GOOD PRACTICES FOR PHOTOMETRIC LABORATORIES

GUIDANCE NOTE

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FOREWORD

In 2014, lighting accounted for approximately 15% of global electricity consumption. The United Nations Secretary-General's Sustainable Energy for All initiative identified energy efficient lighting as a "high impact opportunity", with the potential to reduce countries' greenhouse gas emissions, generate significant economic benefits and improve people's wellbeing.

High efficiency lighting technologies, such as light emitting diode lamps and smart control systems, offer up to an 85% improvement in efficacy, compared with conventional lighting technologies, while providing a better quality service.

Minimum energy performance standard programmes are a crucial policy tool for improving the energy efficiency of lighting, by contributing to the elimination of the least efficient products from the market, and accelerating the phase-in of energy saving technology replacements. However, while an increasing number of countries are adopting minimum energy performance standards, the continued availability of non-compliant, inefficient products jeopardises the achievement of countries' energy efficiency goals.

Robust monitoring, verification and enforcement schemes are crucial to safeguarding the energy efficiency benefits of performance standards and regulations. These activities protect markets from products that fail to perform as declared, or required; guarantee that products meet consumers' expectations; and ensure that policymakers, government regulators and programme administrators attain their energy saving objectives. Monitoring, verification and enforcement activities also protect suppliers' competitiveness by ensuring that they are all subject to the same market entry conditions.

Successful monitoring, verification and enforcement implementation requires long-term policy commitment and planning. The Government of Australia has long been committed to the development and implementation of monitoring, verification and enforcement policy and activities on its own territory, as part of its Equipment Energy Efficiency Program. Since 2009, Australia has been assisting other developed and developing countries to follow the same path, by sharing its expertise and best practices, and making its resources available to other countries[1].

Most recently, the Government of Australia has provided its financial and technical support to the United Nations Environment Programme-Global Environment Facility en.lighten initiative to strengthen capacities for monitoring, verification and enforcement in Southeast Asia and the Pacific. As part of this project, and drawing on the experience and knowledge of international experts and practitioners, the United Nations Environment Programme developed a series of six guidance notes on specific aspects of monitoring, verification and enforcement.

This guidance note and its associated publications are designed as manuals for government officials, technical experts and others around the world responsible for developing, implementing and refining structured and effective monitoring, verification and enforcement programmes. They describe the technical, methodological and institutional resources required, and provide easy-to-use, generic tools and templates that readers can adapt to their particular country situations.

We hope that these guidance notes will convince governments of the importance and benefits of monitoring, verification and enforcement and assist with implementation. We strongly encourage policymakers and those involved in implementing monitoring, verification and enforcement policies to take advantage of the practical advice presented.

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1 Including: International Electrotechnical Commission (IEC), International Energy Agency 's Energy Efficient End-use Equipment Solid State Lighting Annex (IEA 4E SSL Annex), lites.asia, Pacific Appliance and Labelling Programme (PALS), Vietnam Energy Efficiency Standards and Labels (VEESL), and others

ABOUT THE UNEP-GEF EN.LIGHTEN INITIATIVE

The United Nations Environment Programme (UNEP)-Global Environment Facility (GEF) en.lighten initiative was established in 2010 to accelerate a global market transformation to environmentally sustainable, energy efficient lighting technologies, as well as to develop strategies to phase out inefficient incandescent lamps to reduce CO_2 emissions and the release of mercury from fossil fuel combustion.

The en.lighten initiative serves as a platform to build synergies among international stakeholders; identify global best practices and share this knowledge and information; create policy and regulatory frameworks; address technical and quality issues; and encourage countries to develop National and/or Regional Efficient Lighting Strategies.

The United Nations Secretary General's Sustainable Energy for All (SE4ALL) initiative selected the UNEP en.lighten initiative to lead its lighting 'Energy Efficiency Accelerator'.

The initiative is a public/private partnership between the United Nations Environment Programme, OSRAM and Philips Lighting, with the support of the Global Environment Facility. The National Lighting Test Centre of China became a partner in 2011, establishing the Global Efficient Lighting Centre, and the Australian Government joined in 2013 to support developing countries in Southeast Asia and the Pacific.

In 2015, based on the lessons learned from the en.lighten initiative, UNEP launched the United for Efficiency (U4E) initiative to support countries in their transition to energy efficient appliances and equipment, including room air conditioners, residential refrigerators, electric motors, distribution transformers and information and communication technologies.

ABOUT THE UNEP-GEF EN.LIGHTEN INITIATIVE MONITORING, VERIFICATION AND ENFORCEMENT SERIES

This guidance note is one of a series of six publications on monitoring, verification and enforcement (MVE) commissioned by the UNEP-GEF en.lighten initiative under its Southeast Asia and Pacific Monitoring, Verification and Enforcement Project, funded by the Australian Government:

- *Developing Lighting Product Registration Systems;*
- *Efficient Lighting Market Baselines and Assessment;*
- *Enforcing Efficient Lighting Regulations;*
- *Good Practices for Photometric Laboratories;*
- *Performance Testing of Lighting Products;*
- *Product Selection and Procurement for Lamp Performance Testing.*

The series provides practical tools in support of lighting policy compliance frameworks and to help countries achieve a successful transition to energy efficient lighting. These publications build on the existing guidance given in the UNEP-GEF en.lighten reference manual, *Achieving the Global Transition to Energy Efficient Lighting Toolkit*. They focus on individual aspects of an effective MVE infrastructure and how these contribute to improved product compliance and the success of policies that aim at transforming the market to efficient lighting.

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ABBREVIATIONS AND DEFINITIONS

CCT	correlated colour temperature
cd	candela
CFL	compact fluorescent lamp
CIE	International Commission on Illumination (Commission Internationale de l´Eclairage)
IEC	International Electrotechnical Commission
IEV	International Electrotechnical Vocabulary
LED	light emitting diode
lm	lumen
MEPS	minimum energy performance standard
NMI	National Metrology Institute
UNEP	United Nations Environment Programme
V	volts
W	watt

GLOSSARY

A

ageing (or seasoning): preconditioning of lamps by operating them at controlled conditions for a specified period. (IEC)

B

(light) bulb: transparent or translucent gas-tight envelope enclosing the luminous element(s). (IEC)

C

calibration: set of operations which establishes, by reference to standards, the relationship which exists, under specified conditions, between an indication [value given by a measuring instrument] and a result of a measurement.
Note 1 – This term is based on the 'uncertainty' approach.
Note 2 – The relationship between the indications and the results of measurement can be expressed, in principle, by a calibration diagram. (IEC)

candela: SI unit of luminous intensity: The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian. Unit: lm/Sr. (IEC)

CIE Source A illuminant: this is intended to represent typical, domestic, tungsten-filament lighting. Its relative spectral power distribution is that of a Planckian radiator at a temperature of approximately 2 856 K. CIE standard illuminant A should be used in all applications of colorimetry involving the use of incandescent lighting, unless there are specific reasons for using a different illuminant. (CIEa; CIEb)

compliance: conforming to a rule, such as a law, policy, specification or standard.

correlated colour temperature: the temperature of the Planckian radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions. Unit: K (IEC)

D

discharge lamp: lamp in which the light is produced, directly or indirectly, by an electric discharge through a gas, a metal vapour or a mixture of several gases and vapours. (IEC)

E

efficacy: see luminous efficacy.

F

fluorescent lamp: a discharge lamp of the low pressure mercury type in which most of the light is emitted by one or several layers of phosphors excited by the ultraviolet radiation from the discharge. Note: These lamps are frequently tubular and, in the UK, are then usually called fluorescent tubes. (IEC)

full procedure verification test: a test where all procedures for measurements and records stipulated in the entry conditions for an accreditation scheme have been followed.

I

international standard: standard recognised by an international agreement to serve internationally as the basis for fixing the values and uncertainties of all other standards for the given quantity. (IEC)

L

lamp: source made in order to produce an optical radiation, usually visible. Note: This term is also sometimes used for certain types of luminaires. (IEC)

light emitting diode: solid state device embodying a p-n junction, emitting optical radiation when excited by an electric current. (IEC)

L

light output ratio: ratio of the total luminous flux of the luminaire, measured under specified practical conditions with its own lamp(s) and equipment, to the sum of the individual luminous fluxes of the same lamp(s) when operated outside the luminaire with the same equipment, under specified conditions (CIEb)

lumen (lm): SI unit of luminous flux: Luminous flux emitted in unit solid angle (steradian) by a uniform point source having a luminous intensity of 1 candela. (IEC)

lumen depreciation: luminous flux lost at any selected, elapsed operating time, expressed as a percentage of the initial output. Converse of lumen maintenance.

lumen maintenance (luminous flux maintenance factor): ratio of the luminous flux of a lamp at a given time in its life to its initial luminous flux, the lamp being operated under specified conditions. Note: This ratio is generally expressed in per cent. (IEC)

luminaire: apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes, except the lamps themselves, all the parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting them to the electric supply.

luminous efficacy: quotient of the luminous flux emitted by the power consumed by the source. unit: lm/W; symbol: ηv or η. (IEC)

luminous flux: quantity derived from radiant flux Φe by evaluating the radiation according to its action upon the CIE standard photometric observer. Unit: lm. (IEC)

luminous intensity (of a source, in a given direction): quotient of the luminous flux $d\Phi v$ leaving the source and propagated in the element of solid angle $d\Omega$ containing the given direction, by the element of solid angle: $Iv = d\Phi v / d\Omega$. Unit: cd = lm/sr. (IEC)

lux: SI unit of illuminance: Illuminance produced on a surface of area 1 square metre by a luminous flux of 1 lumen uniformly distributed over that surface. Unit: lm/m^2. (IEC)

M

model: manufacturer's particular lamp design.

N

national standard: standard recognised by an official national decision as the basis for fixing the values and uncertainties, in a country, of all other standards for the given quantity. (IEC)

O

omnidirectional lamp: emits light in all (or near to all) directions.

P

photometer: instrument for measuring photometric quantities (IEC)

R

reference standard: standard, generally having the highest metrological quality available at a given location or in a given organization, from which measurements made there are derived. (IEC)

S

spectroradiometer: instrument for measuring radiometric quantities in narrow wavelength intervals over a given spectral region (IEC)

standard lamp: lamp used as a reference in photometric or spectroradiometric measurements for which the calibration is traceable to a primary photometric or spectroradiometric standard. (CIEb)

Z

zonal luminous flux: difference of the cumulative fluxes of the source for the solid angles subtended by the upper and lower boundaries of the zone (CIEb)

EXECUTIVE SUMMARY

Performance testing programmes, whether for market intelligence, monitoring compliance with minimum energy performance standard and labelling programmes, verifying manufacturer/ retailer declarations, or conducting product benchmarking, all require product testing to be conducted at accredited independent laboratories. This guidance note provides an explanation of the internal steps required to prepare a photometric laboratory to conduct photometric performance testing as a competent testing laboratory.

It targets those seeking to improve conformance of existing laboratories, those establishing a new laboratory and technically minded government staff involved in the development of the more technical components of monitoring, verification and enforcement activities. The focus is on residential lighting products and includes the common lamps found in various countries around the world.

The main objective of the guidance note is to provide step by step test procedures for internally calibrating test equipment in a photometric laboratory. This important process ensures that the tests conducted using this equipment are traceable to internationally recognised units of measure. The guidance note also introduces the concepts of uncertainty of measurement and spectral mismatch, their importance to confidence in correct measurement results and how to identify/test for occurrences within test equipment. Where a detailed discussion of a topic is beyond the scope of this document, the reader is referred to independent non-commercial material, where it is available, to complement the introductory discussion in the guidance note.

The two principle items of photometric measurement equipment are the integrating sphere and the goniophotometer. General practice considerations for use of these items are addressed in the guidance note. The intention is to bring the key considerations relating to this equipment to the attention of the reader rather than to provide comprehensive coverage of all aspects of their operation. These common general practices are often overlooked in technical documents such as laboratory test procedures and test standards and, although some seem obvious in nature, they are commonly inadvertently neglected. Their mention here is as a reminder to the reader.

Finally all reputable laboratories have commendable housekeeping practices. Maintenance of laboratory records, tracking systems, test product unique identification coding and safe, secure storage of lamps are all components of a successful system which facilitates a robust quality management system. These practices are as important as testing integrity, as they could be scrutinised as part of legal action resulting from test results used in support of compliance activities.

1 INTRODUCTION

Measurement of the performance of a product, as part of a coordinated monitoring, verification and enforcement strategy, provides the foundation for the effective implementation of energy efficient lighting policies and regulations. However, measurement results from a laboratory are meaningless if they cannot be supported by evidence of: the validity of the measurement values obtained; the confidence in their measurement accuracy; and conformance with the specified test procedures and conditions. This guidance note is intended to assist lighting testing laboratories develop proficiency in lighting product testing to achieve these outcomes. In particular, it is aimed at laboratories wishing to acquire accreditation to conduct photometric testing, which could be used by governments and markets where energy efficient lighting policies are being implemented. It is equally relevant for laboratory staff who are establishing a photometric laboratory or for those improving the conformance of an existing laboratory.

While this guidance note provides some general advice/guidance on conducting tests, it does not attempt to provide detailed advice on conducting particular tests. This information is articulated within the specified test standards stipulated by the relevant regulation. Instead, this guidance note's main purpose is to assist with the internal calibration, equipment characterisation processes and general operational practices within a photometric laboratory to enable accurate, reproducible tests to be conducted with acceptable precision. Further general advice on performance testing for lighting products can be found in the UNEP-GEF en.lighten guidance note, *Performance Testing of Lighting Products.*

The essential elements for the operation of a testing laboratory to obtain robust, reliable and legally defensible testing results are shown in Figure 1 and are discussed further in the subsequent chapters of this guidance note.

⇨ **CHAPTER 2** provides an introduction to traceability of measurement and the internationally recognised accreditation process and associated proficiency testing.

⇨ **CHAPTER 3** provides advice on fundamental laboratory test practices such as: the use of externally calibrated equipment to internally calibrate specific equipment; managing stray light within the laboratory; monitoring of ambient conditions; and internal calibration procedures. A list of externally traceable calibrated equipment required for particular internal calibrations is also provided.

⇨ **CHAPTER 4** provides a brief overview of the techniques for determining uncertainty of measurement.

⇨ **CHAPTER 5** draws attention to some of the general considerations when conducting tests as specified in particular testing standards. These are more general testing issues which may not be specifically mentioned in test standards.

⇨ **CHAPTER 6** discusses the key considerations associated with good maintenance of laboratory records including administrative and logistical functions that are critical to the smooth operation of a laboratory.

⇨ **CHAPTER 7** summarises the advice provided in this guidance note which will assist independent photometric laboratories to conduct defendable photometric performance testing with competence.

⇨ **CHAPTER 8** signposts general resources that provide additional information for policymakers, laboratory personnel, and other practitioners and stakeholders and lists the references used in compiling this guidance note.

Figure 1

Essential elements for the reliable operation of a testing laboratory

TRACEABILITY AND ACCREDITATION

- Linking measuring equipment to SI unit
- Accreditation for specific test procedures
- Proficiency testing

CALIBRATION

- Externally calibrated reference lamps and meters
- Internal equipment calibration
- Monitoring laboratory conditions

UNCERTAINTIES

- Confidence intervals
- Determining the uncertainty

TESTING

- General considerations
- Integrating sphere considerations
- Goniophotometer considerations

HOUSEKEEPING

- Record keeping system
- Lamp identification
- Storage conditions
- Length of time
- Lamp disposal

2 TRACEABILITY AND ACCREDITATION

In order to demonstrate the reliability and replicability of its measurement processes, a photometric laboratory should have traceability of calibration of its physical standards and measurement equipment to the relevant SI unit (i.e. candela, ampere, metre, kelvin, second etc.). This should also be combined with accreditation from a relevant accreditation body, which indicates the competency of staff when conducting the specified test procedures with the calibrated physical standards and equipment. Maintaining this accreditation is heavily supported by participation in proficiency testing programmes co-ordinated by a regionally authorised accreditation body.

2.1 TRACEABILITY OF MEASUREMENT

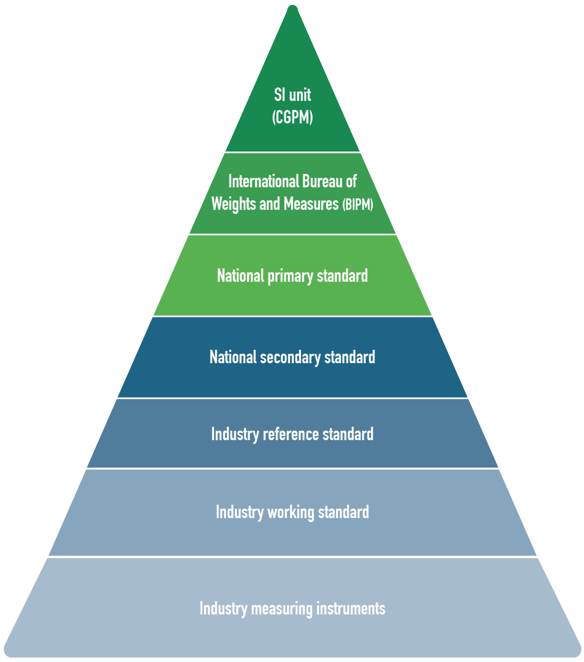
In order to achieve validity of measured values obtained by a laboratory, it must be possible to relate those values to a primary standard through an unbroken chain of calibrations. This is known as traceability of measurement.

The hierarchy of calibration of physical standards is shown diagrammatically in Figure 2. With progress of the calibration of reference lamps and measurement equipment through this hierarchy, from the SI unit down to the industry, the uncertainty in each measurement step accumulates the uncertainty of measurement of all the preceding levels. Therefore, the more levels in the calibration process, the greater is the uncertainty in the calibration measurement of the equipment

The candela is the basic unit for photometric laboratories. It is one of the seven base units within the International System of Units (Système International d'Unités, with the international abbreviation SI).[2] All fundamental units within the SI have an internationally agreed definition for their physical existence, established through the General Conference of Weights and Measures (CGPM). The primary standards for all SI units[3] are now realized and maintained by the National Metrology Institutes (NMIs)[4] in each country. These NMI's are the primary, or highest-quality, laboratory within each country and usually have responsibility for legal metrology within the country.

Within each NMI, these primary standards are verified for consistency through international or regional comparisons, called key comparisons. These key comparisons are formalised through the International Committee for Weights and Measures Mutual Recognition Arrangement (CIPM MRA). This establishes a global consistency of measurement at the NMI level. The results of key comparisons for various units are published as the evidence for equivalence of national

Figure 2
Hierarchy of calibration of physical standards



2 www.bipm.org/en/measurement-units/
3 With the exception of the kilogram, whose primary standard is maintained by the International Bureau of Weights and Measures (BIPM)
4 www.bipm.org/en/worldwide-metrology/national/

standards in different countries. Based on the key comparison results, CIPM publishes Calibrations and Measurement Capabilities (CMCs). These CMCs are the lists of measurement quantities and the uncertainties in the NMIs' calibration services, certified by the CIPM MRA.

At the national level, an NMI establishes a national primary standard for the SI unit of the candela (in the form of a light source or a detector). As national primary standards for SI base units are not always easy to work with[5] and are expensive to operate, a more manageable national secondary standard is typically calibrated against the national primary standard and used for the routine work of calibrating lower level industry reference standards and instruments. Other units, such as the lumen, are derived from the candela and the same strategies using primary and secondary standard lamps are used.

The industry reference standard lamps used in laboratories generally have a recalibration period specified in terms of number of total operating hours (for example 20 hours of operation). In some cases, these lamps may also have a maximum chronological period of use between calibrations (for example, 3 to 5 years), even if the maximum hours of operation have not been achieved during this period. Recalibration should therefore be carried when either the maximum operating hours or chronological period has been reached.

