Metrologia 27, 3 (1990).

e) The 1990 NIST Scales of Thermal Radiometry, Klaus D. Mielenz, Robert. D. Saunders, Albert C. Parr, and Jack J. Hsia, J. Res. Natl. Inst. of Stds. Tech., **95**, 621 (1990).

f) Spectroradiometric Determination of the Freezing Temperature of Gold, K. D. Mielenz, R. D., Saunders, J. B. Shumaker, J. Res. Natl. Inst. of Stds. Tech., **95**, 49 (1990).

g) Temperature, T. J. Quinn (Academic Press, San Diego) (1990).

h) Theory and Practice of Radiation Thermometry, D. P. Dewitt and Gene D. Nutter, editors (John Wiley and Sons, New York) (1988).

i) Applications of Radiation Thermometry, Joseph C. Richmond and David P. Dewitt, editors (American Society for Testing and Materials, Philadelphia) (1985).

j) Temperature, Its Measurement and Control in Science and Industry, (Instrument Society of America, Pittsburgh) Vol. 4, Part 1 (1972).

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

l) Vacuum Tungsten Strip Lamps with Improved Stability as Radiance Temperature Standards: Temperature, Its Measurement and Control in Science and Industry, T. J. Quinn and R. D. Lee (Instrument Society of America, Pittsburgh: 1972) Vol. 4, Part 1, p. 395.

m) Intercomparison of the IPTS 68 Above 1064 °C by Four National Laboratories: Temperature, Its Measurement and Control in Science and Industry, R. D. Lee, H. J. Kostkowski, T. J. Quinn, P. R. Chandler, T. N. Jones, J. Tapping, and H. Kunz (Instrument Society of America, Pittsburgh, 1972) Vol. 4, Part 1, p. 377.

n) 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 (Oct. 1966).

o) Theory and Methods of Optical Pyrometry, H. J. Kostkowski and R. D. Lee, National Bureau of Standards (US), Monograph 41 (March 1962).

p) Temperature, Its Measurement and Control in Science and Industry (Instrument Society of America, Pittsburgh), Vol. 3, Part 1 (1962).

2.3.3 Statistical process control

The laboratory should have reference and working standards that span the radiance temperature and spectral range for the calibration service provided by the laboratory. At least two working standards, or a number appropriate for the stated uncertainty, should be measured each time a test ribbon filament lamp or test pyrometer is calibrated.

2.3.4 Accommodation and environment

The temperature and relative humidity of the laboratory environment should be monitored and reported in the test report.

2.3.5 Equipment and reference materials

2.3.5.1 The laboratory should maintain a reference standard ribbon filament lamp and/or pyrometer whose radiance temperature calibration is obtained from or traceable to the National Institute of Standards and Technology, other national laboratories, or intrinsic standards. This reference standard should span the radiance temperature and spectral range for the calibration service provided by the laboratory. The accuracy and stability of the reference standard should be verified at least annually.

2.3.5.2 The laboratory should maintain a group of at least three check standard ribbon filament lamps and/or pyrometers whose radiance temperature calibration is traceable to the National Institute of Standards and Technology, other national laboratories, or intrinsic standards through the laboratory's reference standard lamp and/or pyrometer. These check standards should span the radiance temperature and spectral range for the calibration service provided by the laboratory. The accuracy and stability of the check standards should be verified by comparison to the reference standard in support of the laboratory's uncertainty requirements.

2.3.6 Calibration methods

2.3.6.1 Test pyrometers may be calibrated by comparison to a standard pyrometer, by measurement of a standard ribbon filament lamp, using blackbody techniques, or other well derived calibration methods.

2.3.6.2 Test ribbon filament lamps are to be calibrated by spectral comparison to a standard ribbon filament lamp, by measurement with a standard pyrometer, using blackbody techniques, or other well derived calibration methods.

2.3.7 Handling of calibration items

The test lamp should be handled by the lamp base. Care should be exercised when handling the ribbon filament lamps, and the envelope of the lamp should not be touched with bare hands. Gloves or a lint-free cloth should be used when handling the envelope of the lamp to mount the test lamp in a socket. Care should be taken to avoid shock and vibration to the lamp.