Due to these limitations on the operating life and time period between industry reference standard lamp recalibrations, laboratories will often calibrate a number of their own industry working standard lamps, against this industry reference standard lamp, to increase the number of tests and calibrations they can perform. For example, if an industry reference lamp with 20 hours of operation between calibrations is used for 30 minutes each time during calibration of an industry working standard lamp, then 40 calibrations (i.e. 20 hours/0.5 hours = 40 calibrations) of industry working standard lamps could be carried out before the industry standard reference lamp would need recalibration. And if a laboratory industry working standard lamps has 50 hours of operation between calibrations, then a total of 40 calibrations x 50 hours/recalibration, or 2,000 hours of industry working standard lamp operation, can be derived for photometric testing. If in this example, the laboratory has three industry working standard lamps, these 2,000 hours of operation will be divided between these three lamps, with approximately 660 hours each between recalibrations of the industry reference standard lamp.

The laboratory will require a calibration hierarchy (traceability) within the laboratory in terms of the calibration of all their measuring equipment. See Chapter 5 for more information on lamp calibration.

In the case of photometers (industry reference and working photometers), the recalibration period is based on a chronological time period, such as once a year.

Traceability of measurement of a laboratory is demonstrated by the calibration certificates of the reference standards they use. These can be provided directly from an NMI or through a commercial calibration laboratory with appropriate calibration accreditation. In calibration accreditation, the scope of accreditation normally relates to measurement quantities (such as luminous flux, luminous intensity) and their claimed uncertainties. Calibration accreditation should not be confused with testing accreditation, in which photometric laboratories that provide testing of products are accredited for conducting measurements in compliance with specified test procedures for those products. Both types of accreditations are based on ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*. Formal accreditation provides prima facie evidence of the laboratory's competency to undertake the stated calibration or testing work. It should be noted that certification to ISO 9001:2000, *Quality management systems – Requirements*, is not equivalent to ISO/IEC 17025:2005. It is only a quality management system assessment and does not include the assessment of technical competence that is integral to ISO/IEC 17025:2005.

2.2 ACCREDITATION BODIES

A national accreditation body operates accreditation programmes in many different fields, such as biological, chemical, mechanical and non-destructive testing, and calibration. The field of calibration includes optical metrology, within which photometry is a component.

International recognition of lighting testing and reports from laboratories within a country is achieved by having the national accreditation body accredit these laboratories according to the requirements of a global, mutual recognition arrangement framework. The International Laboratory Accreditation Cooperation (ILAC)[6] heads this arrangement framework. ILAC is an international cooperation of laboratory and inspection

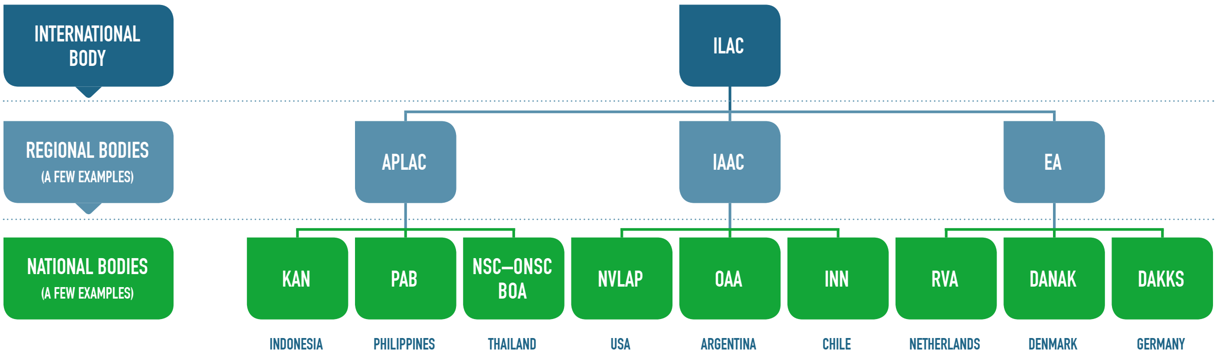
5 They are handmade, and can be more delicate, and users must be exceptionally careful with handling
6 www.ilac.org

accreditation bodies, where signatory status is either individual or through membership of a recognised Regional Cooperation Body.[7]

Laboratories in countries whose accreditation bodies are members of ILAC, or of one of the recognised Regional Cooperation Bodies, are able, and have a requirement, to accept endorsed test, calibration and inspection reports, and other documents, that are issued by laboratories and inspection bodies which are accredited by the signatories of the mutual recognition arrangements. The mutual recognition arrangement may be directly with other members of the same Regional Cooperation Body, or through the ILAC Mutual Recognition Arrangement between different Regional Cooperation Bodies. This relationship is shown diagrammatically in Figure 3.

Figure 3

Hierarchy of accreditation bodies with some example bodies provided



APLAC ASIA PACIFIC LABORATORY ACCREDITATION COOPERATION
EA EUROPEAN ACCREDITATION
IAAC INTER AMERICAN ACCREDITATION
DakkS DEUTSCHE AKKREDITIERUNGSSTELLE GMBH
DANAK DANISH ACCREDITATION FUND
INN INSTITUTO NACIONAL DE NORMALIZACIÓN
KAN NATIONAL ACCREDITATION BODY OF INDONESIA
NSC – ONSC BoA NATIONAL STANDARDIZATION COUNCIL OF THAILAND – OFFICE OF THE NATIONAL STANDARDIZATION COUNCIL BUREAU OF ACCREDITATION
NVLAP NATIONAL VOLUNTARY LABORATORY ACCREDITATION PROGRAM
OAA ORGANISMO ARGENTINO DE ACREDITACION
PAB PHILIPPINE ACCREDITATION BUREAU
RvA DUTCH ACCREDITATION COUNCIL

For a lighting test laboratory to become part of the international accreditation network, thereby gaining international recognition for their lighting testing methods and associated test reports, the laboratory will need to obtain accreditation from one of these national accreditation bodies for each of the desired test methods and demonstrate their compliance with ISO17025, *General requirements for the competence of testing and calibration laboratories*. Once this is achieved, test reports produced by this lighting laboratory using their accredited test methods will then be recognised (accepted) by all jurisdictions which accept the same test results from another accreditation bodies within the ILAC network.

2.3 PROFICIENCY TESTING PROGRAMMES

One of the key purposes of Regional Cooperation Bodies is to establish and maintain mutual confidence between national calibration and testing services. This is achieved by obtaining mutual agreement on the equivalence of operation of their members, national accreditation bodies, and the certificates issued by lighting laboratories accredited by them. These mutual agreements facilitate the removal of technical barriers to trade related to the testing activities which underpin all performance specifications of lighting products traded between countries.

7 http://ilac.org/ilac-membership/#regional-cooperation-bodies

In order to maintain the confidence in these mutual agreements, proficiency (or interlaboratory) tests are conducted. Interlaboratory comparison testing provides a forum for the comparability of testing between laboratories. They are generally conducted by central, or nucleus, laboratories. They also provide confidence in the accreditation process of the accreditation bodies, and in their ability to take the appropriate corrective actions where an interlaboratory comparison exercise reveals testing deficiencies amongst the accreditation body's member laboratories. At a regional level, interlaboratory comparison testing provides a flow of knowledge between the participating accreditation bodies and helps to establish, and to maintain, a collective high level of testing performance within the region.

Proficiency testing will typically be endorsed by a Regional Cooperation Body, and coordinated by a national accreditation body, and is an important step in helping individual laboratories identify any flaws in their test procedures or test equipment. If a flaw[8] is identified, corrective action becomes the responsibility of the laboratory and their accreditation body and should be undertaken as soon as possible. Corrective action may entail:

- Recalculation of uncertainties;
- Recalibration or replacement of measurement and test equipment;
- Revision of staff practices or test methods.

Ultimately, the corrective action may lead to the accreditation body conducting a discussion with the laboratory or, at worst, withdrawal of accreditation for the tests involved.

More information on proficiency testing can be found at: https://www.aplac.org/aplac_pt_programs.html and in the UNEP-GEF en.lighten guidance note, *Performance Testing of Lighting Products*.

8 Significant variation in a test result compared to other laboratories, beyond what could reasonably be attributed to measurement uncertainty

3 LABORATORY PREPARATION FOR CONDUCTING TESTS

Preparing a laboratory to be able to authoritatively conduct a particular test method requires that the laboratory environment (ambient and physical) and the measurement equipment to be used for the particular test be in a state conducive to produce bona fide test results. For this to be the case, the laboratory must have access to externally calibrated measurement equipment, and physical standards, that are necessary to achieve calibration traceability for all measurement equipment, and physical standards, used in that particular test. Also the ambient environment and physical arrangement of the environment must not unknowingly influence the measurement results. This chapter includes advice on: what externally calibrated equipment is required to internally calibrate specific equipment; managing stray light within the laboratory; monitoring of ambient conditions; and internal calibration procedures.

3.1 MONITORING LABORATORY CONDITIONS

Most laboratory test methods are required to be conducted under standard laboratory conditions for ambient temperature and relative humidity. Ideally, therefore, a laboratory needs to monitor, record and store the laboratory test room conditions. At the very least the laboratory should have a calibrated thermometer (or thermocouple) and hygrometer which can be checked, and the levels noted, by laboratory staff at the time of conducting tests.

The thermometer or thermocouple will be shielded from direct optical radiation using a metal can with a reflective polished outside surface (open top and bottom), as absorption of this radiation will produce an artificially elevated temperature. The polished metal can may then need to be baffled from any reflected optical radiation (for example, a polished can inside a black can). This arrangement is shown in Figure 4 and has the additional benefit of shielding the thermomter or thermocouple from drafts, which will lower the temperature reading due to convective cooling.

Alternatively, a recording thermo-hydrograph, as shown in Figure 5, is a very effective way to provide a continuous record of the laboratory conditions.

Figure 4
Thermometer inside draft proof cylinder

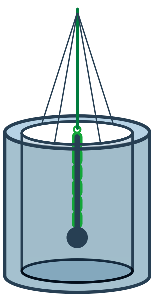
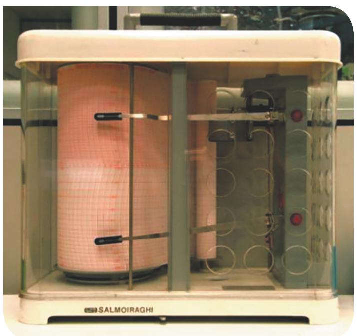


Figure 5
A typical thermo-hygrograph (Photograph courtesy of Luigi Chiesa)



3.2 INFORMATION ON FUNDAMENTAL LABORATORY TEST PRACTICES

This section provides an insight into some test practices fundamental to virtually all measurement procedures. These are the ability to: minimise and measure stray light; measure distances accurately from a light emitting element; and; repeatably establish precise alignment of a light source relative to measurement position.

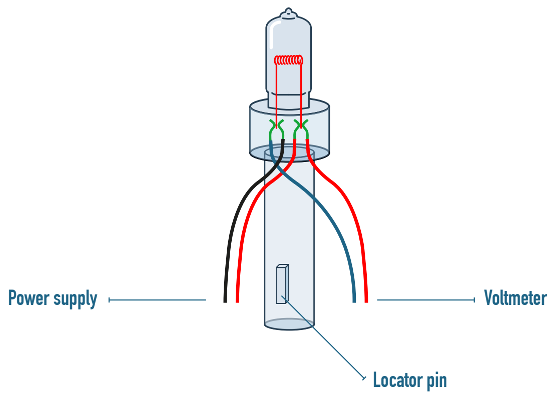
3.2.1 OPTICAL ALIGNMENT OF LUMINOUS INTENSITY STANDARD LAMPS

Luminous intensity standard lamps require calibration of the luminous intensity of the light in a particular direction. An industry reference standard lamp for luminous intensity is required to be calibrated (under CIE Source A conditions signified by a set DC operating current) for the luminous intensity emanating from a particular direction from the lamp for a set orientation of the lamp under standard laboratory environmental conditions (temperature and humidity). Therefore before sending a laboratory's industry reference standard lamp (for luminous intensity) to be externally calibrated in a particular direction, it must be mechanically configured so that this orientation can by reproduced externally by calibration laboratory staff (such as, National Measurement Laboratory) when calibrating it and also by internal laboratory staff when they are to use it. This issue will also apply to any working lamps which are to be internally calibrated for luminous intensity.

There are many options for mechanically achieving alignment of a lamp used as a luminous intensity standard. The critical issue is that the alignment mechanism must be mechanically robust so that the position and alignment of the lamp is reproducible and that any variation produces only an acceptable uncertainty in the luminous intensity provided. Figure 6 shows one such mechanical alignment system, where the lamp is calibrated in the lamp holder that will be used by the laboratory. The lamp holder has some form of locator pin (for controlled orientation of the lamp filament) and has two sets of lead connections to the lamp socket (one heavy duty set for the power supply and the other set for voltage monitoring).

Figure 6

Reference standard lamp in designated holder with separate power supply and voltage measurement leads



3.2.2 THE MEASUREMENT OF DISTANCE ON AN OPTICAL BENCH

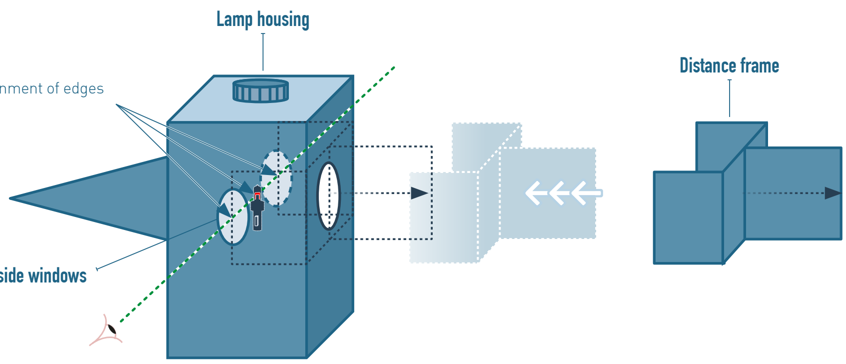
Accurately knowing the distance between the light source and the measurement reference plane is critical in a number of test procedures.[9] This accurate measurement of distance is reliant on the precise location (vertically and along the bench axis) of the lamp filament within the lamp housing. The procedure for determining this location is given below.

9 Such as where the known illuminance at a set distance from a luminous intensity reference standard lamp is used to calibrate illuminance meters

STEP 1 To facilitate an accurate measurement, alignment of the filament is generally required. This is achieved by using a lamp holder with a locator key, or by the use of a laser or a travelling telescope with cross-hairs. As shown in Figure 7, this can be aided by the use of a detachable distance frame which has a known (calibrated) distance from its front to its back.

Figure 7

Alignment of the position of the lamp filament with the distance frame

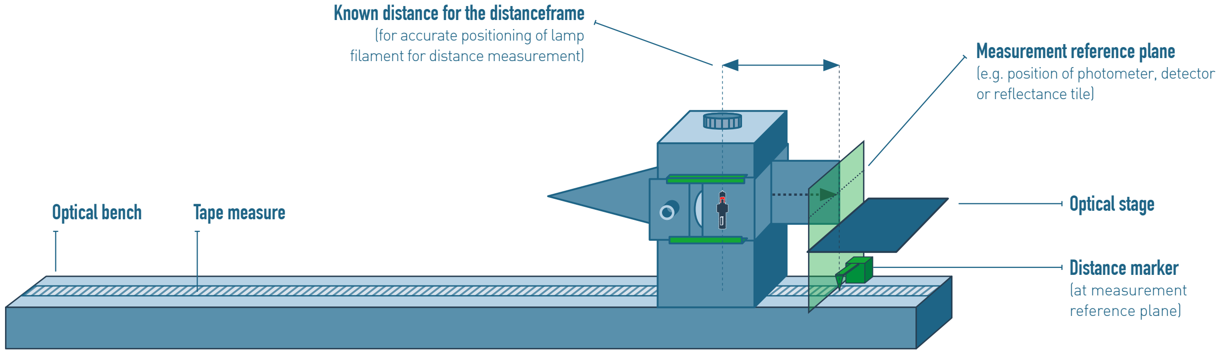


With the side windows to the lamp housing open, the distance frame can be adjusted in position until the edges of the distance frame align with the filament. This process can be aided by operating the lamp on a very low voltage so that the filament has a visually comfortable glow. When in the correctly aligned position, the attached distance frame indicates a fixed distance to the lamp filament, as well as the vertical position of the filament. This facilitates the measurement of distances from the filament to the photometer and setting the photometer at the correct height.

STEP 2 Move the lamp housing up to the measurement reference plane on the optical stage and adjust the target point of the measurement reference plane to the correct height on the optical stage, as shown in Figure 8.

Figure 8

Lamp filament initial positioning by the distance frame at the measurement reference plane



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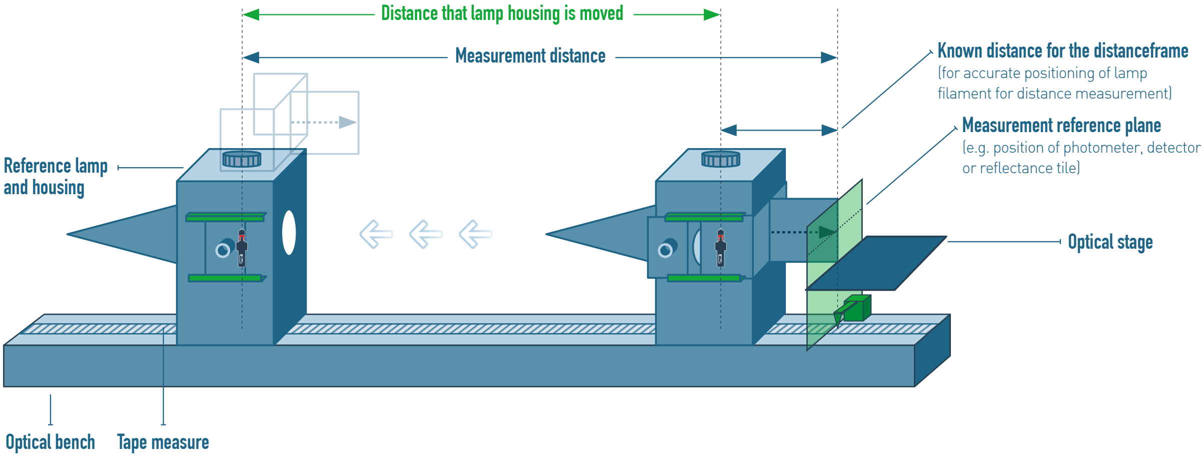
STEP 3 Set the distance marker at the position of the measurement plane. Then move the lamp to the position necessary (taking into account the known distance for the distance frame) to get the required distance from the lamp filament to the measurement reference plane for the test to be conducted, as illustrated in Figure 9.

Figure 9

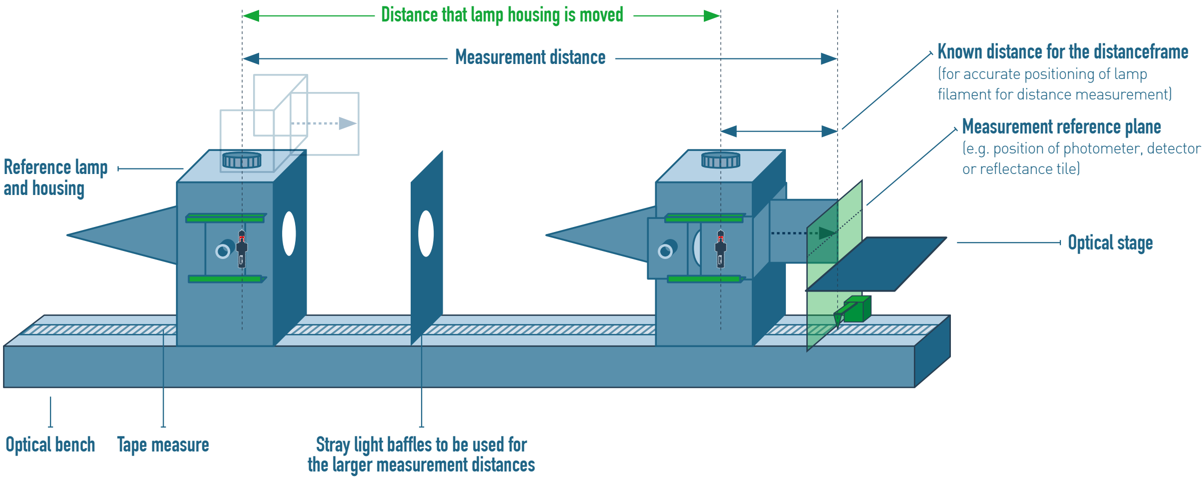
Moving the lamp housing to the prescribed measurement distance



Where the measurement distance is large, include one or more baffles to prevent stray light from affecting the measurement, as shown in Figure 10.

Figure 10

Inclusion of stray light baffles for large distances



3.2.3 MINIMISING STRAY LIGHT

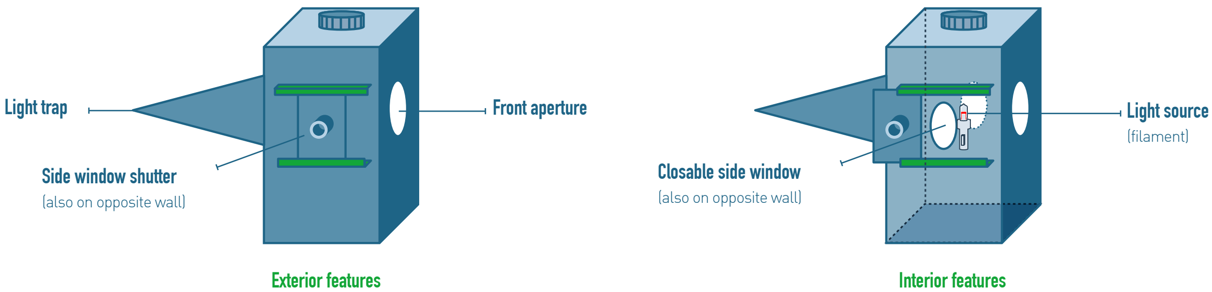
Stray (or background) light is unwanted light from either the test procedure's light source or any other light sources (such as room lights, indicator LEDs or display panels) within the laboratory (or outside it, if their light can enter the laboratory). The light from these light sources may directly or indirectly (multiple reflections) reach the target position (i.e. the reference plane where a detector or object is placed) and adversely affect the test result. Therefore, minimising the stray light within the laboratory room is very important and can be achieved by a combination of the following actions:

- Containing the test procedure's lamp within a housing which blocks and absorbs the light, except that directed through a front aperture to the target position;
- Using a set of baffles with apertures between the lamp and target position;
- Having matt finish black walls and black curtains to minimise any unwanted indirect reflected light to the target position.

Figure 11 illustrates a typical housing for enclosing the lamp to minimise stray light within the laboratory room. Such housings typically have a:

- Front aperture for the light to travel down the optical bench;
- Light tight air vent on top, with an exhaust fan to avoid overheating the lamp which will affect its light output;
- Light trap (in the form of a matt black internally painted cone) behind the lamp to avoid reflection back out the front aperture;
- Two closable windows on the sides of the housing adjacent to the lamp filament to permit accurate alignment of filament for distance measurements.

Figure 11
Typical lamp housing for use on an optical bench



3.2.4 MEASUREMENT OF STRAY LIGHT

As well as minimising the potential impact of stray light by good design of the test room equipment, any stray light which does exist needs to be identified, by following a systematic approach to checking for stray light readings. If found to be present, the source of the stray light should be located and removed (or minimised to insignificance), if it is practical to do so. This is usually achieved by putting in stray light baffles to block the light from reaching the test photometer. If the stray light cannot be removed, a background measurement will be required at the beginning and end of all tests, and at all distances that the reference lamp is positioned from the photometer, to enable a systematic correction of the measurement results.

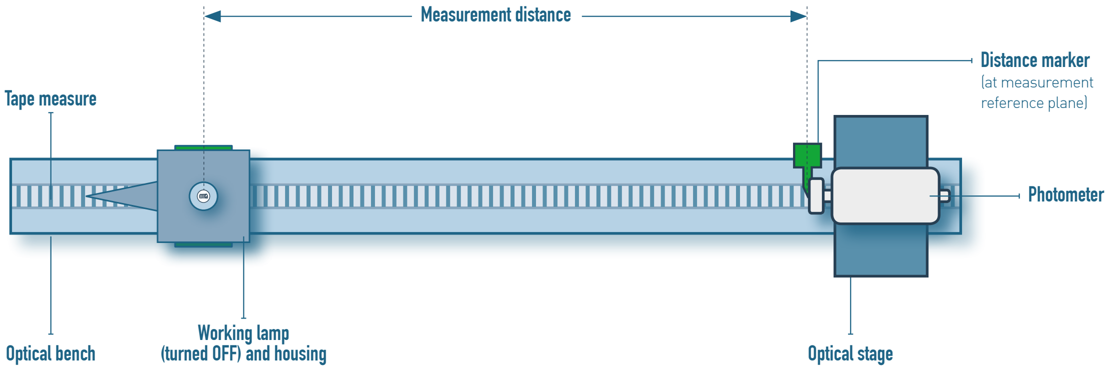
3

To identify any stray light from sources other than the lamp used for the tests:

1. Move the lamp housing to the approximate distances where tests are normally conducted;
2. Place the photometer at the measurement reference plane (or use reflectance tile and luminance meter), as shown in Figure 12;
3. Set the laboratory lighting conditions to those normally used during test measurement procedures. This can include closing down any doors between the lamp and the detector and hanging black cloth around the edge of the optical bench. Room lights should be turned off, and the laboratory door closed, when measurements are taken;
4. With the lamp turned OFF, record the light measurement;
5. If the measurements are not zero (or not deemed too low to be significant) identify the source of the light reaching the photometer;
6. If there is difficulty in identifying where the stray light is originating (this applies particularly for illuminance measurements, as the detector collects light over almost a full hemisphere), move the photometer and place your eye at the measurement reference plane looking towards the lamp housing. This should assist in identifying the stray light source.

Figure 12

Initial set-up for the equipment for measurement of stray light

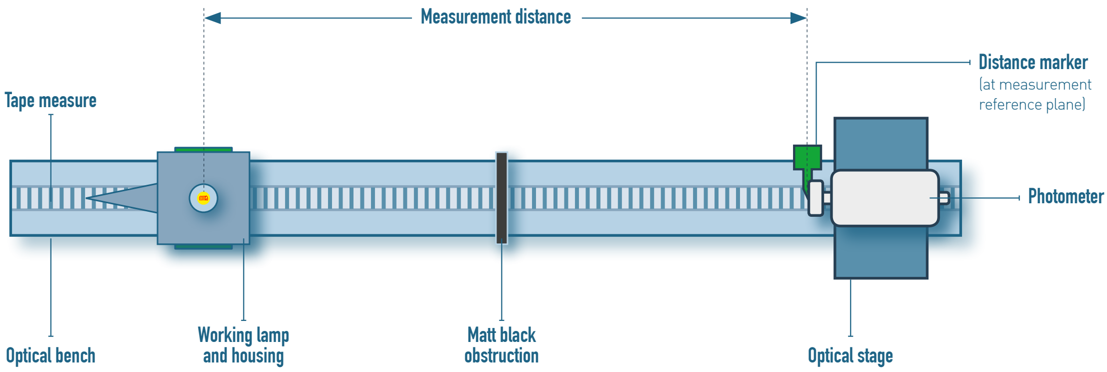


To identify any stray light from the lamp reflected into the photometer by the surrounding equipment:

1. Move the lamp housing to the approximate distances where tests are normally conducted;
2. Block any direct light from the lamp to the photometer by placing a matt black obstruction at the approximate midpoint of the measurement distance. Place the photometer at the measurement reference plane (or use reflectance tile and luminance meter), as shown in Figure 13;
3. Set the laboratory lighting conditions to those normally used during test measurement procedures. This can include closing any doors between the lamp and the detector and hanging black cloth around the edge of the optical bench. Room lights should also be turned off and the laboratory door closed when measurements are taken;
4. With the lamp turned ON, record the light measurement;
5. If the measurements are not zero (or equal to the reading obtained with the light source turned OFF), identify the source of the light reaching the photometer;
6. If there is difficulty in identifying where the stray light is originating (this applies particularly for illuminance measurements as the detector collects light over almost a full hemisphere), move the photometer and place your eye at the measurement reference plane looking towards the lamp housing. This should assist in identifying the stray light source.
7. Move the matt black obstruction to another position (for example, to about one third of the measurement distance from either end) to check that the original position was not obstructing a particular stray light path (as well as the direct light).

Figure 13

Matt black obstruction to allow stray light measurement



3.3 EXTERNAL CALIBRATIONS

To calibrate any item, be it a physical standard or measuring apparatus, all other items used to conduct the calibration must themselves be calibrated. That is, there must be only one unknown element (or combination of elements that are always used together) in the experiment that is yet to be calibrated. Therefore, before any internal calibrations of physical standards or measurement equipment can occur, the laboratory must possess the necessary externally calibrated items to allow the particular internal calibrations to be undertaken. These external calibrations need to be from traceable sources (as discussed in Section 2.1) to ensure measurement traceability is realised for the internally-calibrated laboratory equipment.

The items within a photometric laboratory that must be externally calibrated depends on the measurements the laboratory wishes to undertake. Some typical items are shown in table1.

Table 1

Items in a photometric laboratory that would require external calibration

Item Requiring External Calibration[10]	Calibration Parameters	Items of Equipment Used to Internally Calibrate Specified Parameters							
		Illuminance meters	Luminance meters	Working standard lamps	Colour meters	Monochromators	Photodetectors	Integrating sphere	Goniophotometer
Reference lamps (typically CIE Source A) *Minimum of three*	Luminous intensity	✓	✓	✓	✓		✓		✓
	Luminous flux			✓				✓	✓
	Spectral radiant flux				✓	✓			
	Spectral irradiance				✓	✓	✓		
Photodetector	Spectral response					✓	✓	✓	✓
Reflectance tile[11]	Visible luminous reflectance		✓		✓				
	Spectral reflectance			✓					

10 In some situations, these items may be subject to internal calibration (based on external reference standards and recognised by accreditation).

11 The reflectance tile is a spectrally unbiased surface which has a highly diffuse reflectance that exhibits Lambertian behaviour. These are obtained from scientific optical materials suppliers.

Item Requiring External Calibration[1]	Calibration Parameters	Items of Equipment Used to Internally Calibrate Specified Parameters							
		Illuminance meters	Luminance meters	Working standard lamps	Colour meters	Monochromators	Photodetectors	Integrating Sphere	Goniophotometer
Voltmeter (DC)	DC voltage	✓	✓	✓	✓	✓	✓	✓	✓
Power meter	AC power								
	Voltage								
	Current							✓	✓
	Power factor								
Resistor	Resistance	✓	✓	✓	✓	✓	✓	✓	✓
Thermometer	Temperature	✓	✓	✓	✓	✓	✓	✓	✓
Hygrometer	Relative humidity	✓	✓	✓	✓	✓	✓	✓	✓
Inclinometer	Vertical angle								✓
Measuring tape	Distance	✓	✓	✓					✓
Colour tiles	Colour				✓				
Colour filters	Colour		✓		✓				
Neutral density filter	Luminous transmittance	✓	✓						

3.4 INTERNAL CALIBRATIONS OF LABORATORY METERS, WORKING LAMPS AND OTHER TEST APPARATUS

This section is intended to provide examples of step by step test procedures for conducting internal calibrations of standard lamps, meters and optical elements in a photometric laboratory. Those presented are lamp-based calibration methods when using externally calibrated reference standard lamps. Note that equivalent internal calibrations can be achieved by using detector-based calibration methods.

3.4.1 CALIBRATION OF LABORATORY ILLUMINANCE METERS

Calibration of an illuminance meter (photometer) is achieved by placing the illuminance meter facing towards the standard lamp, which is oriented in the direction that the lamp is calibrated for luminous intensity, as shown in Figure 14. Knowing the distance that the detector is placed from the lamp, it is possible to calculate the illuminance at the position of the illuminance meter.

A typical procedure would then be:

STEP 1 Insert the primary standard lamp in the lamp housing on the optical bench, using a locator pin at the bottom of the lamp shaft to align the lamp correctly along the optical bench (as per the method described in Section 3.2.1) or using another similar alignment method.

STEP 2 Connect the heavy duty set of leads from the lamp socket to the power supply, in series with the standard resistor, and the other set of leads to the voltage reference input of the power supply. If the power supply does not have a voltage reference input, then these leads may be connected to a calibrated digital volt meter to monitor the lamp voltage, or just left free.

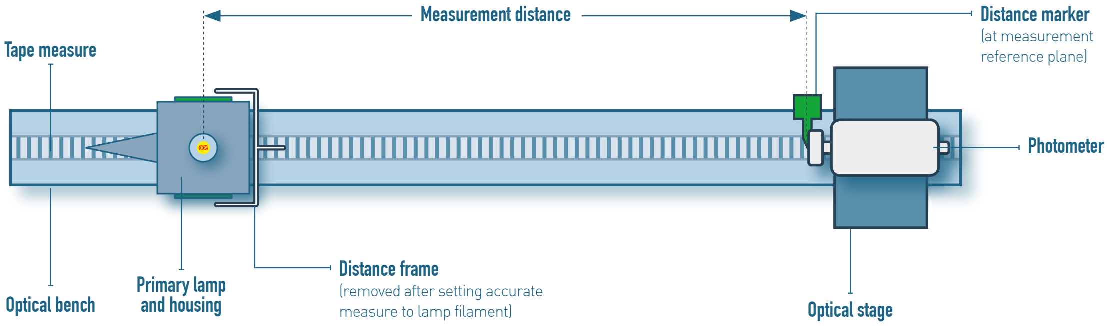
STEP 3 Attach the distance frame to the lamp housing, aligning correctly with the lamp filament. Having the lamp powered at a low level assists with locating the filament position.

STEP 4 Adjust the illuminance meter to the correct vertical height on the optical stage, by referring to the attached distance frame.

STEP 5 Move the lamp housing along the optical bench to set the illuminance meter at the required calibration distance specified by the external calibration laboratory. Check with the manufacturer as to where the reference plane of the illuminance meter is located as it may not be the front diffuser surface of the meter.

STEP 6 Remove the distance frame.

Figure 14
Set-up for illuminance meter calibration



STEP 7 From the (external) calibration current given for the primary standard lamp, calculate the corresponding voltage required across the calibrated resistor to achieve CIE illuminant A conditions.

STEP 8 Turn on the power supply to the lamp and increase the current until the voltage across the calibrated resistor reads this value. The current flowing through the filament will now be the calibration current as reported by the external laboratory. Continue to re-adjust back to this current (by maintaining this voltage reading) for approximately 15 minutes until the lamp's operating conditions (manifested by changing filament resistance) become stable.

STEP 9 Once the lamp is stable, the luminous intensity in the direction of the illuminance meter will now be as reported by the external laboratory.

STEP 10 The illuminance at the position of the illuminance meter is calculated by:

$$E = \frac{I}{d^2}$$

Where:

- E is the illuminance
- I is the calibrated luminous intensity of the primary standard lamp reported by the external laboratory
- d is the calibration distance between the lamp filament and the reference plane of the illuminance meter

Note:This formula is valid only if: d > (10 x filament size) because from the perspective of the illuminance meter, the lamp filament must effectively act as a point source at this distance and beyond.

STEP 11 Before measuring the illuminance at this position, place the cap on the illuminance meter or cover with an opaque material so no light enters the illuminance meter. This will be the 'zero (also known as the dark current) reading'.

STEP 12 Record this 'zero reading'. (Recording this value assists with maintaining a record of the drift over time of the calibration of the meter. If the magnitude of the drift increases then either the calibration interval needs to be reduced or the meter replaced.) If it is not actually zero, where provision exists on the illuminance meter to adjust the reading, adjust it to zero. Where no such provision exists, this 'zero reading' correction needs to be applied to all future measurements and as such, becomes part of (i.e. is incorporated into) the calibration factor adjustment value.

STEP 13 Remove the illuminance meter cap or opaque material cover.

STEP 14 Make a note of the illuminance and, calculate the calibration factor (E_{CF}) required to be applied to the displayed reading ($E_{Reading}$) to obtain the corrected reading ($E_{Corrected}$). This is an absolute value (the mathematical difference between the actual reading and the correct value) and will vary depending on the illuminance level.

$$E_{CF} = (E_{Reading} - E_{Corrected})$$

STEP 15 Record and tabulate these calibration factors. If the illuminance meter has more than one measurement range scale, this process will need to be repeated for each scale, as a different amplifier circuit is in operation within the meter for these scales.

NOTE

The procedure described here is a lamp-based calibration method. It is also possible to perform the calibration by direct comparison with another calibrated illuminance meter (detector-based calibration method).

3.4.2 CALIBRATION OF LABORATORY LUMINANCE METER

Calibration of a luminance meter is achieved by placing the luminance meter in a position facing towards a calibrated reference tile, which is positioned at a set distance to receive a known illuminance from the calibrated luminous intensity of the primary standard lamp in that direction. This set-up is illustrated in Figure 15 and the typical steps in the calibration process are:

STEP 1 Insert the primary standard lamp in the lamp housing on the optical bench, using a locator pin at the bottom of the lamp shaft to align the lamp correctly along the optical bench.

STEP 2 Connect the heavy duty set of leads from the lamp socket to the power supply, in series with the standard resistor, and the other set of leads to the voltage reference input of the power supply. If the power supply does not have a voltage reference input, then these leads may be connected to a calibrated digital voltage meter to monitor the lamp voltage, or just left free.

STEP 3 Attach the distance frame to the lamp housing, aligning correctly with the lamp filament. Having the lamp powered at a low level assists with locating the filament position.

STEP 4 Place the externally calibrated reflectance tile (standard tile) in the holder on the optical bench.

STEP 5 Adjust the standard tile to the correct vertical height on the optical stage, by referring to the attached distance frame. The orientation of the tile relative to the lamp and the luminance meter should be the same as during the external calibration procedure for the tile. Typically this is (0°/45°); signifying (incident light angle)/(measured reflected light angle), i.e. the incident light is normal to the tile and the tile is viewed from an angle of 45° from the normal.

STEP 6 Set the standard tile at the measurement reference plane and adjust the lamp to the calibration distance determined by the calibration report for the tile (either conducted internally within the laboratory or externally by a calibration laboratory).