2.3.8 Certificates and reports

2.3.8.1 The calibration report for a pyrometer should give the radiance temperatures of the reference and the radiance temperatures measured by the test pyrometer.

2.3.8.2 The calibration report for a ribbon filament lamp should give the radiance temperatures, test current, and voltage across the filament of the test ribbon filament lamp.

2.4 Photometry

2.4.1 Scope

This section contains specific technical criteria which a laboratory should meet if it is to be recognized as competent to carry out photometric calibrations.

2.4.2 References

a) NIST Measurement Services: Photometric Calibrations, Y. Ohno, NIST Special Publication 250-37 (July 1997).

b) Photometry, J. W. T. Walsh, 3rd edition, Constable, London, 1958.

c) IES Guide for the Selection, Care and Use of Electrical Instruments in the Photometric Laboratory, IES LM-28-1989.

d) IES Approved Method for the Electrical and Photometric Measurements of Fluorescent Lamps, IES LM-9-1999.

e) IES Practical Guide to Colorimetry of Light Sources, IES LM-16-84.

f) IES Guide to Spectroradiometric Measurements, IES LM-58-94.

g) IES Approved Method for Electrical and Photometric Measurements of General Service Incandescent Filament Lamps, LM-45-00.

h) IESNA Approved Method for the Electrical and Photometric Measurements of High Intensity Discharge Lamps, LM-51-00 IESNA Approved Method for the Electrical and Photometric Measurements of High Intensity Discharge Lamps, LM-51-00.

i) IESNA Guide for the Measurement of Ultraviolet Radiation from Sources, LM-55-96.

j) The Basis of Physical Photometry, 1983, CIE Publication #18.2.

k) Methods of Characterizing Illuminance Meters and Luminance Meters, CIE Publication #69, (1987).

l) Measurement of Luminous Flux, CIE Publication #84, (1989).

m) Colorimetry, CIE Publication #15.2, 2nd ed., (1986).

2.4.3 Statistical process control

The laboratory should have control standards that adequately span the range of artifacts, wavelengths, and intensities calibrated by the laboratory. Working standards should be measured each time calibration is done. The number of working standards depends on the level of uncertainty.

2.4.4 Accommodation and environment

2.4.4.1 The temperature and humidity of the laboratory environment should be monitored and declared in the test report. The ambient temperature of fluorescent lamps should be controlled to a nominal 25 °C (±1 °C is recommended) during calibration.

2.4.4.2 Air draft variations should be considered and, if necessary, minimized or controlled, since they could affect the output of electrical discharge lamps. They can be detected and analyzed by means of a hot-wire anemometer or other sensitive air movement instruments.

2.4.5 Equipment and reference materials

2.4.5.1 The laboratory should have standard measuring shunts, stable DC power supplies, high accuracy digital voltage meters, stable mounting fixtures and other equipment necessary to make high accuracy electrical and photometric measurements.

2.4.5.2 A laboratory that makes luminous intensity and/or illuminance measurements should have either luminous intensity standard lamps or standard photometers which are traceable to NIST. Radiometric standards can also be used with well-derived and documented procedures.

2.4.5.3 A laboratory that makes total luminous flux measurements normally uses an integrating sphere and total luminous flux standard lamps which are traceable to NIST. Other methods, including use of goniophotometers, can be used with photometric standards traceable to NIST and with well-documented procedures.

2.4.5.4 A laboratory that makes measurements of spectral flux and light source color should ideally use an integrating sphere connected to a spectroradiometer and spectral flux standard lamps that are obtained from or traceable to NIST. Other techniques may be used for less accurate measurements.

2.4.5.5 A laboratory that makes luminance measurements should have either standard sources or standard photometers that are traceable to NIST. Standard sources can be integrating sphere sources or transmitting/reflecting diffusers irradiated at known illuminance.

2.4.6 Calibration methods

Laboratories may use the instrumentation and the test procedures described in the reference documents, including the specific photometric and colorimetric procedures for each lamp type for which the laboratory is seeking accreditation. Laboratories may use other well-derived and documented procedures.

2.4.7 Handling of calibration items

2.4.7.1 Care should be exercised when handling the lamps. Never touch the envelope of the lamp with bare hands. Handle the lamp by its base or use gloves or a lint-free cloth when handling the envelope of the lamp. Avoid mechanical shock to the lamps.