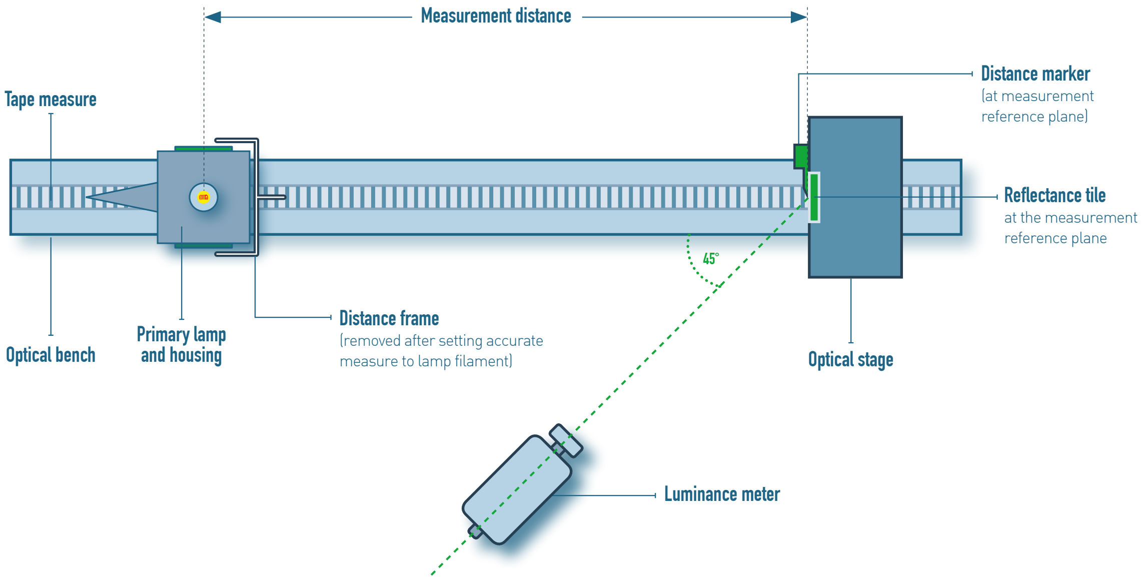
STEP 7 Remove the distance frame.

STEP 8 Set the luminance meter to observe the reflected light from the standard tile at the angle specified (see Step 5). If the lamp was without a housing, a heat shield may be required between the lamp and the luminance meter to avoid heating of the meter, which will affect its calibration.

STEP 9 Ensure the viewing area of the luminance meter is within the boundaries of the standard tile by adjusting the distance of the meter from the standard tile.

Figure 15

Set-up for luminance meter calibration



STEP 10 From the (external) calibration current reported for the primary standard lamp, calculate the corresponding voltage required across the calibrated standard resistor.

STEP 11 Turn on the power supply to the lamp and increase the current until the voltage across the standard resistor reads this value. The current flowing through the filament will now be the calibration current as reported by the external laboratory. Continue to re-adjust back to this current (by maintaining this voltage reading) for approximately 15 minutes as the lamp's operating conditions (manifested by changing filament resistance) become stable.

STEP 12 Once the lamp is stable, the luminous intensity in the direction of the tile will now be the same as reported by the external laboratory.

STEP 13 If the tile is calibrated for total reflectance only, then assuming the standard tile to be a perfect diffuser, the luminance of the tile is calculated by:

$$L = \frac{\rho E}{\pi}$$

Where:

- L is the illuminance
- ρ is the calibrated reflectance of the standard tile reported by the external laboratory for the geometric arrangement (0°/45°), that has photometric data V(λ) corrected and using illuminant CIE Source A.
- E is the known illuminance incident at the tile's position.

Record the luminance and, where provision exists on the luminance meter, adjust any calibration controls on the meter so that it displays the known luminance reading from the standard tile. If there are no calibration controls, calculate the correction factor required to be applied to the displayed reading. These are absolute values (the mathematical difference between the actual reading and the correct value) and will vary depending on the luminance level. Record these calibration factors.

$$L_{CF} = (L_{Reading} - L_{Corrected})$$

STEP 14 If the luminance meter has selectable viewing areas (field of view), change the field of view and repeat Steps 8, 9 and 14 as a different aperture and amplifier circuit is in operation within the meter for these scales. Note that luminance of the standard tile is unchanged so the same measurement reading should be obtained, otherwise different calibration factors are required for each field of view.

NOTE

The procedure described here is a lamp-based calibration method. It is also possible to perform the calibration by direct comparison with another calibrated luminance meter (detector-based calibration method).

3.4.3 CALIBRATION OF LABORATORY COLOUR METER

Generally the colour meter is also a luminance meter. Calibration for luminance and colour can be done at the same time. Calibration of a colour meter is achieved by placing the meter in a position facing towards a calibrated reference tile, which is positioned to receive a light from a calibrated primary standard lamp. Some colour meters can operate in selectable modes displaying different colour system parameters: tri-stimulus coordinates X, Y, and Z; the CIE chromaticity coordinates x and y; the associated parameters of CIELUV and CIELAB systems[10] and the correlated colour temperature, CCT. With a primary standard lamp operating at the conditions of a CIE Source A light source, the chromaticity co-ordinates are x = 0.4476, y = 0.4075, z = 0.1449, and the colour temperature is 2856 K.

The experimental arrangement is the same as that given in 3.4.2 for calibrating the laboratory luminance meters from Steps 1 to 12, with the field of view of the colour meter noted and recorded. Once these steps have been completed and the laboratory standard lamp is in stable operation, CIE Source A conditions will prevail. The procedure for calibrating the colour meter can then be continued:

STEP 13 Using the display mode switch, switch through all the colour measurement modes, recording each set of values. In particular, confirm that:

a. Y values should be identical to L values
b. L* should be 100 while a*, b*, u* and v* should be zero

12 For more information see CIE publication, CIE 15:2004, *Colorimetry*

STEP 14 Record the colour parameter measurements and, where provision exists on the colour meter, adjust any calibration controls on the meter so that it displays the known colour reading from the standard tile. If there are no calibration adjustment controls, calculate the correction offset, (the difference between the actual reading and the correct value), required to be applied to the displayed reading. These correction offsets will most likely differ in different areas of the colour space. Record these calibration offsets.

$$P_{CF} = (P_{Reading} - P_{Corrected})$$

Where:

P is colour parameter

STEP 15 Additional calibration checks can be conducted by using an externally calibrated set of colour filters and/or colour tiles, following the same procedure.

3.4.4 CALIBRATION OF LABORATORY WORKING LAMPS (CIE SOURCE A)

Working lamps are critical to the practical operation of a laboratory. For lamp stability and filament longevity, working lamps are typically of extra low voltage (12 V) halogen technology. A 50 W lamp will provide an appropriate luminous flux level for measurements. Working lamps are firstly calibrated for CIE Source A operation against the calibrated reference tile and calibrated colour meter. Calibration for intensity in a fixed direction is achieved at a fixed distance by calibrating against the calibrated illuminance meter, or by using the calibrated reference tile and calibrated luminance meter. The example given here is for a calibrated reference tile and calibrated luminance meter, and the set-up is shown in Figure 16.

STEP 1 Make sure the working lamp has been aged for at least 24 hours.

STEP 2 Mount the lamp on a lamp holder similar to those developed for the laboratory's standard lamps, i.e. one that includes a physical locator for lamp orientation and dual lead set.

STEP 3 Insert the working standard lamp in the lamp housing on the optical bench, using the locator pin at the bottom of the lamp shaft to align the lamp correctly along the optical bench.

STEP 4 Connect the heavy duty set of leads from the lamp socket to the power supply, in series with the standard resistor, and the other set of leads to the voltage reference input of the power supply. If the power supply does not have a voltage reference input, then these leads may be connected to a calibrated digital voltage meter to monitor the lamp voltage, or just left free.

STEP 5 Attach the distance frame to the lamp housing, aligning correctly with the lamp filament. Having the lamp powered at a low level assists with locating the filament position.

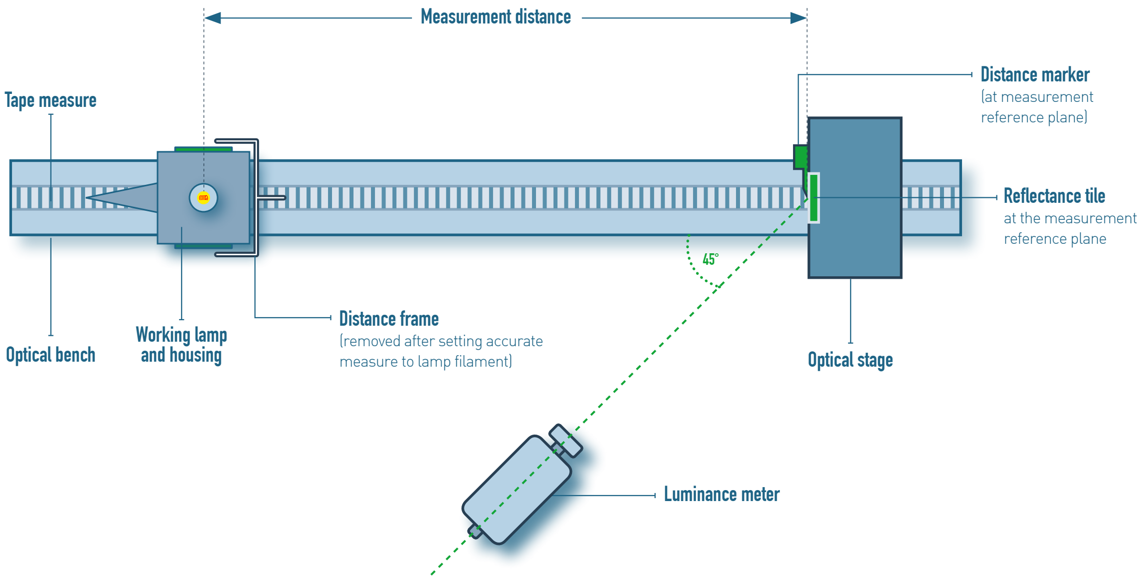
STEP 6 Place the externally calibrated reflectance tile (standard tile) in the holder on the optical bench.

STEP 7 Adjust the standard tile to the correct vertical height on the optical stage, by referring to the attached distance frame. The orientation of the tile relative to the lamp and the luminance meter should be the same as during the external calibration procedure for the tile. Typically this is (0°/45°); signifying (incident light angle)/(measured reflected light angle).

STEP 8 Set the standard tile at a distance which will become the calibration distance for intensity from this working lamp.

STEP 9 Remove the distance frame.

Figure 16
Set-up for calibration of working lamp with luminance meter



STEP 10 Set the combined colour/luminance meter to colour meter mode or use a colour meter.

STEP 11 Set the colour meter to observe the reflected light from the standard tile at the angle specified (typically 45°)

STEP 12 Ensure the viewing area of the colour meter is within the boundaries of the standard tile by adjusting the distance of the meter from the standard tile.

STEP 13 Turn on the power supply to the lamp and increase the current until the colour meter reads CIE Source A conditions (x=0.4476, y=0.4075), accounting for any calibration offset requirements for the colour meter.

STEP 14 Continue to re-adjust the current to maintain this colour reading for approximately 15 minutes as the lamp's operating conditions (manifested by changing filament resistance) become stable.

STEP 15 Once the lamp is stable, record the voltage across the calibrated resistor. The current flowing through the filament at this voltage will become the calibration current.

STEP 16 Using Ohm's Law[13], calculate and record the calibration current.

To measure the intensity of the working lamp now operating in Source A conditions, if using a luminance meter to calibrate for luminous intensity:

STEP 17 Switch the colour/luminance meter to luminance mode or replace colour meter with a luminance meter, and record the luminance of the standard tile.

13 voltage (V) = current (I) x resistance (R)

STEP 18 Assuming the standard tile to be a perfect diffuser, the luminous intensity in the direction of the standard tile is calculated by:

$$I = \frac{\pi d^2 L}{\rho}$$

Where:

- I is the luminous intensity
- d is the set calibration distance from the standard tile to the working lamp filament
- ρ is the calibrated reflectance of the standard tile reported by the external laboratory for the geometric arrangement (0°/45°), that has photometric data V(λ) corrected and using illuminant CIE Source A.
- L is the measured luminance incident on the tile

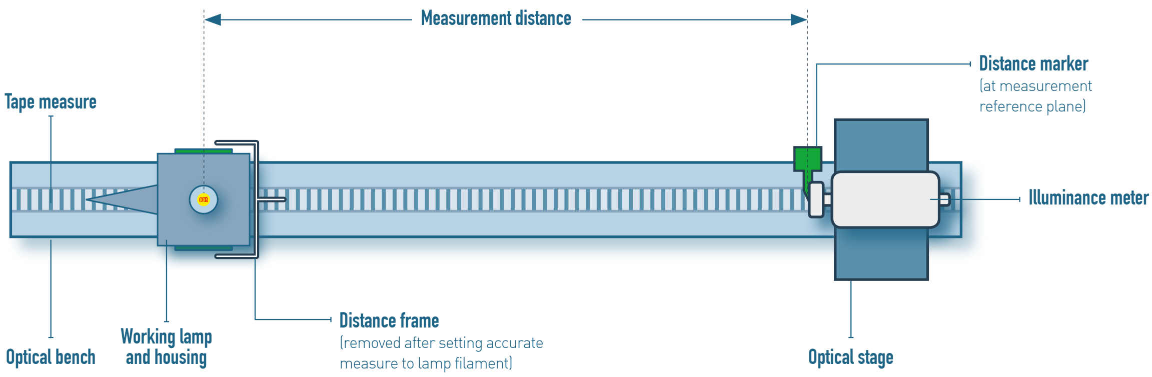
STEP 19 Record the luminance and calculate the luminous intensity.

STEP 20 Record the luminous intensity of the working standard lamp, the operating current and the set calibration distance.

If using an illuminance meter to calibrate for luminous intensity:

STEP 17 Remove the standard tile and place the illuminance meter in the same position, as shown in Figure 17.

Figure 17
Set-up for calibration of working lamp with illuminance meter



STEP 18 The luminous intensity in the direction of the illuminance meter is calculated from the illuminance measured at the position of the illuminance meter by:

$$I = Ed^2$$

Where:

- I is the luminous intensity
- d is the set calibration distance from the illuminance meter to the working lamp filament
- E is the illuminance at the set calibration distance from the working lamp filament

STEP 19 Record the illuminance and calculate the luminous intensity.

STEP 20 Record the luminous intensity of the working standard lamp, the operating current and the set calibration distance.

3

3.4.5 CALIBRATION OF A LABORATORY REFLECTANCE TILE

Calibration of a laboratory reflectance tile is achieved by calibrating the measured luminance from the externally calibrated standard reference tile from a CIE Source A working standard against the luminance measured from the laboratory reflectance tile in the same situation. The steps for this procedure are given below and the set-up is shown in Figure 18.

STEP 1 Insert the working standard lamp in the lamp housing on the optical bench, using a locator pin at the bottom of the lamp shaft to align the lamp correctly along the optical bench.

STEP 2 Connect the heavy duty set of leads from the lamp socket to the power supply in series with the standard resistor and the other set of leads to the voltage reference input of the power supply. If the power supply does not have a voltage reference input, then these leads may be connected to a calibrated digital voltage meter to monitor the lamp voltage, or just left free.

STEP 3 Attach the distance frame to the lamp housing aligning correctly with the lamp filament. Having the lamp powered at a low level assists with locating the filament position.

STEP 4 Place the externally calibrated reflectance tile (standard tile) in the holder on the optical bench.

STEP 5 Adjust the standard reference tile to the correct vertical height on the optical stage, by referring to the attached distance frame. The orientation of the tile relative to the lamp and the luminance meter should be the same as during the external calibration procedure for the tile. Typically this is (0°/45°); signifying (incident light angle)/(measured reflected light angle).

STEP 6 Set the standard tile distance at a known distance.

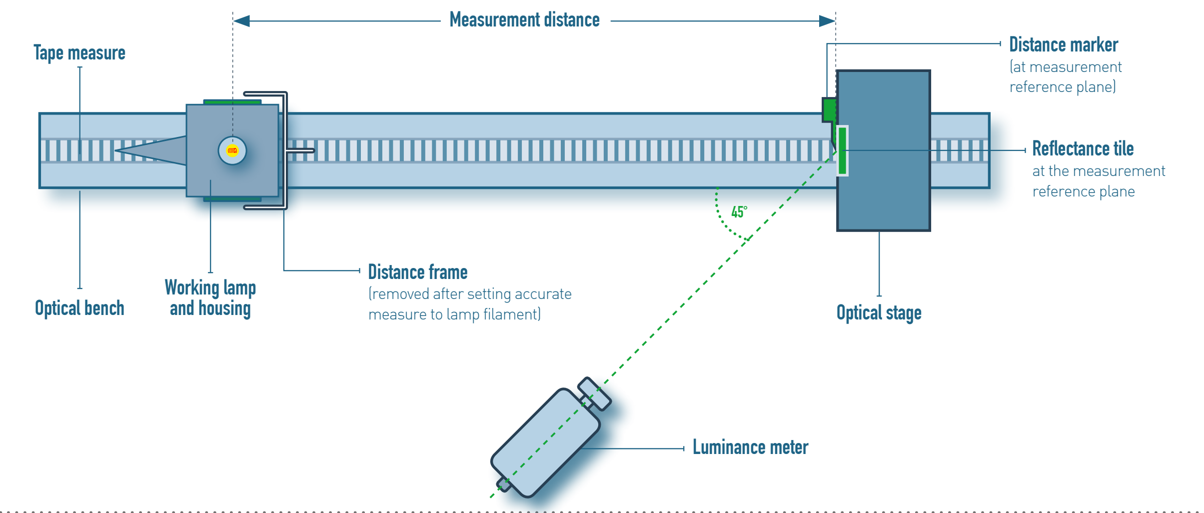
STEP 7 Remove the distance frame.

STEP 8 Set the luminance meter to observe the reflected light from the standard tile at the angle specified (see Step 5).

STEP 9 Ensure the viewing area of the luminance meter is within the boundaries of the standard tile by adjusting the distance of the meter from the standard tile.

Figure 18

Set-up for calibration of reflectance tile with luminance meter



STEP 10 From the calibration current recorded (reported in the calibration report) for the working standard lamp, use Ohm's Law[14] to determine the corresponding voltage required across the calibrated resistor to achieve CIE Source A illuminant conditions.

STEP 11 Turn on the power supply to the lamp and increase the current until the voltage across the standard resistor reads this value. Continue to re-adjust back to this current (by maintaining this voltage reading) for approximately 15 minutes as the lamp's operating conditions (manifested by changing filament resistance) become stable.

STEP 12 Record the luminance of the standard tile.

STEP 13 Assuming the standard tile to be a perfect diffuser (as claimed by the tile manufacturer) but not 100% reflective, the 100% luminance of the tile is calculated by:

$$L_{100\%} = \frac{L_\rho}{\rho}$$

Where:

$L_{100\%}$ is the calculated luminance incident from a 100% reflectance tile at this position
ρ is the calibrated reflectance of the standard tile reported by the external laboratory
L_ρ is the measured luminance incident at the reference tile's position

STEP 14 Remove the reference tile and replace with the laboratory reflectance tile in the same position. If the laboratory reflectance tile is smaller than the reference tile, check that the entire viewing area of the luminance meter is within the boundaries of the laboratory reflectance tile. If not, move the luminance meter closer until the entire viewing area is within the boundaries of the tile and start from Step 4 again.

STEP 15 Record the luminance of the laboratory tile.

STEP 16 The reflectance of the laboratory reflectance tile is calculated by:

$$\rho_w = \frac{L_{\rho w}}{L_{100\%}}$$

Where:

ρ_w is the calibrated reflectance of the laboratory reflectance tile
$L_{\rho w}$ is the luminance measured from the laboratory reflectance tile
$L_{100\%}$ is the calculated luminance incident from a 100% reflectance tile at this position

STEP 17 Calculate and record the reflectance of the laboratory reflectance tile.

3.4.6 TESTING LINEARITY OF PHOTOMETERS

The linearity of measurements from photometers, either illuminance or luminance meters, can be checked using the inverse square law[15] with a calibrated standard lamp (for an illuminance meter) or with a calibrated standard lamp and a calibrated reflectance tile (for a luminance meter). This test method assists in determining whether a meter measures correctly at different light levels and is a necessary calibration test for determining measurement uncertainty of photometers. It is critical in this method to know the measurement plane (which may not be the front surface) of the photometer under test. This information should be provided by the manufacturer.