2.4.7.2 Incandescent lamps should be turned on and off slowly (for approximately 30 s each). Incandescent lamps should not be moved while turned on. If a lamp must be moved during calibration, it should be done carefully. Burning position of lamps should always be kept the same. Measurements should be made only after the lamp has stabilized.

2.4.7.3 Discharge lamps should be operated with reference ballasts specified in the reference documents.

2.4.7.4 Measurements should be made only after the lamp has been stabilized for a sufficient period of time depending on type of lamp (usually stabilization takes approximately 10 min for incandescent lamps and 15 to 40 min for electrical discharge lamps).

2.4.8 Certificates and reports

2.4.8.1 The report of calibration of lamps should include the operating condition of the lamps (current, voltage, and other parameters as applicable), as well as photometric values.

2.4.8.2 The report of the luminous intensity calibration should include the reference point of the lamp, alignment procedure, and the photometric distance used for the calibration.

2.4.8.3 The report of calibration of photometers should include the reference point of the photometer, specification of light sources used, and the ambient temperature or photometer temperature at the calibration.

2.4.8.4 The reproducibility of photometric values of lamps (especially electrical discharge lamps) should be included in the uncertainty of calibration.

2.5 Spectrophotometry

2.5.1 Scope

This section contains specific technical criteria which a laboratory should meet and demonstrate if it is to be recognized as competent to carry out spectrophotometric calibrations in the following parameters: Regular Transmittance, Specular Reflectance, 6°/Hemispherical Reflectance Factor, 45°/0° Reflectance Factor.

2.5.2 References

a) P.Y. Barnes, E.A. Early, and A.C. Parr, "NIST Measurement Services: Spectral Reflectance," NIST Special Publication 250-8 (1998).

b) K.L. Eckerle, J.J. Hsia, K.D. Mielenz, V.R. Weidner, NBS Measurement Services: Regular Spectral Transmittance, NBS Special Publication 250-6 (1987).

c) NBS Measurement Services: Spectral Reflectance, V. R. Weidner and J. J. Hsia, National Bureau of Standards (U.S.), Special Publication 250-8 (July 1987).

d) National Scales of Spectrometry in the U.S., J. J. Hsia, Advances in Standards and Methodology in Spectrophotometry 1987, Elsevier Science Publishers, B. V., Amsterdam, pp. 99-109 (1987).

e) Measurement Assurance Program Transmittance Standards for Spectrophotometric Linearity Testing: Preparation and Calibration, J. Res. Natl. Bur. Std. 88 25 (Jan.-Feb. 1983).

f) Radiometric and Photometric Characteristics of Materials and their Measurement, 1977, CIE Publication #38.

g) Absolute Methods for Reflection Measurements, 1979, CIE Publication #44.

h) A Review of Publications on Properties and Reflection Values of Material Reflection Standards, 1979, CIE Publications #46.

i) Recalibration of the NBS Glass Standards of Spectral Transmittance, J. Res. Natl. Bur. Std. (U.S.) 67A, 577 (1963).

j) NBS Research Paper RP 2093, Permanence of Glass Standards of Spectral Transmittance, J. Res. Natl. Bur. Std. (U.S.) 44, 463 (1950).

2.5.3 Statistical process control

The laboratory should have working standards that span the specific spectrophotometric measurement calibrated by the laboratory. Standards of the type to characterize measurement process, intensities, and wavelength region should be measured each time calibration is performed. Records of measurement parameters and results should be kept.

2.5.4 Accommodation and environment

2.5.4.1 The temperature and humidity of the laboratory environment should be monitored and declared in the test report.

2.5.4.2 When ultraviolet sources are used, adequate exhaust and ventilation should be provided. UV eye protection should be worn by the occupants of the room.

2.5.4.3 Lasers should be shielded from direct eye view of the operator or eye protection rated for the class of the laser should be worn.

2.5.5 Equipment and reference materials

Equipment for spectrophotometric measurements should be calibrated and carefully documented in accordance with standard practices. The appropriate spectral sources, reference materials, predispersing devices, monochromators, integrating/averaging spheres, detectors and/or aperture should be properly selected and maintained for each specific spectral region.