For an illuminance meter:
The steps in the procedure for testing the linearity of an illuminance meter are given below and the set-up is shown in Figure 19.

14 voltage (V) = current (I) x resistance (R)
15 For perpendicular arrangement (i.e. light incident at right angle to surface): illuminance (E) = intensity (I) / distance (d)^2

NOTE

The effect of stray light on measurements may be different at each position of the light source on the optical bench. This should be checked at each position by placing a block (obstruction) in the direct path of the light to the reflectance tile and taking a zero reading that is subtracted from the recorded reading at each position. Also, when the neutral density filter (NDF) is required in the test method, the effect of stray light may be different than when the NDF is not in place, so the stray light may need to be checked by putting a mask over the NDF and taking a zero reading that is subtracted from the recorded reading with the NDF at each position.

STEP 1 Insert the working standard lamp in the lamp housing on the optical bench, using a locator pin at the bottom of the lamp shaft to align the lamp correctly along the optical bench.

STEP 2 Connect the heavy duty set of leads from the lamp socket to the power supply, in series with the standard resistor, and the other set of leads to the voltage reference input of the power supply. If the power supply does not have a voltage reference input, then these leads may be connected to a calibrated digital voltage meter to monitor the lamp voltage, or just left free.

STEP 3 Attach the distance frame to the lamp housing aligning correctly with the lamp filament. Having the lamp powered at a low level assists with locating the filament position.

STEP 4 Adjust the illuminance meter to the correct vertical height on the optical stage, by referring to the attached distance frame.

STEP 5 Set the illuminance meter at the recorded calibration distance as set out in Table 2 below to achieve the recorded calibrated illuminance (also specified in the table).

STEP 6 Remove the distance frame.

STEP 7 From the calibration current recorded for the working standard lamp, using Ohm's Law[16], calculate the corresponding voltage required across the calibrated resistor to achieve CIE Source A illuminant conditions.

STEP 8 Turn on the power supply to the lamp and increase the current until the voltage across the standard resistor reads this value. Continue to re-adjust back to this current (by maintaining this voltage reading) for approximately 15 minutes as the lamp's operating conditions (manifested by changing filament resistance) become stable.

STEP 9 Once the lamp is stable, the luminous intensity in the direction of the illuminance meter will now be that recorded during the calibration of the working standard lamp.

STEP 10 Calculate the distances needed to obtain a range of illuminance values for positioning the illuminance meter by using:

$$d = \sqrt{\frac{I}{E}}$$

Where:

- ***d*** is the distance between the lamp filament and the illuminance meter (whereby d > 10 x (filament size); because from the perspective of the illuminance meter, the lamp filament is effectively a point source at this distance)
- ***I*** is the calibrated luminous intensity of the working standard lamp recorded by the laboratory
- ***E*** is the expected illuminance

An example of such a range of illuminances and associated calculated distances is provided in Table 2.

STEP 11 Cover the illuminance meter so that no light can be received. Record this reading as the 'zero reading'.

16 voltage (V) = current (I) x resistance (R)

STEP 12 Move the working lamp to the specified distances in the table and, after 30 seconds to allow for dissipation of any residual movement, record the illuminance reading.

Figure 19

Set-up for linearity test of an illuminance meter

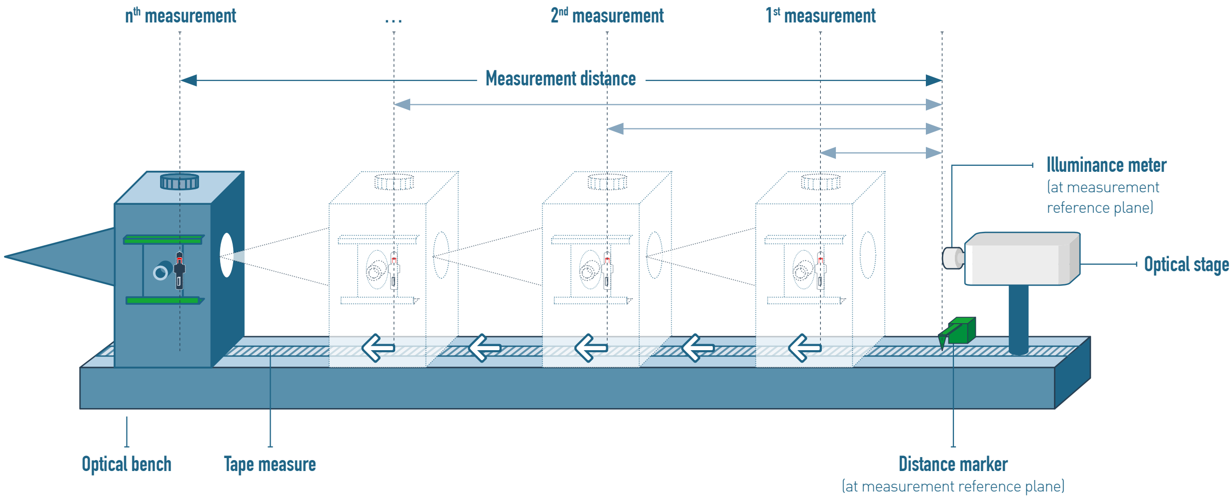


Table 2 provides an example of how these distances and corresponding illuminance values may be tabulated.

Table 2

Example of tabulation of linearity measurement distances and corresponding expected and measured illuminance values

Distance Between Lamp Filament and Photometer (m) (using relevant equations in this section)	Expected Illuminance Reading (lux) (based on lamp calibration)	Measured Illuminance (lux)
Recorded calibration distance	Recorded calibration illuminance	
With meter covered	0.0	
+ NDF	1.0	
+ NDF	2.0	
	5.0	
	10.0	
	25.0	
	50.0	
	100.0	
	250.0	
	500.0	
	750.0	
	1000.0	
	2000.0	
Recorded calibration distance	Recorded calibration illuminance	

Note: NDF = Neutral density filter (see Step 13)

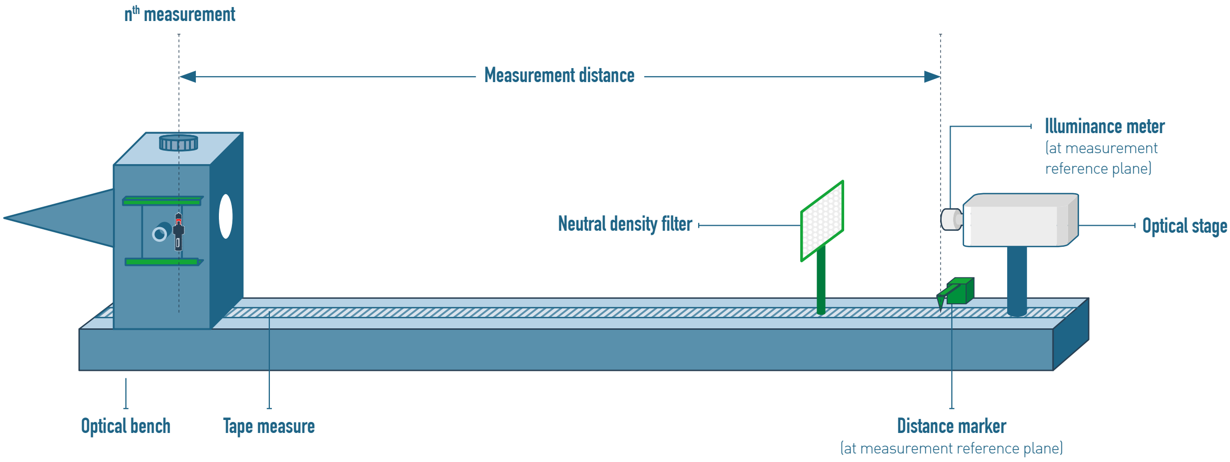
STEP 13 For distances beyond those achievable in the laboratory (necessary to reduce the illuminance at the measurement plane), the intensity of the lamp can instead be reduced by the use of a neutral density filter. Calculate the revised distances when using calibrated neutral density filters in the optical path (as shown in Figure 20) to achieve these lower illuminance levels by:

$$d = \sqrt{\frac{(TI)}{E}}$$

Where:

d	is the distance between the lamp filament and the illuminance meter
T	is the calibrated luminous transmittance that has photometric data V(λ) corrected and using illuminant CIE Source A of the neutral density filter recorded by the laboratory
I	is the calibrated luminous intensity of the working standard lamp recorded by the laboratory
E	is the expected illuminance

Figure 20
Inclusion of neutral density filter for low level measurements



STEP 14 On completion of all measurement distances, return to the calibration distance, record the illuminance and compare this with the initial illuminance value at this distance. Check that any discrepancy is within expected tolerance. Not achieving a similar measurement within the expected tolerance highlights that something in the measurement procedure has not remained consistent and a re-test may be required.

For a luminance meter:

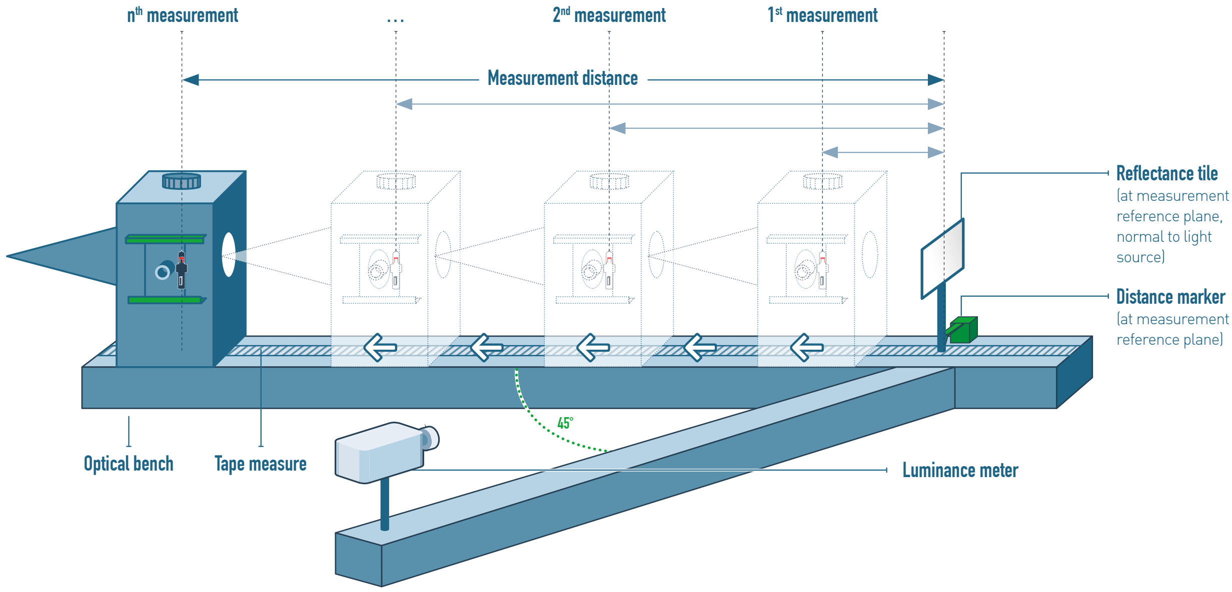
The steps in the procedure for testing the linearity of a luminance meter are given below and the set-up is shown in Figure 21.

NOTE

The effect of stray light on measurements may be different at each position of the light source on the optical bench. This should be checked at each position by placing a block (obstruction) in the direct path of the light to the reflectance tile and taking a zero reading that is subtracted from the recorded reading at each position. Also with the neutral density filter (NDF) in place the effect of stray light may be different than when the NDF is not in place, so the stray light may need to be checked by putting a mask over the NDF and taking a zero reading that is subtracted from the recorded reading with the NDF at each position.

Figure 21

Set-up for linearity test of an illuminance meter



STEP 1 Insert the working standard lamp in the lamp housing on the optical bench, using a locator pin at the bottom of the lamp shaft to align the lamp correctly along the optical bench.

STEP 2 Connect the heavy duty set of leads from the lamp socket to the power supply in series with the standard resistor and the other set of leads to the voltage reference input of the power supply. If the power supply does not have a voltage reference input, then these leads may be connected to a calibrated digital voltage meter to monitor the lamp voltage, or just left free.

STEP 3 Attach the distance frame to the lamp housing aligning correctly with the lamp filament. Having the lamp powered at a low level assists with locating the filament position.

STEP 4 Place the calibrated reflectance tile in the holder on the optical bench.

STEP 5 Adjust the standard tile to the correct vertical height, by referring to the attached distance frame. The orientation of the tile relative to the lamp and the luminance meter should be the same as during the external calibration procedure. Typically this is (0°/45°); signifying (incident light angle)/(measured reflected light angle)

STEP 6 Adjust the lamp to the calibration distance determined by the calibration report for the tile (either conducted internally within the laboratory or externally by a calibration laboratory).

STEP 7 Remove the distance frame.

STEP 8 Set the luminance meter (for example, on a tripod or on another optical bench) to observe the reflected light from the standard tile at the angle specified (see Step 5).

STEP 9 Ensure the viewing area of the luminance meter is within the boundaries of the standard tile by adjusting the distance of the meter from the standard tile.

STEP 10 From the calibration current given for the working standard lamp, using Ohm's Law[17] calculate the corresponding voltage required across the calibrated resistor to achieve CIE Source A illuminant conditions.

STEP 11 Turn on the power supply to the lamp and increase the current until the voltage across the standard resistor reads this value. Continue to re-adjust back to this current (by maintaining this voltage reading) for approximately 15 minutes as the lamp's operating conditions (manifested by changing filament resistance) become stable.

STEP 12 Once the lamp is stable, the luminous intensity in the direction of the tile will now be that as recorded during the calibration of the working standard lamp.

STEP 13 Calculate the distances needed to obtain a range of luminance values for positioning the luminance meter by using:

$$d = \sqrt{\frac{(\rho I)}{(\pi L)}}$$

Where:

- ***d*** is the distance between the lamp filament and the reflectance tile
- ***ρ*** is the calibrated reflectance of the standard tile recorded by the laboratory
- ***I*** is the calibrated luminous intensity of the working standard lamp recorded by the laboratory
- ***L*** is the expected luminance incident at the tile's position

STEP 14 Cover the luminance meter so that no light can be received. Record this reading as the 'zero reading'.

STEP 15 Move the working lamp to the specified distances in the table and, after 30 seconds to allowing for dissipation of any residual movement, record the luminance reading.

Table 3 provides an example of how these distances and corresponding luminance values may be tabulated

Table 3

Example of tabulation of linearity measurement distances and corresponding expected and measured luminance values

Distance Between Lamp Filament and Reflectance Tile (m) (using relevant equations in this section)	Expected Luminance (cd/m²) (based on lamp calibration)	Measured Luminance (cd/m²)
Recorded calibration distance	Recorded calibration luminance	
With meter covered	0.0	
+ NDF	1.0	
+ NDF	2.0	
	5.0	
	10.0	
	25.0	
	50.0	
	75.0	
	100.0	
	200.0	
	300.0	
	400.0	
Recorded calibration distance	Recorded calibration luminance	

Note: NDF = Neutral density filter

17 voltage (V) = current (I) x resistance (R)

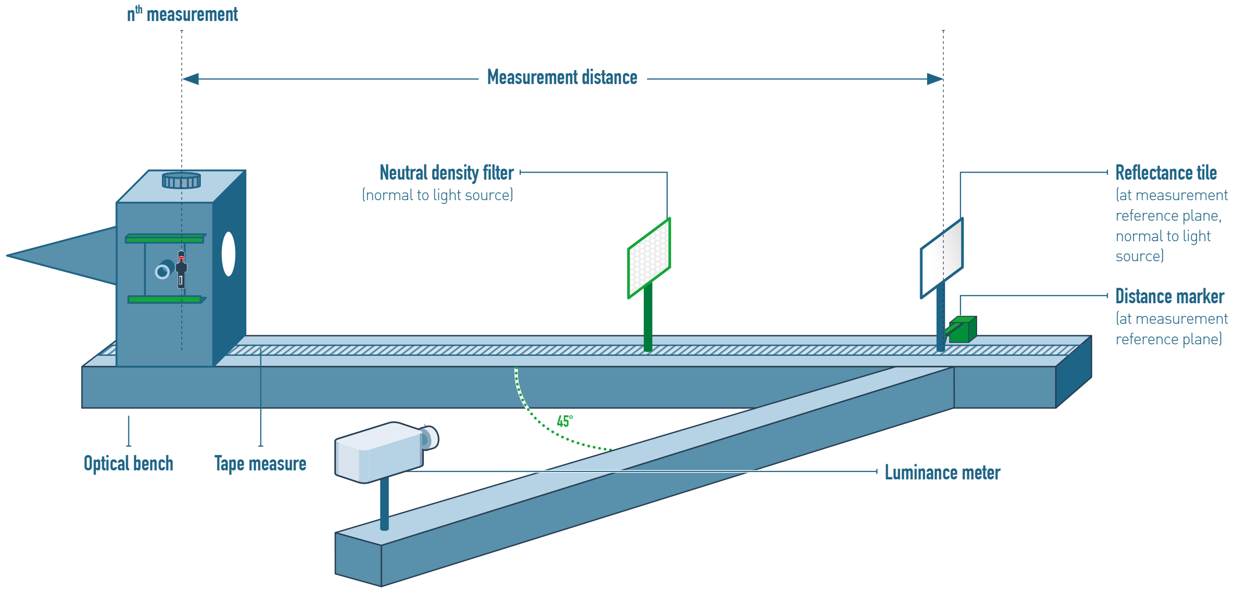
STEP 16 For distances beyond those achievable in the laboratory (necessary to reduce the luminance at the reflectance tile), the intensity of the lamp can instead be reduced by the use of a neutral density filter. Calculate the revised distances when using calibrated neutral density filters in the optical path (oriented normal to the light source), as shown in Figure 22, to achieve these lower luminance levels by:

$$d = \sqrt{\frac{(\rho T I)}{(\pi L)}}$$

Where:

- ρ is the calibrated reflectance of the standard tile recorded by the laboratory
- T is the calibrated luminous transmittance of the neutral density filter recorded by the laboratory
- I is the calibrated luminous intensity of the working standard lamp recorded by the laboratory
- L is the expected luminance incident at the tile's position

Figure 22
Inclusion of neutral density filter for low level measurements



STEP 17 On completion of all measurement distances return to the calibration distance and record and compare with the initial luminance and check within expected tolerance.

3.4.7 UNDERTAKING LINEARITY AND DATA INPUT TESTS

As an alternative to the method outlined in Section 3.4.6, the linearity of photometers (illuminance and luminance meters) and any connected data acquisition systems can be checked using the principle of addition of radiant flux[18] from two sources (working lamps).

The steps in this procedure are given below and illustrated in Figure 23 to Figure 27:

STEP 1 The two working lamps are mounted, preferably on the optical bench (or goniometer) for stability, side by side and about 15 centimetres apart, with a baffle between them so that the light from one lamp is blocked from the

18 The combined radiant flux from two sources will be the algebraic sum of the individual radiant fluxes.

other lamp. A rectangular board (or housing/stop) is mounted about 5 centimetres in front of the lamps so the light from each lamp can pass through a window towards the measuring instrument (illuminance meter or reflectance tile for luminance meters).

STEP 2 The two lamps are connected in series to the power supply, so both lamps receive the same power and emit approximately the same illumination.

STEP 3 The measurements required for the linearity test are the individual readings from each lamp, obtained as the aperture of each lamp is covered in turn (as illustrated in Figure 23 and Figure 24); and the combined reading with both apertures open (as illustrated in Figure 25.