2.5.6 Calibration methods

Laboratories may use the instrumentation and test procedures described in the reference documents. Calibration methods should consist of well-documented and established techniques that are reviewed periodically in order to embody accepted laboratory standard practices.

2.5.7 Handling of calibration items

2.5.7.1 Care should be exercised when handling reference standards; never touch the front surface of the standard.

2.5.7.2 Extreme caution should be used when it is necessary to clean reference standards. Cleaning the standards can damage the surface and the measurement history.

2.5.7.3 It is strongly recommended that a face mask be worn to prevent contamination of the calibration surface. It is further recommended that both hands be covered with lint-free gloves to prevent fingerprints on calibration surfaces. If a whole glove confines movement, the non-contact portion of the glove may be removed, or finger cots may be used.

2.5.7.4 If dust must be removed from the test surface, it is recommended that a clean air bulb with low airflow be used so as not to generate condensation.

2.5.8 Certificates and reports

The calibration report should include the wavelength versus measured parameters, and experimental parameters specified by the customer.

2.6 Spectral radiance and spectral irradiance

2.6.1 Scope

This section contains specific technical criteria which a laboratory should meet if it is to be recognized as competent to carry out spectral radiance or spectral irradiance calibrations.

2.6.2 References

a) NBS Measurement Services: Spectral Irradiance Calibrations, J. H. Walker, R. D. Saunders, J. K. Jackson, and D. A. McSparron, National Bureau of Standards (U.S.), Special Publication 250-20 (Sept. 1987).

b) NBS Measurement Services: Spectral Radiance, J. H. Walker, R. D. Saunders, and A. T. Hattenburg, National Bureau of Standards (U.S.), Special Publication 250-1 (Jan. 1987).

c) Spectral Irradiance Standard for the Ultraviolet: The Deuterium Lamp, R. D. Saunders, W. R. Ott, and J. M. Bridges, Applied Optics 17, 593 (1978).

d) The 1973 NBS Scale of Spectral Irradiance, R. D. Saunders and J. B. Shumaker, National Bureau of Standards (U.S.), Tech. Note 594-13 (1977).

e) High-Accuracy Spectral Radiance Calibration of Tungsten-Strip Lamps, H. J. Kostkowski, D. E. Erminy, and A. T. Hattenburg, Adv. Geophys., 14, 111 (1970).

f) Methods of Characterizing the Performance of Radiometers and Photometers, 1982, CIE Publication #53.

g) The Spectroradiometric Measurement of Light Sources, 1984, CIE Publication #63.

2.6.3 Statistical process control

The laboratory should have at least one reference standard lamp similar to the lamps calibrated by the laboratory. The reference standard should span the spectral range for the calibration service provided by the laboratory. Check standards should be measured each time calibration is done. The number of working standards depends on the level of uncertainty.

2.6.4 Accommodation and environment

2.6.4.1 The temperature and humidity of the laboratory environment should be monitored and declared in the test report.

2.6.4.2 When ultraviolet sources are used, UV eye protection and skin protection should be both worn by the occupants of the room. Lasers should be shielded from direct eye view of the operator, and eye protection rated for the class of laser should be worn.

2.6.5 Equipment and reference materials

2.6.5.1 The laboratory should maintain a reference standard lamp whose spectral radiance or spectral irradiance calibration is obtained from or traceable to the National Institute of Standards and Technology or another national laboratory, or intrinsic standards.

2.6.5.2 The laboratory should have standard measuring shunts, stable DC power supplies, high accuracy digital voltage meters, stable mounting fixtures, and other equipment necessary to make high accuracy spectroradiometric measurements.

2.6.5.3 The laboratory should have the equipment and expertise to measure and quantify possible measurement errors.

2.6.6 Calibration methods

2.6.6.1 Polarity of lamp currents should be maintained throughout their measurements. Laboratories should have the capability to set and/or reproduce source electrical operating parameters.

2.6.6.2 At least three working standards should be used for each calibration. Less than three working standards may be used depending on the level of uncertainty.

2.6.6.3 At least three measurements should be made on each source to maintain statistical control of the process.

2.6.7 Handling of calibration items

2.6.7.1 The test lamps should be handled by the lamp base. Care should be exercised when handling the lamps; do not touch the envelope of the lamp with bare hands. Gloves or a lint-free cloth should be used when handling the envelope of the lamp to mount the test lamp in a socket. Avoid mechanical shock to the filament of the lamp.