Figure 23
Linearity test: Source 1 shutter open

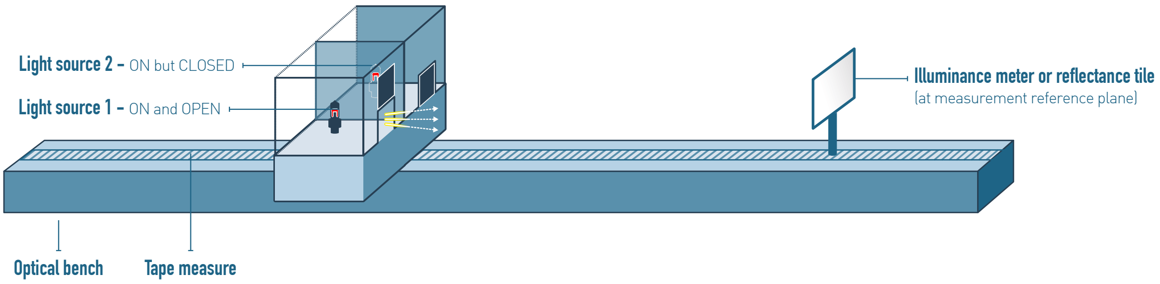
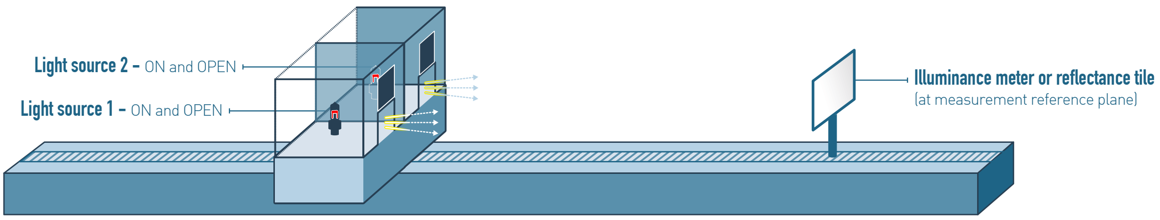


Figure 24
Linearity test: Source 2 shutter open

Figure 25
Linearity test: Source 1 and 2 shutters open



STEP 4 Readings are taken firstly at very low values (around 1 lux or 1 cd/m2) then values obtained by increasing the power to the lamps until individually they have about the same value as their sum from the previous reading. For example, if individually each lamp registers about 1 lux at the illuminance meter giving a combined reading of about 2 lux, then the next set of readings is taken with individual readings at about 2 lux (then 4 lux, 8 lux etc.). A similar progression applies for luminance measurements.

Note that the CCT of the lamps will change as the power is altered. It is therefore advisable that, when adjusting the power of the lamps, the CCT of both lamps is similar at each particular setting so that the spectral mismatch errors V(λ)[19] are minimised and do not affect the results of the linearity test.

As the power to the lamps is varied, the lamps should be left for about 30 seconds to stabilise before readings are taken.

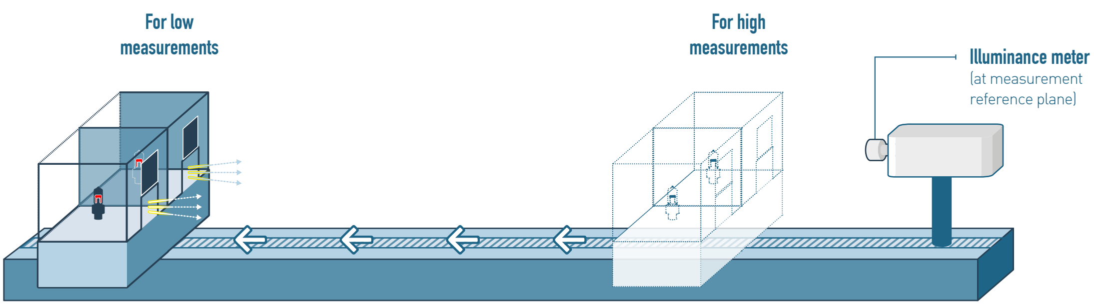
STEP 5 At the start of the measurements, and from time to time through the test, a background reading should be acquired by obtaining a reading at the meter with both apertures covered. If the background reading is greater than 0.1% of an individual reading, black cloth may need to be draped around to minimise the stray light reaching the relevant meter (and/or tile). Alternatively, the background reading can be subtracted from all readings.

STEP 6

For an illuminance meter:

The meter can be set up at any suitable distance from the lamp/stop assembly. Typically, placement 3 to 5 metres away allows testing at low values, while setting up about 60 to 80 centimetres away allows testing at the higher end of the meter scales. Although the range of measurement values can be obtained by varying the measurement distance (as illustrated in Figure 26) it can be more easily be achieved by changing the power to the lamps, as it is not necessary that they be operating at CIE Source A conditions.

Figure 26
Linearity test: Use of distance to change measurement level



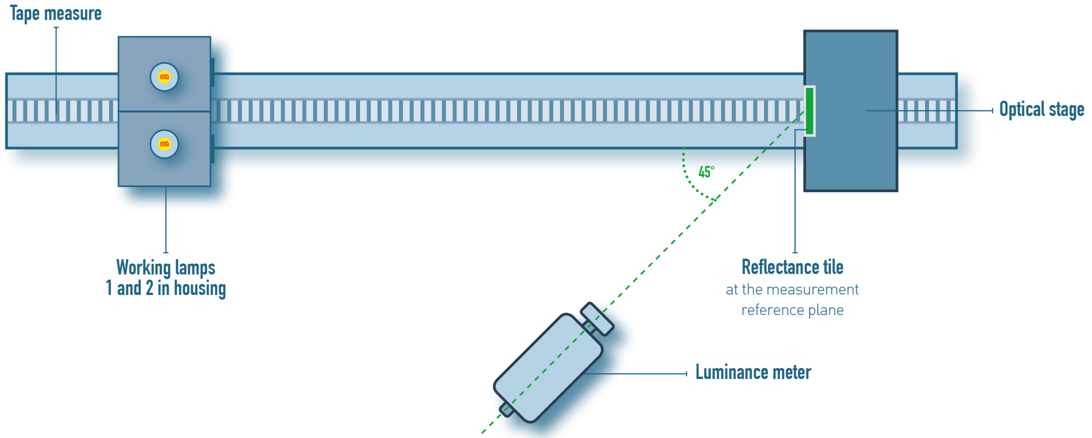
For a luminance meter:

When testing a luminance meter, the laboratory reflectance tile is set up as discussed in Section 3.4.2, and the meter is mounted (for example, on a tripod or on another optical bench) to measure the luminance at the tile, as illustrated in Figure 27. The measurement angle is approximately 45°.

19 Spectral mismatch is where a meter does not have a spectral response similar to the human eye (known as the photopic response) and therefore will provide incorrect measurements under spectrally different light sources.

Figure 27

Linearity test: Luminance meter set-up



STEP 7 Record the set of readings (as described in Step 4) in a table. Table 4 shows an example of a recording table for this data.

STEP 8 Calculate the relative linearity error (based on the range limit for the measurements) using:

$$f_3(Y) = \left| \frac{Y}{Y_{max}} \cdot \frac{X_{max}}{X} - 1 \right|$$

Where:

- $f_3(Y)$ *is the relative linearity error*
- Y *is the reading from combined light sources 1 and 2*
- Y_{max} *is the maximum reading obtained from the combined light sources*
- X *is the arithmetic sum of the individual readings for light source 1 and 2*
- X_{max} *is the maximum arithmetic sum of the individual readings for light source 1 and 2*

STEP 9 The maximum relative linearity error, $f_3(Y)_{max}$, is assigned as the linearity error for the range of measurements.

Table 4

Example of a recording table for linearity test readings when using the principle of addition of radiant flux from two sources

Reading from Light Source 1	Reading from Light Source 2	Arithmetic Sum of Readings	Reading from Combined Light Sources 1 & 2	Relative Linearity Error
Y_1	Y_2	$X = Y_1 + Y_2$	Y	$f_3(Y)$
	Range limit	X_{max}	Y_{max}	
			Max value ($f_3(Y)_{max}$)	

3.4.8 UNDERTAKING A BROADBAND SPECTRAL SENSITIVITY TEST OF A PHOTOMETER

Externally calibrated laboratory glass filters can be used to perform a spectral calibration of laboratory photometers (luminance and illuminance meters). The measurement of the luminous transmittance of each filter (luminance mode) is compared with the known (calibrated) luminous transmittance.

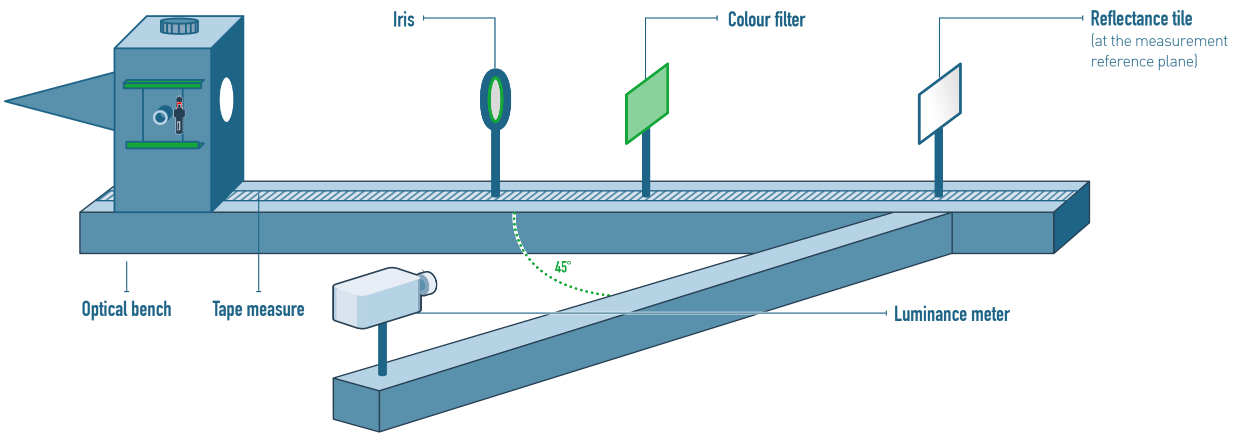
For a luminance meter:
The steps in the procedure for spectral calibration of a luminance meter are given below and the set-up is shown in Figure 28:

STEP 1 The primary standard lamp (or working lamp) does not need to be at any specific distance from the reflectance tile, but will provide greater accuracy if brought to about 1 metre from the tile. This increases the signal-to-noise ratio of the meter response.

STEP 2 The reflectance standard is set up on the optical stage at the end of the optical bench perpendicular to the lamp, at the same height as the filament of the lamp. The luminance meter is set up (for example, on a tripod or on another optical bench) at the same height as the filament of the lamp, at an angle of 45° to the angle of incidence to observe the reflected light from the reflectance standard, as shown in Figure 28. Care should be taken to ensure that the viewing angle (or field of view) of the detector is small enough (by moving the meter closer to the reflectance tile) so that only reflected light from the standard reaches the detector.

STEP 3 Luminance measurements are made firstly with direct light (i.e. with no filter) illuminating the tile; then with the respective calibrated colour filters placed in turn in the filter holder in the beam path from the source to the tile. An iris should be placed between the lamp and the filter and closed down to restrict the light to the filter area only.

Figure 28
Set-up for broadband spectral sensitivity of luminance meter



STEP 4 The ratio of the luminance measurement with the filter present to that with no filter present gives the luminous transmittance of the filter. This ratio is then compared to the calibrated luminous transmittance value for that filter and a percentage error calculated to give a measure of the spectral response of the meter in the spectral region of each filter.

STEP 5 Using the percentage error calculated for each filter, a total broadband spectral response for the meter can be obtained by determining the root-mean-square error for the six filters, using:

$$TBSR = \sqrt{PE_A^2 + PE_B^2 + \ldots + PE_F^2}$$

Where:

TBSR is the total broadband spectral response

PE_X is the percentage error of the luminance transmittance of filter X.

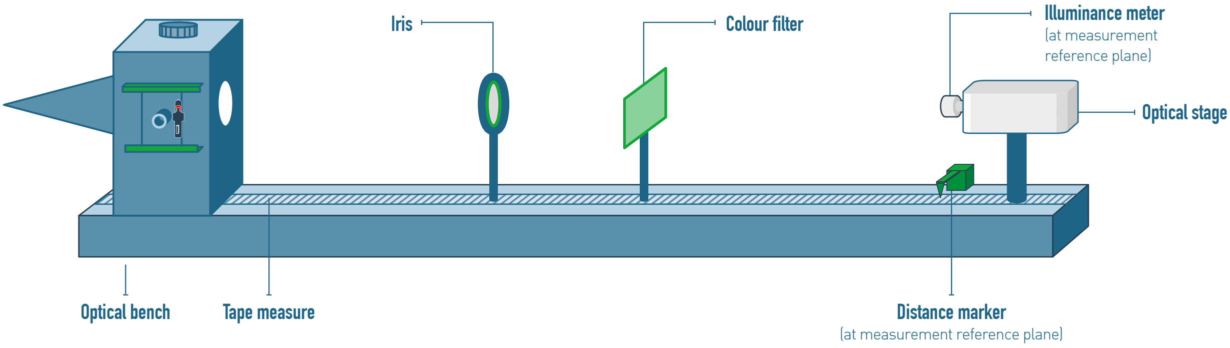
STEP 6 The root-mean-square error is then used as the uncertainty in the spectral response of the luminance meter and incorporated into total uncertainties for the instrument. Broadband spectral uncertainties obtained should be checked against previous results and, if necessary, consequent relevant uncertainties recalculated.

For an illuminance meter:

The steps in the procedure for spectral calibration of an illuminance meter are the same as those described for a luminance meter. However, in this case, the illuminance meter is situated in place of the (unnecessary) reflectance tile, with the detector facing the primary standard lamp, as shown in Figure 29.

Figure 29

Set-up for broadband spectral sensitivity of illuminance meter



4 CONDUCTING MEASUREMENTS FOR DETERMINING UNCERTAINTY

No measurement result is complete without a statement of the associated uncertainty in obtaining that result. This uncertainty of measurement characterises the dispersion of the values that could reasonably be attributed to the quantity to be measured. This chapter provides a brief overview of the techniques for determining uncertainty[20].

4.1 CONFIDENCE INTERVALS

Inherently, any measurement result is imperfect. The result of a test or measurement is our best estimate of the true value of the quantity to be measured. However, the true value exists within a range of values about the measurement result, which are described by the measurement uncertainty. The estimate of the magnitude of this range is expressed as a given level of confidence (or confidence interval). Uncertainty of measurement is usually given as a 95% confidence interval, indicating a 95% surety that the true value lies within the stated uncertainty limits.

4.2 DETERMINING THE UNCERTAINTY

Determining the uncertainty associated with a measured value requires consideration of all the factors which may influence the measurement. The combined influences then propagate through the measurement process to affect the final measurement value. Some of these influences are dependent on other factors, while others are totally independent of all other factors. As an example, the uncertainty in the known light output from a lamp will be influenced by the variation in the electrical current supplied to a lamp due to the squared relationship between power delivered and the current supplied:

$$P = I^2R$$

Where:

- P is the electrical power delivered which manifests as light
- I is the electrical current passing through the lamp filament
- R is the resistance of the lamp filament [20]

There are four basic methods for determining the influence of a parameter on the measurement value. These are:

- Conduct a sensitivity experiment where the parameter under investigation is varied slightly and the effect on the measurement value is recorded;
- Calculate the sensitivity by investigating the mathematical relationship between the parameter and the measurement value. This is the mathematical process of differentiation;
- Creating a mathematical model (in a computer spreadsheet program) where the parameter's value can be varied slightly in subsequent rows of the spreadsheet and then plotted against the calculated 'measurement value';
- Using a Monte Carlo simulation program which randomly selects a very large number of values for the parameters and calculates the 'measurement value' and the statistical variance.

Detailed information on these procedures can be found in ISO and CIE documents noted in the reference section at the end of this document and UNEP-GEF enlighten initiative webinar and *lites.asia* training on uncertainties.[21]

20 For more details on uncertainty and its implications for the analysis of results, see the UNEP-GEF en.lighten guidance note, *Performance Testing of Lighting Products* and the presentation, *Uncertainty Evaluation for LED Products Measurement*, available at http://www.lites.asia/downloads/beijing-laboratory-training

21 UNEP en.lighten webinar, *CIE Test Method for LED Lamps*, and *lites.asia* training, *Uncertainty of measurement*, available at http://learning.enlighten-initiative.org/Webinars.aspx and www.lites.asia/downloads/in-country-training respectively

5 CONSIDERATIONS WHEN CONDUCTING TESTS

When conducting tests as specified in particular testing standards, there may be some more general testing issues which are not specifically mentioned. This chapter draws attention to some of these general considerations, but is not intended to be an exhaustive list, or to provide comprehensive details on all matters arising. The considerations discussed include: determining correction factors for unavoidable test method variations; spectral mismatch of photodetectors; selection of a reference standard lamp for a test procedure and monitoring of its electrical supply; and integrating sphere and goniophotometer specific measurement anomalies.

5.1 GENERAL CONSIDERATIONS

5.1.1 ALTERNATIVE TEST METHODS

When conducting photometric testing to a given standard, absolutely all of the test conditions stipulated must be followed, and they must be within the tolerance intervals provided within that standard. This ensures that the measurements can be considered to comply with standard conditions. Substituting an equivalent test method may be permitted in some standards/situations (for example if stated by a regulatory body), and will be explicitly stated, but the laboratory must provide a justification and proof of equivalence of the results from the changed conditions.

An example of this is the use a of a correction factor for testing a lamp in a non-specified orientation. For some lamp types, the orientation of operation has an effect on light output, and as such they are to be tested as specified by the manufacturer. However, photometric equipment may only allow for specific configurations, such as cap up or cap down. To accommodate this particular issue, a correction factor can be determined by conducting a short additional test using a swing arm bench to find the relative difference between performances at the two orientations. This factor is then applied to the final photometric result.

5.1.2 AMBIENT CONDITIONS

Prior to taking final measurements, take a moment to check that the ambient laboratory conditions (temperature in the immediate test room), and the electrical conditions (voltage, current) are within the specified tolerance of the level stated for the test, and note this for every individual test.

5.1.3 HANDLING

Lamps should never be handled with bare hands, as the glass and other lamp packaging materials may interact with body oils; wear soft fabric gloves. These can also provide some insulation from heat when changing lamps out of measuring equipment.

Allow lamps to cool slightly in position before extracting from test equipment (particularly lamps which operate at high temperatures, such as incandescent, halogen and some fluorescent and compact fluorescent lamps, as they are more susceptible to breaking when they are hot.

5.1.4 SPECTRAL MISMATCH

A photometer detector, as used with a goniophotometer or an integrating sphere system, should have a spectral responsivity that matches the spectral luminous efficiency function for photopic vision $V(\lambda)$[22]. Where this is not the case, spectral mismatch correction may need to be applied. The requirement for this correction can be initially determined by conducting a broadband spectral sensitivity test as outlined in Section 3.4.8.[23] For this correction, knowledge of the relative spectral distribution of the device under test is required, along with the relative spectral responsivity of the

22 Vision by the normal eye when it is adapted to levels of luminance of at least several candelas per square metre. Note: The cones are the principal active photoreceptors in photopic vision. (IEC)

23 If a correction is required then information on this process can be found in the presentation, *Spectral correction of photodetectors for LED products*, available at http://www.lites.asia/downloads/beijing-laboratory-training

measurement system. In the case of goniophotometers, this means the spectral responsivity of the photometer and any mirrors which may be present. In the case of integrating sphere-photometers systems, this means the spectral throughput of the sphere and the spectral responsivity of the photometer. Integrating sphere-spectroradiometer systems do not have any spectral mismatch considerations. However they have other properties that require checking, such as spectral stray light, and they may have greater issues with non-linearity.