2.6.7.2 The lamps should be turned on and off slowly (for approximately 30 s each time). Measurements should be made only after the lamp has stabilized (approximately 20 min after the lamps are turned on).

2.6.8 Certificates and reports

The calibration report should provide the spectral radiance or spectral irradiance versus wavelength, the lamp current, and the lamp voltage. Measurements are reported for specific lamp orientation and current. If necessary, documentation is included to interpolate data at wavelengths other than those reported. This does not apply to fluorescent lamps.

2.7 Spectral responsivity

2.7.1 Scope

This section contains specific technical criteria which a laboratory should meet if it is to be recognized as competent to carry out spectral responsivity calibrations of optical radiation detectors (referred to as "detectors" throughout the remainder of this section).

2.7.2 References

a) "Spectroradiometric Detector Measurements: Part I - Ultraviolet Detectors and Part II - Visible to Near-Infrared Detectors," NIST Special Publication 250-41, T.C. Larason, S.S. Bruce, and A.C. Parr (1998).

b) "Spectroradiometric Detector Measurements: Part III - Infrared Detectors," NIST Special Publication 250-42, A.L. Migdall and G.P. Eppeldauer (1998).

c) "Determination of the Spectral Responsivity of Optical Radiation Detectors," CIE Publication 64.

d) "Optical Radiation Measurements," Editors: F. Grum and C. J. Bartleson, Vol. 1: "Radiometry," F. Grum and R. J. Becherer; Vol. 4: "Physical Detectors of Optical Radiation," W. Budde. Academic Press, New York, Vol. 1: Vol. 4: 1983.

e) C. L. Wyatt, "Radiometric Calibration: Theory and Methods," Academic Press, New York, 1978.

f) E. F. Zalewski and C. R. Duda, "Silicon Photodiode Device with 100 % External Quantum Efficiency," Applied Optics 22, 2867-2873 (1983).

g) "New Developments and Applications in Optical Radiometry III," Metrologia 28 (1991).

h) "New Developments and Applications in Optical Radiometry IV," Metrologia 30 (1993).

2.7.3 Statistical process control

The laboratory should have an adequate number of working standard detectors that span the spectral range of the detectors calibrated by the laboratory. A laboratory performing frequent calibrations should have a group of at least three working standards.

Control charts are a statistical tool used for tracking a process or performance over time. Working standard performance should be checked on a periodic basis.

2.7.4 Accommodation and environment

2.7.4.1 In some cases, the temperature and humidity of the laboratory environment should be monitored and recorded.

2.7.4.2 Appropriate eye protection or shielding should be used if a potentially hazardous source is used (e.g., uv source or laser). Other safety hazards should be properly handled (e.g., proper ventilation for ozone producing lamp).

2.7.5 Equipment and reference materials

2.7.5.1 The laboratory should maintain a reference standard detector whose spectral responsivity calibration is obtained from or traceable to NIST. This reference standard should span the spectral range of the calibration service provided by the laboratory. The reference standard should be verified annually or on a well-derived and documented interval.

2.7.5.2 The laboratory should maintain a working standard detector(s) whose spectral responsivity is traceable to NIST through the laboratory's reference standard detector. The working standard(s) should span the spectral range of the calibration service provided by the laboratory. The working standard(s) should be verified by comparison to the reference standard on an appropriate schedule. The reference standard detector may be used as the working standard when justified by the calibration workload.

2.7.6 Calibration methods

Calibration methods should consist of well-documented and established techniques that are reviewed periodically to embody accepted laboratory practices.

2.7.7 Handling of calibration items

2.7.7.1 Care should be exercised when handling the test detectors, especially not to touch their windows or bare active areas. In the event that the detector or radiometer is equipped with a precision aperature, the inside edge of the precision aperture is extremely delicate and should not be touched with fingers or any other object. Some test detector windows can be cleaned with lens tissue and spectral grade solvent. The precision aperture should be removed before cleaning the detector window (if possible).