LED lamps introduce additional colour issues for spectral mismatch, due to their peak in radiant output in the blue colour region; care must be taken to ensure that the photometer spectral response in this colour region is properly calibrated and corrected for colour mismatch.

5.1.5 STANDARD LAMPS

Put simply, a standard lamp may be defined as a lamp that: has no physical deformities or variations from what would be normally expected for that type of lamp; has been correctly aged (as stated in the relevant test standard for that lamp technology, typically up to 100 hours) and has a very stable output after aging; and whose luminous flux or luminous intensity in a particular direction has been measured by an external certified laboratory.

Wherever possible, the standard lamp chosen to measure the lumen output of the test lamp(s) should be of the same type of light source i.e. having the same physical size and dimensions as the test lamp, the same light output aperture. As an example a standard lamp should be placed in the sphere in the same position and orientation as the test lamps. If this is not possible, then selection of the standard lamp should match the test lamp in as many of the above characteristics as possible. It is not necessary that the standard lamp and test lamp have the same power, although they should match as much as possible. A factor of approximately three between the two lamps (for example, 12 W and 35 W or say, 200 lm and 600 lm) is acceptable. If linearity of the detector/measurement system has been established then this limitation to a factor of three can be ignored.

5.1.6 ELECTRICAL SUPPLY TO THE LAMP

Constant electrical supply to the lamp is critical during testing in all test configurations (for example, spheres, goniometers and optical benches). Wherever possible, the lamp voltage should be measured at the terminals of the lamp and via a separate set of leads to those providing the electrical supply (this arrangement of separate leads is illustrated in Figure 6). Current can be measured near the power supply. Connection of any electrical circuits between components should only be carried out by laboratory staff who have undertaken appropriate electrical training, and who fully understand the function and operation of all components in the circuit, and the requirements of the test being undertaken. Using staff who have been laboratory trained to perform electrical work is very important to the integrity of test results; be aware that resorting to the temporary hire of an outside electrician to conduct laboratory work can lead to test results being incorrect. If there is any doubt about any aspect of the circuit to be used, qualified advice should be sought.

In some situations, providing power from an external power source to a lamp, such as inside a sphere, will involve using connecting cables and wires. Care should be taken to minimise the likelihood of shorting between two parts of the same circuit, or another piece of apparatus (such as the sphere itself). Electrical insulation should be used to protect exposed metallic surfaces.

5.2 CONSIDERATIONS FOR INTEGRATING SPHERES

5.2.1 SPATIAL NON-UNIFORMITY

Integrating spheres do not have perfectly uniform responsivity over their internal surfaces. The responsivity will usually be less sensitive in the lower half of the sphere due to contamination by dust, aging and damage to the sphere coating. Be mindful that damage to the internal sphere surface coating can occur while installing lamps and making changes to the lamp mounting set-up. A method of catching accidentally dropped lamps, equipment or tools, such as a temporary basket or thick fabric placed on the lower floor of the sphere, can assist in its longevity. However, care should be taken in arranging the basket or fabric so that it doesn't damage the coating.

The internal surface of the sphere should be coated uniformly with diffuse non-spectrally selective paint in accordance with CIE 84:1989, *The Measurement of Luminous Flux*. In addition, all support components required to mount lamps (including auxiliary lamps) inside the sphere should be painted with the same coating.

As a guide, it is expected that the largest physical dimension of the light source should be no greater than 10% of the diameter of the integrating sphere. This means that for a 1,500 millimetres sphere, the largest physical dimension of the lamp should not exceed 150 millimetres.

Larger lamp sources such as linear tubes may be up to 50% of the diameter of the sphere, but they must be oriented such that the smallest dimension of the lamp faces the detector so the baffle can remain as small as possible. Note that uncertainties in measurement will increase with the physical size of the lamp, and as such the size and distribution of the test lamp should be similar to the reference lamp.

Unless otherwise stated, the lamp should be mounted such that the optical centre of the emitting surface(s) is as close as possible to the centre of the sphere.

5.2.2 SPECTRAL MISMATCH

In addition to the generic considerations relating to spectral mismatch (as described in Section 5.1.4), it should be noted that the relative spectral throughput of an integrating sphere changes with time, especially from when the sphere is new to when the sphere has been heavily used and subject to contamination. Spectral throughput should be measured periodically to update the spectral mismatch correction data.

5.2.3 SELF-ABSORPTION

If there are variations in the physical colour and dimensions between the test lamp and reference lamp, a different amount of self-absorption may occur, and this can be significant. For example, products such as LED modules come with external drivers that will usually be connected via a short lead, and it may not be practical to extend the leads so that the drivers are outside the sphere while testing is being performed. Test methods (such as CIE 84-1989, *The Measurement of Luminous Flux*) instruct that a self-absorption correction factor should be applied by use of the auxiliary lamp method. In this method, two measurements are made:

- The reference lamp is placed in the sphere by itself and, with this switched off, the auxiliary lamp measurement is taken, as illustrated in Figure 30;
- The reference lamp is then taken out and replaced with the test lamp (also switched off) and the driver (if also required), and the auxiliary lamp measurement is again taken, as illustrated in Figure 31.

Figure 30

Measurement with reference lamp in sphere

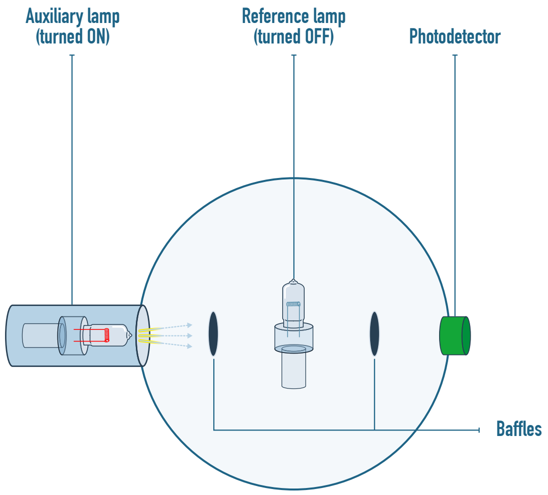
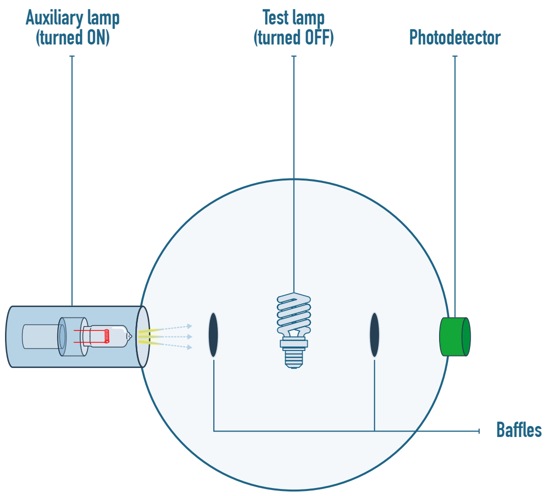


Figure 31

Measurement with test lamp in sphere



The ratio of the two auxiliary lamp measurements gives the correction factor for the difference in self-absorption between the reference lamp and the test lamp (plus driver, if also required) and is incorporated into the relevant calculations.

For example, with inclusion of the self-absorption measurement, the luminous flux of a test lamp, when tested with a luminance meter, would be calculated as follows:

$$\Phi_t = \Phi_s \cdot \frac{L_t}{L_s} \cdot \frac{L_{as}}{L_{at}}$$

Where:

Φ_t	is the luminous flux of the reference standard lamp
L_t	is the luminance reading of the test lamp, turned ON
L_s	is the luminance reading of the reference standard lamp, turned ON
L_{as}/L_{at}	is the absorption correction factor, determined by use of the auxiliary lamp
L_{as}	is the luminance of the auxiliary lamp, turned ON with test lamp turned OFF and mounted in the sphere
L_{at}	is the luminance of auxiliary lamp with reference standard lamp, turned OFF and mounted in the sphere.

The self-absorption test should be performed for every individual test lamp, unless the test lamp is very similar in size and colour to the reference lamp. In addition, for multiple test lamps in a range of exactly the same model, this data can be shared.

5.2.4 BEAM ANGLE

Directional lamps must be tested using a reference standard lamp which has an equivalent beam angle (±25%). It should not be assumed that the test lamp beam angle is as specified on the lamp packaging. It can be checked by using a bench goniometer to take a nadir reading (i.e. at 0° orientation) to find maximum beam intensity, and rotating the lamp to the (positive gamma) angle at which 50% beam intensity occurs. On the same C-plane[24], check the negative gamma angle to confirm the result. This is equivalent to going to the opposite C-plane and measuring the gamma angle, for example, measure in the 0° C-plane first and then in the 180° C-plane.

5.2.5 THERMAL BEHAVIOUR

Lamps should be mounted in the operating position recommended by the manufacturer for their intended use, such that their thermal condition, due to air flow inside and around the lamp, will be the same as its normal use condition.

During the stabilisation period it may be necessary to keep the integrating sphere doors partly open to avoid overheating the test lamp or affecting the ambient test temperature required in test methods. Stabilisation time will vary depending on the type of light source and operating conditions, and this should be confirmed through continuous monitoring of photometer, voltage and current readings until the output no longer shows a trend in a particular direction. Standards such as CIE S025/E:2015, *Test Method for LED Lamps, LED Luminaires and LED Modules*, provide guidance on when a lamp is considered to be stable.

5.2.6 TESTING

When testing, the procedure for each lamp test should be as follows:

- Pre-heat lamp in position, while leaving the sphere partly open for air circulation to maintain ambient temperature conditions;
- After the recommended stabilization time, close the sphere;
- Ensure the lamp is operating at the specified voltage/current to within 0.1%;
- Take an appropriate number of measurement readings (at least three) from the detector. These will be averaged for final calculations;
- Record circuit current, voltage and temperature at the sphere.

5.3 CONSIDERATIONS FOR GONIOPHOTOMETERS

5.3.1 GENERAL INFORMATION

Measurements of intensity distribution (and related parameters such as light output ratio and zonal luminous flux) involve photometric and angular measurements. This is achieved by use of a goniophotometer. Goniophotometers have an angular scan range covering the entire solid angle that a lamp can emit light.

24 See Section 5.3.1 for a description of C-plane and gamma angle.

Specific requirements for the number of intensity measurement points and their geometric distribution (in degrees) differ depending on the lamp technology and/or luminaire type being tested (as per the test method which would apply), and whether the lamp is directional or non-directional. The geometric distribution is generally described as planes, and angles within these planes. There are three basic measurement plane systems, where the polar axis through each plane within a system is in a different orientation relative to the lamp. Each system has a particular usefulness for measurement of lighting products for different applications. The system most relevant to interior lamps and luminaires is that where the polar axis of the measurement plane system is vertical and is known as the C, gamma (γ) system; (C-plane, gamma angles). This is illustrated in Figure 32 and Figure 33. The angular steps in the C-plane and gamma angles are typically nominated in the test standard but the principal to step size is that there should be relatively consistent change between any two measurements.

The number of planes, and number of angles within the planes, for a particular test must be checked for the specific test lamp to ensure that the minimum requirement is achieved.

Luminaires and lamps should be tested in their normal operating orientations. Luminaires must be secured rigidly on the goniophotometer, particularly if the goniophotometer is of the type where the luminaire moves during the measurement process. Every precaution must be taken to ensure that the luminaire doesn't rock as it rotates or vibrate as other parts move around it.

Figure 32

One vertical C-plane with gamma angles within for lamp

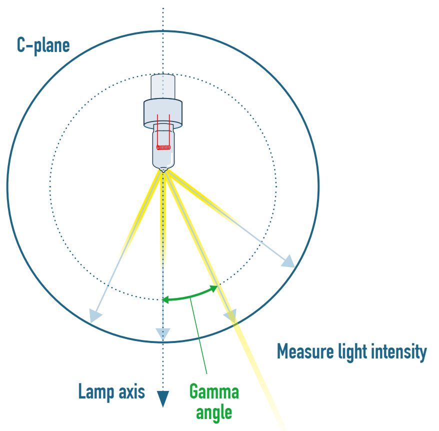
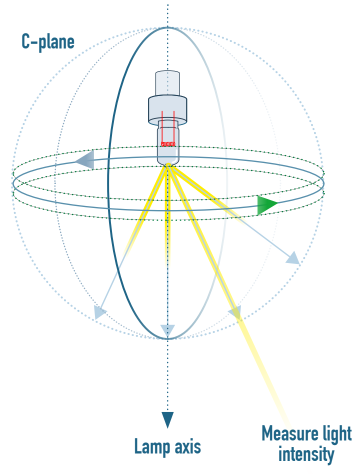


Figure 33

Rotation to the next C plane



5.3.2 STRAY LIGHT

Screening against stray light is critical in goniophotometry. This is because it may not be a constant systematic error. Its presence and level potentially vary due to the movement of the measurement components, which may include a mirror, the photodetector and the light source. Some steps which will help minimise the measurement errors from stray light are:

- Remove the presence of all unnecessary light sources in the measurement room;
- For a goniophotometer without a mirror, the photometer should be screened with baffles and apertures to the extent of 'seeing' only the light source (i.e. lamp or luminaire);
- For a goniophotometer with a mirror, the photometer should be screened with baffles and apertures to the extent of 'seeing' only the image of the light source, and not receiving any light directly from the light source;
- Where possible, all surfaces within the field of view of the photometer should be have a matt black finish, including the bevelled edges of mirrors. Note that many matt black paints can have reflectances as high as 4 per cent for normally incident light;
- Other non-black surfaces should be covered with black velvet or black carpet.

Where stray light cannot be eliminated, it should be measured and then subtracted from the test measurements. This stray light measurement is obtained by placing a screen between the light source and the photodetector and recording the reading. There may be residual stray light which cannot be accounted for, where the screen also obstructs the path of stray light via the mirror to the photodetector. Note that this stray light assessment needs to take into account the variation of stray light with light source position.

5.3.3 DISTANCE MEASUREMENT AND ALIGNMENT

The intensity for the intensity distribution is calculated by:

$$I = Ed^2$$

Where:

- ***I*** is the intensity
- ***E*** is the illuminance
- ***d*** is the calibration distance between the lamp filament and the reference plane of the photometer

The distance from the light source to the photodetector, the optical path length, must therefore be accurately known. This will vary as the light source and/or the mirror rotate unless the photometric centre of the lamp is co-incident with the optical centre of the rotating goniophotometer system. It is therefore necessary to ascertain the photometric centre of the test lamp or test luminaire. The photometric centre is defined as the point in a luminaire or lamp from which the inverse square law operates most closely. The typical determinations for the photometric centre for various lamp technologies and luminaire types are shown in Table 5.

Positioning of the test lamp/luminaire at the optical centre of the goniophotometer is best assisted by using laser pointers on three perpendicular axes which intersect at the optical centre. These lasers should be permanently fixed in the laboratory and turned on for the test lamp/luminaire alignment process. Care should be taken to maintain eye safety during this process.

The optical path length must be large enough that the inverse square law[25] should apply. For light sources with a relative light intensity distribution which is similar to the cosine distribution (relative to cosine of the angle from the lamp axis), Figure 34, a minimum path length of five times the largest luminous portion of the light source is required.

Table 5

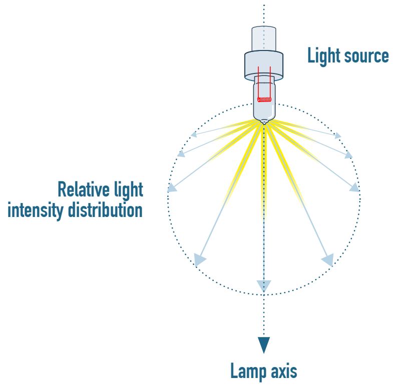
Typical determinations for photometric centre of various lamp technologies and luminaire types

Lamp Technology or Luminaire Type	Position of Photometric Centre
Filament lamps, clear or lightly diffusing bulb	At the centre of the solid figure bounded in outline by the filament
Filament lamps, diffusing bulb	At the centre of the diffusing portion of the lamp envelope
Discharge Lamps, straight arc (includes straight fluorescents, blended lamps and discharge lamps with colour-correcting or diffusing envelopes)	At the mid-point of the centre line of the arc discharge
Discharge Lamps, curved arc (includes circular and bent fluorescents, U-limb sodium lamps)	At the centre of the plane figure formed in outline by the centreline of the arc discharge
Lamps with an integral reflector	At the centre of the plane figure formed in outline by the main opening of the reflector
Luminaires with substantially opaque sides	At the centre of the main luminaire opening or diffusing member across the opening, or at the lamp photometric centre if it is outside the plane of this opening
Luminaires with diffusing sides	At the centre of the solid figure bounded in outline by the luminous surfaces, but at the lamp photometric centre if it is outside the plane of this solid figure
Luminaires with transparent sides or without side members	At the lamp photometric centre

25 For perpendicular arrangement (i.e. light incident at right angle to surface): illuminance (E) = intensity (I) / distance (d)^2

Figure 34

Lamp with a light intensity distribution which is a cosine distribution



For broad angular distribution (beam angle ≥ 60°), but less than cosine distribution, a minimum path length of 10 times the largest luminous portion of light source is required. For narrower beams a minimum path length of 15 times the largest luminous portion of light source is required.

Greater resolution in angular measurements, and therefore intensity variation, is achieved at greater optical path lengths. However, the disadvantage of making measurements at large distances is that in directions where the intensity is quite low (for example, in the upward direction for a primarily downward acting light source), the photodetector may be recording very low readings that approach values at which uncertainties increase considerably.

Most goniophotometers use mirrors to reduce the total physical area required for the goniophotometer system. While mirrors present problems of cleaning, alignment and flatness, the advantages of the reduced physical area required generally outweigh these disadvantages. Mirrors should be flat, both overall (e.g.no curvature) and local (e.g. no dimples), with no scratches, and the reflectivity should be constant over the whole surface to within ±2%.

5.3.4 PHOTOMETER AND MEASUREMENTS

Photometer considerations:

- The photodetector must be able to see all of the light source at all possible angles during the rotation process;
- It is advisable to have a goniophotometer system where the photodetector is stationary, rather than moving/rotating about the light source. In addition to reducing the issues associated with cabling and connections, the stray light issues are easier to analyse, control and minimise with a stationary photodetector. With a moving photodetector, the background surfaces in the field of view of the photodetector are constantly changing throughout the entire measurement process thereby increasing the complexity of analysis and control.

Measurement considerations:

- For absolute measurements, the goniophotometer must be calibrated in the appropriate SI units. Measurement of luminous intensity distribution, can be achieved by using either: a calibrated luminous intensity standard lamp or a previously calibrated photodetector to measure illuminance and converting to intensity using the inverse square law;
- The goniophotometer itself must, therefore, be calibrated. In the case of a measurement of luminous intensity distribution, this can be done using either: a calibrated luminous intensity standard lamp or a previously calibrated photometer head to measure illuminance and converting to intensity using the photometric inverse square law; [26]
- Repeatability of measurements needs to be established in relation to the movement of the lamp or mirror. This is achieved by taking a measurement of luminous intensity at the nadir and then moving the mirror at normal speed (for undertaking a test) through one full rotation (of gamma angles), after which the luminous intensity at the nadir should immediately be measured again. The difference between the two luminous intensity readings should not exceed 2%. A similar test should be conducted to check the effect of rotating the lamp at normal speed about the nadir i.e. through 360° in azimuth (horizontal plane);
- Before commencing test measurements, allow the measurement instruments to stabilise. Then check for stray light and check the zero reading with the photodetector covered;
- Once the test lamp/luminaire has stabilised photometrically (i.e. the change in intensity over a 15 minute period is less than 1%), the measurement procedure can begin. However, check measurements (for example, of luminous intensity) should be made at regular intervals (for example, every 5 minutes), particularly for extended measurement procedures, to ensure stability is maintained. This check is critical to the integrity of the test results.

26 For perpendicular arrangement (i.e. light incident at right angle to surface): illuminance (E) = intensity (I) / distance (d)^2

6 HOUSEKEEPING

Good administrative and logistical functions are critical to the smooth operation of a laboratory. This chapter discusses the key considerations associated with this, which involves: good record keeping; a system of unique codes for marking test products (and laboratory equipment), which facilitates unambiguous identification of the same; and appropriate storage conditions for test products and test equipment to maintain their operational integrity.

6.1 RECORD KEEPING SYSTEM

The primary considerations for a good record keeping system are given below.

- Laboratory procedures, test methods, test results, and equipment calibration certificates and instructions should be stored in a logically ordered and accessible filing system. A system should be in place for the regular backup of computer records to ensure that no data is lost in the event of failed equipment;
- The laboratory should establish specific spreadsheet TEST TEMPLATES for taking results for every single test method that will be carried out. This should include details about ambient laboratory conditions, which are to be recorded at the time of each individual test;
- Test reports should specify the laboratory uncertainty for all tests;
- If results are to be written on a printed out version of this spreadsheet and then transcribed back to the computer spreadsheet, this process should be very carefully double checked, and originals should be stored in a RESULTS file in case of error;
- Reports should be prepared so they at least meet the minimum reporting requirements of the laboratory's accrediting body. Some test method standards provide a basic report template for reporting outcomes of a given test procedure (typically found in the final pages of the standard document). However, agreement should be reached with the customer on any additional reporting (such as, reporting spreadsheets) in advance of the tests being conducted to ensure that all required information is collected. Copies of the issued reports should be filed under the name of the client, or at least using a cross-referencing system such as a database. All information related to each test, including the report, should be identified by the Job Number as recorded in the JOB FILE.

6.2 LAMP IDENTIFICATION

All lamps in the laboratory should be labelled with a unique identifier code/number, including reference standard lamps and all test lamps. This helps with tracking lamps and results. To indelibly mark the product with the code, use a point tipped permanent marker, and write the code somewhere on the lamp that does not obstruct light output, and preferably where the lamp won't get too hot, otherwise the mark might fade or wear off (i.e. avoid writing on the heat-sink section of a light emitting diode lamp, if possible). The lamp packaging should also be labelled, so as to avoid potential confusion if a lamp is placed in the wrong box.

Take photographs of all the lamp samples and all sides of their packaging. Examples are provided in Figure 35; try to avoid camera flash flare on the surface of the packaging, as depicted in the image of the lamp box in Figure 36.

Figure 35

Photographs of lamp packaging and lamp and various orientations

Figure 36

Camera flash flare on packaging obscuring information

6.3 STORAGE OF LAMPS

Calibrated reference lamps are to be stored in a protected temperature-stable and humidity-stable location, such as a cupboard. They should be clearly labelled and arranged in an ordered way such that they do not have to be over-handled while staff search for the relevant model to use in testing.

There should be a capacity to safely store test lamps while they are at the location, such that their presence does not impinge on the safe operation of laboratory duties, or create a likelihood that they may be accidentally damaged i.e. do not crowd the hallways, computer or photocopier rooms. There should be a designated space for this storage purpose. Test lamps should be retained at least until the customer has received and had time to consider the test report. Agreement between the customer and the testing laboratory should be made upfront regarding how long the test lamps will be retained and how they will be returned or disposed of. Disposal of lamps should be in an environmentally sound manner, in accordance with relevant local waste disposal and recycling laws.

7 | RECOMMENDATIONS

Performance testing programmes, whether for market intelligence, monitoring compliance with minimum energy performance standard and labelling programmes, verifying manufacturer/retailer declarations, or conducting product benchmarking, all require product testing to be conducted at accredited independent laboratories. Following the advice provided in this guidance note will assist photometric laboratories to conduct photometric performance testing as a competent testing laboratory. The key recommendations for consistently conducting independent, defendable testing are summarised in Figure 37.

Figure 37

Recommendations for consistently conducting independent, defendable testing

1. Ensure familiarity with its internal equipment in the form of performance characterisations and calibrations, noting that internal calibrations can only be conducted with the use of traceable externally calibrated equipment.
2. Have clear traceability of measurement and calibration hierarchy.
3. Follow the detailed advice on conducting specific tests as detailed within the relevant test standard.
4. Be aware that common general practices are often overlooked in laboratory test procedures and test standards, and establish procedures and implement best practice to address these.
5. Ensure that robust housekeeping procedures and logistical functions are in place and strictly adhered to.
6. Consult with accreditation bodies to ensure that their requirements/expectations of the laboratory are met.
7. Give consideration to proficiency training.

8 RESOURCES AND REFERENCES

To support countries and regions in the development of efficient lighting activities and strategies, the UNEP-GEF en.lighten initiative, CLASP and other organisations offer a wide array of practical tools. The most relevant of these are described below. This chapter also includes details of the the references used in compiling this guidance note.

UNEP-GEF EN.LIGHTEN INITIATIVE PUBLICATIONS

Achieving the Transition to Energy Efficient Lighting Toolkit – delivers best practice guidance for policy development and provides technical and practical tools for those directly involved in national phase-out activities. This toolkit is available online in five languages: Arabic, English, French, Russian and Spanish.

http://www.enlighten-initiative.org/ResourcesTools/EfficientLightingToolkit.aspx

Developing Minimum Energy Performance Standards for Lighting Products: Guidance Note for Policymakers - illustrates how to develop MEPS for lighting products. It is a practical resource for governments on the processes to follow when establishing MEPS in a national or regional market.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Developing Lighting Product Registration Systems: Guidance note – provides practical guidance and examples to energy efficiency programme administrators on how to develop, operate and maintain a registration system for lighting products.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Efficient Lighting Market Baselines and Assessment: Guidance note – provides practical guidance to policymakers and energy efficiency programme administrators on how to determine national baselines, use this data for market monitoring purposes, and how to monitor the market to continuously update the baselines.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Enforcing Efficient Lighting Regulations: Guidance note – presents best practices for enforcing energy efficiency regulations for lighting products. It can be used as a practical resource by policymakers and enforcement bodies when developing or revising their enforcement regime.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Good Practices for Photometric Laboratories: Guidance note – provides guidance on the operation of photometric laboratories to ensure that testing results are fully supported by evidence of the legitimacy of the measurement values obtained and to give confidence in the accuracy of these results and conformance with test procedures/conditions.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Performance Testing of Lighting Products: Guidance note - outlines the process for carrying out energy efficiency performance testing for lamps, and how to interpret and use the data. It is a practical resource for energy efficiency policymakers and programme administrators.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Product Selection and Procurement for Lamp Performance Testing: Guidance note – provides guidance on the steps required when selecting and procuring residential lamps to undergo performance testing, including defining the product scope, selection methodology, and the procurement and tracking protocol.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Global Compact Fluorescent Lamp Check Test Results and Analysis Report – provides results and analysis of the safety, performance and mercury content of 47 models of CFLs tested at the Global Efficient Lighting Centre in 2013. The lamps were sampled in 10 countries (Azerbaijan, Chile, Costa Rica, Dominican Republic, Guinea-Bissau, Lebanon, Panama, Tonga, Tunisia and Uruguay) with the support of the UNEP en.lighten initiative.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Inter-laboratory Comparison Testing of Light Emitting Diode (LED) Lamps - presents the results of an inter-laboratory comparison testing exercise undertaken by six laboratories in Southeast Asia in 2015 (in accordance with ISO/IEC 17043, *Conformity assessment - General requirements for proficiency testing*), with the Global Efficient Lighting Centre as the nucleus laboratory.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Lamp Sampling in Cambodia, Indonesia, Lao PDR, the Philippines, Thailand and Viet Nam – presents a summary of a 2014 lamp sampling exercise coordinated by the International Institute for Energy Conservation to identify and sample compact fluorescent and LED lamps in six target countries. The objective of the exercise was to provide participating agencies with guidance on, and experience in, conducting a retailer survey, lamp purchasing and witnessing, and packing and shipping; and to sample lamps for subsequent testing undertaken by the Global Efficient Lighting Centre.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Southeast Asia Compact Fluorescent Lamp Performance and Mercury Testing and Analysis Report – presents the results and analysis of testing undertaken by the Global Efficient Lighting Centre on CFLs purchased in six Southeast Asian countries (Cambodia, Indonesia, Lao PDR, Philippines, Thailand and Viet Nam in 2014.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

Southeast Asia Light Emitting Diode Lamp Performance Testing and Analysis Report – presents the results and analysis of testing undertaken by the Global Efficient Lighting Centre on LED lamps purchased in six Southeast Asian countries (Cambodia, Indonesia, Lao PDR, Philippines, Thailand and Viet Nam in 2014.

http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx

CLASP PUBLICATIONS

Energy Efficiency Labels and Standards: A Guidebook for Appliances, Equipment and Lighting – provides guidance for government officials and others responsible for developing, implementing, enforcing, monitoring, and maintaining labelling and standards-setting programmes.

http://clasp.ngo/Resources/Resources/StandardsLabelsGuidebook

Compliance Counts: A Practitioner's Guidebook on Best Practice Monitoring, Verification, and Enforcement for Appliance Standards & Labeling - provides guidance on designing and implementing effective compliance frameworks, and directs the reader to references and other relevant resources.

http://clasp.ngo/Resources/MVEResources/MVEGuidebook

Assessment of Opportunities for Global Harmonization of Minimum Energy Performance Standards and Test Standards for Lighting Products - presents an assessment of test procedures and MEPS globally and identifies key gaps and similarities between them. It also examines the opportunities for the alignment of various economies to one global test procedure, and corresponding MEPS, for CFLs and LEDs and provides recommendations on possible steps to encourage and accelerate the global uptake of energy-efficient lighting technologies.

http://clasp.ngo/Resources/Resources/PublicationLibrary/2011/Global-Harmonization-Lighting-MEPS-TestStandards

Assessment of Verification Testing Capacity in the APEC Region and Identification of Cost Effective Options for Collaboration- presents the results of a comprehensive survey of APEC countries to identify qualified testing facilities and analyse cost-effective policy options for conducting compliance testing.

http://clasp.ngo/Resources/MVEResources/MVEPublicationLibrary/APEC-Assessment-of-Testing-Capacity-Facilitates-Compliance-Collaboration

EXPERTISE AND COLLABORATIVE PROGRAMMES

UNEP-GEF en.lighten initiative Centre of Excellence – comprised of a network of over 50 lighting experts representing over 30 countries – offers recommendations, technical guidance and efficient lighting expertise to assist countries in the shift to energy efficient lighting. The Centre is based in Paris, France.

http://www.enlighten-initiative.org/

UNEP-GEF en.lighten initiative online support centre, 'en.lightened learning' - provides targeted technical advice and contains forecasting tools, publications and guidance documents. It also includes a series of informational webinars that provide more detailed guidance on specific aspects of MVE including:

- *Best Practices for Enforcing Efficient Lighting Regulations;*
- *CIE Test Method Standard for LED Lamps;*
- *Communication of Lighting Product Performance Standards and Labelling Programmes to Supply Chain Providers;*
- *Developing a Legislative Framework to Support Successful Monitoring, Verification and Enforcement Activities for Energy Efficient Lighting;*
- *Evaluation Indicators for Energy Efficient Lighting MVE Policy;*
- *How to Create and Operate a Lighting Product Registration System;*
- *Lamp Product Performance Tests and Interpretation of Results;*
- *Lighting Product Benchmarking as an Energy Baseline for Change;*
- *Lighting Product Registration Systems: Design and Operation;*
- *Market Baselines and Surveillance for Efficient Lighting Products;*
- *Testing Lamp Efficacy, Lumen Maintenance, Rated Life and Uncertainties.*

http://learning.enlighten-initiative.org/

UNEP Collaborating Centre for Energy Efficient Lighting, China - GELC offers a wide range of technical services to developing countries including laboratory training and establishing systems for lamp quality control.

http://www.enlighten-initiative.org/About/GlobalEfficientLightingCentre.aspx

lites.asia - is a network of lighting efficiency regulators and policy makers in the Asia region. Since its formation in 2009, membership of the lites.asia network has increased to over 700 participants from 30 economies, with delegates actively participating in IEC meetings, sharing knowledge on local standards and labelling electronically and in regional meetings, plus a number of other cooperative actions. The *lites.asia* website contains a range of resources on lighting efficiency and regulation including presentations from regular regional meetings and collaborative project and survey results, such as the regional labelling display survey.

http://www.lites.asia/

Australian and New Zealand Equipment Energy Efficiency (E3) Program - is a cooperative government programme that applies a combination of MEPS and energy rating labelling to a range of energy using products including lighting in order to inform consumers and increase the range of efficient products in the market. The Energy Rating website contains a range of reports on lighting related baseline data and analysis for the Australian and New Zealand markets, as well as a publically accessible database of registered lighting products.

http://www.energyrating.gov.au/

CLASP - Works to improve the environmental and energy performance of appliances and related systems, lessening their impacts on people and the world around us. CLASP develops and shares practical and transformative policy and market solutions in collaboration with global experts and local stakeholders. It is a non-profit international organisation promoting energy efficiency standards and labels for appliances, lighting, and equipment. Since 1999, CLASP has worked in over 50 countries on six continents pursuing every aspect of appliance energy efficiency, from helping to structure new policies to evaluating existing programmes.

http://www.clasponline.org/en

The Clean Energy Ministerial's Clean Energy Solutions Center - offers no-cost expert policy assistance, webinars and training forums, clean energy policy reports, data, and tools provided in partnership with more than 35 leading international and regional clean energy organisations.

https://cleanenergysolutions.org/

IEA - the International Energy Agency (IEA) is an autonomous organisation which works to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The IEA's four main areas of focus are: energy security; economic development; environmental awareness; and engagement worldwide. Founded in response to the 1973/4 oil crisis, the IEA's initial role was to help countries coordinate a collective response to major disruptions in oil supply through the release of emergency oil stocks. It has a staff of 260 professionals (energy analysts, modellers, data managers/statisticians, technicians, secretaries and support staff) working together on global energy challenges.

http://www.iea.org/

IEA 4E Solid State Lighting Annex – the Solid State Lighting Annex was established in 2009 under the framework of the International Energy Agency's Efficient Electrical End-Use Equipment (4E) Implementing Agreement to provide advice to its ten member countries seeking to implement quality assurance programmes for solid state lighting. This international collaboration brings together the governments of Australia, China, Denmark, France, Japan, The Netherlands, Republic of Korea, Sweden, United Kingdom and United States. China works as an expert member of the Annex. The Annex website provides information on recommended performance specifications for LED lighting, as well as reports and advice on LED product testing, lighting and health and lifecycle analysis.

http://ssl.iea-4e.org/

LED Lighting Facts - LED Lighting Facts® is a programme of the United States Department of Energy that showcases LED products for general illumination from manufacturers who commit to testing products and reporting performance results according to industry standards. Their website contains information on their verification testing policy, a list of accredited laboratories in the United States and a list of products with their energy performance information. This is a useful web portal for policymakers and programme administrators to inform themselves about efficient lighting policies and testing.

http://www.lightingfacts.com/

SEAD Initiative - The Super-efficient Equipment and Appliance Deployment (SEAD) Initiative is a voluntary collaboration among governments working to promote the manufacture, purchase, and use of energy-efficient appliances, lighting, and equipment worldwide. SEAD is an initiative under the Clean Energy Ministerial and a task of the International Partnership for Energy Efficiency Cooperation.

www.superefficient.org

LABORATORY SPECIFIC RESOURCES

International Organization for Standardization

ISO/IEC Guide 98-1:2009, *Uncertainty of measurement - Part 1: Introduction to the expression of uncertainty in measurement*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement*

ISO/IEC Guide 98-3:2008/Suppl 1:2008, *Propagation of distributions using a Monte Carlo method*

www.iso.org

National Measurement Institute Australia Monograph Series

Monograph 1, *Uncertainty in Measurement: The ISO Guide (2005, eleventh edition).*

Monograph 2, *Statistical Background to the ISO Guide to the Expression of Uncertainty in Measurement (2011, third edition).*

Monograph 3, *Traceable Measurements (2005, fourth edition).*

Monograph 10, *Introduction to Radiometry (2008, first edition, second revision).*

http://www.measurement.gov.au/

International Commission on Illumination

CIE 084:1989, *The Measurement of Luminous Flux*

CIE 070:1987, *The Measurement of Absolute Luminous Intensity Distributions*

CIE 121:1996, *The Photometry and Goniophotometry of Luminaires*

CIE 198:2011, *Determination of Measurement Uncertainties in Photometry*

CIE 198-SP1.1:2011, 198-SP2:2011, 198-SP3:2011, 198- SP4:2011, *Determination of Measurement Uncertainties in Photometry - Supplement 1: Modules and Examples for the Determination of Measurement Uncertainties (4 Parts)*

ISO/CIE 19476:2014, *Characterization of the Performance of Illuminance Meters and Luminance Meters*

CIE S025/E:2015, *Test Method for LED Lamps, LED Luminaires and LED Modules*

http://www.cie.co.at/

Standards Australia

HB 86.1:1996, *A guide to the selection, care, calibration and checking of measuring instruments in industry - General principles*

www.standards.org.au

REFERENCES

CIEa

ISO 11664-2:2007(E)/CIE S 014-2/E:2006: Joint ISO/CIE Standard, *Colorimetry — Part 2: CIE Standard Illuminants for Colorimetry*

http://cie.co.at/index.php?i_ca_id=484

CIEb

e-ILV Termlist

http://eilv.cie.co.at/termlist

IEC

Electropedia

http://www.electropedia.org/iev/iev.nsf/index?openform&part=845

ABOUT THE UNEP DIVISION OF TECHNOLOGY, INDUSTRY AND ECONOMICS

The UNEP Division of Technology, Industry and Economics (DTIE) helps governments, local authorities and decision-makers in business and industry to develop and implement policies and practices focusing on sustainable development.

The Division works to promote:

- → sustainable consumption and production,
- → the efficient use of renewable energy,
- → adequate management of chemicals,
- → the integration of environmental costs in development policies.

The Office of the Director, located in Paris, coordinates activities through:

- → **The International Environmental Technology Centre** - IETC (Osaka, Shiga), which implements integrated waste, water and disaster management programmes, focusing in particular on Asia.
- → **Production and Consumption** (Paris), which promotes sustainable consumption and production patterns as a contribution to human development through global markets.
- → **Chemicals** (Geneva), which catalyzes global actions to bring about the sound management of chemicals and the improvement of chemical safety worldwide.
- → **Energy** (Paris), which fosters energy and transport policies for sustainable development and encourages investment in renewable energy and energy efficiency.
- → **OzonAction** (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition to ensure implementation of the Montreal Protocol.
- → **Economics and Trade** (Geneva), which helps countries to integrate environmental considerations into economic and trade policies, and works with the finance sector to incorporate sustainable development policies.

UNEP DTIE activities focus on raising awareness, improving the transfer of knowledge and information, fostering technological cooperation and partnerships, and implementing international conventions and agreements.

For more information,
see **www.unep.fr**

www.unep.org

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This guidance note provides assistance to lighting testing laboratories seeking to develop proficiency in product testing and prepare for accreditation to conduct photometric testing. It is directed towards laboratory staff responsible for establishing a photometric laboratory or for improving the conformance of an existing laboratory. While it provides some general guidance on conducting tests, it does not attempt to provide detailed advice on conducting specific tests, as this is detailed within the relevant test standard. Instead, its main purpose is to assist with the internal calibration and characterisation processes within a photometric laboratory to enable accurate, repeatable tests to be conducted. Some laboratory housekeeping activities are also discussed, such as monitoring laboratory ambient conditions, record keeping and lamp storage practices.

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