2.7.7.2 Some detector surfaces, especially bare surfaces, can absorb moisture and should be stored appropriately.

2.7.8 Certificates and reports

2.7.8.1 The report should describe the methodology and instrumentation used to determine the spectral response.

2.7.8.2 The report should indicate the spectral responsivity versus wavelength and measurement uncertainties.

2.8 Laser power and energy

2.8.1 Scope

This section contains specific technical criteria which a laboratory should meet if it is to be recognized as competent to carry out laser power and energy calibrations of laser radiation detectors and meters (referred to as "detectors" throughout the remainder of this section).

2.8.2 References

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

b) T. R. Scott, "NBS Laser Power and Energy Measurements," Proc. S SPIE O-E LASE '88, Optoelectronics and Laser Applications in Science and Engineering (1988).

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

d) P. A. Simpson, "A System for Measuring the Characteristics of High Peak Power Detectors of Pulsed CO_2 Radiation," Natl. Bur. Stand. (U.S.), Tech. Note 1023 (Sept. 1980).

e) E. D. West, "A System for Calibrating Laser Power Meters for the Range 5-1000 W," Natl. Bur. Stand. (U.S.), Tech. Note 685 (May 1977).

f) A. A. Sanders and A. R. Cook, "An NBS Measurement Assurance Program," Proc. Electro-Optics Laser Conference (1976).

g) D. L. Franzen and L. B. Schmidt, "Absolute Reference Calorimeter for Measuring High-Power Laser Pulses," Appl. Opt. 15, 3115 (Dec. 1976).

h) E. D. West, W. E. Case, A. L. Rasmussen, and L. B. Schmidt, "A Reference Calorimeter for Laser Energy Measurement," J. Res. Natl. Bur. Stand. (U.S.), 76A, No. 1, 13 (Jan.-Feb. 1972).

i) J. H. Lehman, "Calibration Service for Spectral Responsivity of Laser and Optical-Fiber Power Meters at Wavelengths Between 0.4 mm and 1.8 mm," NIST SP 250-53, 39 pp (Dec. 1999).

2.8.3 Statistical process control

The laboratory should have at least two working standard detectors that span the spectral and power ranges of the detectors calibrated by the laboratory. At least one working standard should be measured each time a sample is calibrated.

2.8.4 Accommodation and environment

2.8.4.1 The temperature and humidity of the laboratory environment should be monitored and recorded.

2.8.4.2 Appropriate eye protection and shielding should be used when lasers are in use. Other safety hazards should be properly handled (e.g., proper ventilation for toxic gases, etc.).

2.8.5 Equipment and reference materials

2.8.5.1 The laboratory should maintain a thoroughly characterized primary standard whose calibration is traceable to NIST. This calibration should be performed at the wavelengths, power/energy ranges, and temporal modes (i.e., cw or pulsed) to be used in the calibration services provided by the laboratory.

2.8.5.2 The laboratory should maintain a minimum of two working detectors whose response characteristics are traceable to NIST through the laboratory primary standard. The responses of these working standards should be characterized at the wavelengths, power/energy ranges, and temporal modes (i.e., cw or pulsed) to be used in the calibration services provided by the laboratory.

2.8.5.3 The laboratory should have the appropriate instrumentation for transferring the calibration at the wavelengths, power/energy ranges, and temporal modes of the calibration service provided by the laboratory.

2.8.6 Calibration methods

The test detectors should be calibrated by comparison to the working detectors at the appropriate wavelength, power/energy, temporal mode, and power density.

2.8.7 Handling of calibration items

2.8.7.1 If appropriate, the test detectors should be kept in their shipping containers until ready for testing. Care should be exercised when handling the test detectors, especially not to touch their windows or bare active areas. If necessary, a test detector window can be cleaned with lens tissue and spectral grade solvent. Before calibration begins, the test detector should be allowed sufficient time to reach equilibrium with the laboratory environment.

2.8.7.2 Alternatively, the test detectors can be kept in a dust-free enclosure that is maintained at the same temperature and humidity levels as the laboratory.

2.8.8 Certificates and reports

2.8.8.1 The report should describe the method and associated instrumentation used to determine the response of the test detector to a measured amount of laser radiation input. This description should include all pertinent information concerning the test detector (such as power/energy range, wavelength setting, etc.).

2.8.8.2 The report should give the average output response of the test detector relative to the power/energy incident onto the detector at the power/energy levels and wavelengths used in the calibration. The report should also include information on the bias condition on the detector.

2.8.8.3 The report should give the associated measurement uncertainty for each calibration number provided for the test detector. The report should describe the pertinent uncertainty components and the method used to combine these factors into a single uncertainty.

2.9 Optical fiber power

2.9.1 Scope

This section contains specific technical criteria which a laboratory should meet if it is to be recognized as competent to carry out fiber optic power calibrations of detectors and power meters (referred to as "detectors" throughout the remainder of this section).

2.9.2 References

a) X. Li and R. L. Gallawa, "Calibrated Optical Fiber Power Meters: Errors Due to Variations in Connectors," Fiber and Integrated Optics, Vol. 7 (Mar. 1988).

b) R. L. Gallawa and X. Li, "Calibration of Optical Fiber Power Meters: The Effect of Connectors," Appl. Opt. 26, 1170 (Apr. 1987).

c) R. L. Gallawa and S. Yang, "Optical Fiber Power Meters: A Round Robin Test of Uncertainty," Appl. Opt. 25, 1066 (Apr. 1986).

d) I. Vayshenker, S. Yang, X. Li, T. R. Scott, C. L. Cromer, "Optical Fiber Power Meter Nonlinearity Calibrations at NIST," NIST SP 250-56, 29 pp (Aug. 2000).

e) I. Vayshenker, X. Li, D. Livigni, T. R. Scott, C. L. Cromer, "Optical Fiber Power Meter Calibrations at NIST," NIST SP 250-54, 36 pp (June 2000).

2.9.3 Statistical process control

The laboratory should have at least two working standard detectors that span the spectral and power ranges of the detectors calibrated by the laboratory. At least one working standard should be measured each time a sample is calibrated.

2.9.4 Accommodation and environment

2.9.4.1 The temperature and humidity of the laboratory environment should be monitored and recorded.

2.9.4.2 Appropriate eye protection and shielding should be used when lasers are in use. Other safety hazards should be properly handled (e.g., proper ventilation for toxic gases, etc.).

2.9.5 Equipment and reference materials

2.9.5.1 The laboratory should maintain a thoroughly characterized primary standard whose calibration is traceable to NIST on an annual basis or in support of the laboratory's stated uncertainty. This calibration should be performed at the wavelengths, power/energy ranges, and input modes (i.e., parallel beam or connectorized fiber) to be used in the calibration services provided by the laboratory and commensurate with the uncertainty and device design.

2.9.5.2 The laboratory should maintain a minimum of two working detectors whose response characteristics are traceable to NIST through the laboratory primary standard. The responses of these working standards should be characterized at the wavelengths, power/energy ranges, and input modes (i.e., parallel beam or connectorized fiber) to be used in the calibration services provided by the laboratory.

2.9.6 Calibration methods

2.9.6.1 The test detectors should be calibrated by comparison to the working detectors at the appropriate wavelength, power/energy, and input mode.

2.9.6.2 The dependency of the device response on the calibration source wavelength should be considered.

2.9.7 Handling of calibration items

2.9.7.1 If appropriate, the test detectors should be kept in their shipping containers until ready for testing. Care should be exercised when handling the test detectors, especially not to touch their windows or bare active areas. If necessary, a test detector window can be cleaned with lens tissue and spectral grade solvent. Optical fiber ends should be inspected and cleaned as appropriate. Before calibration begins, the test detector should be allowed sufficient time to reach equilibrium with the laboratory environment.

2.9.7.2 Alternately, the test detectors can be kept in a dust-free enclosure that is maintained at the same temperature and humidity levels as the laboratory.

2.9.8 Certificates and reports

2.9.8.1 The report should describe the method and associated instrumentation used to determine the response of the test detector to a measured amount of radiation input. The measurement description should include all pertinent information about the test detector conditions (such as power range setting, connector/fiber types, wavelength setting, etc.).

2.9.8.2 The report should give the average output response of the test detector relative to the power incident onto the detector at wavelengths and power levels used.

2.9.8.3 The report should give the associated measurement uncertainty for each calibration number provided for the test detector. The report should describe the pertinent uncertainty components and the method used to combine these factors into a single uncertainty.