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TECHNICAL SPECIFICATION

Nanomanufacturing – Key control characteristics – Part 7-2: Nano-enabled photovoltaics – Device evaluation method for indoor light

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**Part 7-2: Nano-enabled photovoltaics –
Device evaluation method for indoor light**

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IEC TS 62607-7-2 has been prepared by IEC technical committee 113: Nanotechnology for electrotechnical products and systems. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
113/710/DTS	113/737/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts of the IEC TS 62607 series, published under the general title *Nanomanufacturing – Key control characteristics*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- transformed into an International Standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Commercialization of nano-enabled solar cells, such as organic solar cells, is being promoted by utilizing their advantages over conventional solar cells, such as light weight, flexibility, colour, transparency, and coating processability. Energy harvesting applications that generate power using indoor light have been recognized as important applications for nano solar cells in conjunction with recent advances in the Internet of Things. In general, nano solar cells have a large band gap and are suitable for power generation under indoor lighting whose spectra are localized in the visible light region. In addition, since the low illuminance characteristics can be improved by devising the configuration, it is expected to be suitable for energy harvesting using indoor light.

The IEC 60904 series specifies evaluation methods for sunlight. In IEC 60904, the most important factors in evaluating a solar cell are the selection of a light source and the method of adjusting its irradiance for measurement. By changing the light source from sunlight to indoor light, an evaluation method under indoor light can be obtained. The clause structure of this document corresponds to that of IEC 60904. While light sources are limited to sunlight in the outdoor environment, various light sources are used indoors, such as fluorescent lamps and LED lamps in addition to sunlight. The indoor brightness is expressed by illuminance in lux (lx), which takes into account the sensitivity of the human eye. Strictly speaking, since the spectral characteristics of the eyes are different from those of solar cells, there is not always a correlation between the illuminance and the power generation of solar cells. For example, a crystalline Si solar cell could generate power using only near-infrared light which is invisible to human eyes, i.e. zero lux. However, high-efficiency lighting other than incandescent lamps has a spectrum concentrated in the visible light region, thus expressing the efficiency of an indoor solar cell based on the spectrum of sunlight is not appropriate.

In this document, such uncertainties due to the use of illuminance instead or irradiance are eliminated by setting a reference spectrum for indoor light sources. The reference indoor light spectra are representatives of the spectrum of light sources used for indoor lighting, are defined only between 380 nm and 780 nm, and have no component outside of this wavelength range. Therefore, this document provides a method to evaluate solar cells with illuminance. Since the illuminance is obtained by the overlap integral of the spectral irradiance of the light source and the luminosity, there could be an infinite number of spectral irradiances that give the same illuminance. A large error could arise due to light in the wavelength region with low luminosity. In an extreme case, invisible light has a finite output even at zero illuminance. In this document, however, the output by zero lux illuminance is supposed to be zero, that is, the output is not guaranteed.

The target of this document is to define the output of a solar cell in a bright (finite illuminance) indoor environment. The output with light other than the reference spectrum is out of this target. If it is necessary to include such cases, they will be treated as individual cases. In that case, one would extend the reference spectrum and build an evaluation technique that uses irradiance instead of illuminance. Special illumination conditions can be used by using a user-defined reference spectrum. In this case, however, illuminance can be meaningless if the illumination contains a significant amount of invisible light.

Illumination includes not only the light that the eyes of humans are sensitive to, but also the infrared energy contained in incandescent lighting and sunlight that enters from outdoors. But because incandescent lighting is used less and less due to its poor energy efficiency, this document defines measurement methods with two standard indoor light sources specified by CIE: FL10 and LED-B4, corresponding to the fluorescent lamp and the white LED lamp, respectively, the correlated colour temperatures (CCT) of which are approximately 5 000 K. Other light sources such as sunlight or incandescent lamps are not appropriate because they contain much invisible infrared light and illuminance is not a good measure for performance evaluation of photovoltaic devices, because they contain a significant amount of invisible light.

This document, along with FL10 and LED-B4, establishes methods for evaluating photovoltaic cells under indoor conditions. This document assumes that an arbitrary photovoltaic cell will be measured under indoor lighting. For requirements not listed in this document, refer to the relevant normative references.

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 7-2: Nano-enabled photovoltaics – Device evaluation method for indoor light

1 Scope

This Technical Specification specifies the efficiency testing of photovoltaic cells (excluding multi-junction cells) under indoor light. Although it is primarily intended for nano-enabled photovoltaic cells (organic thin-film, dye-sensitized solar cells (DSC), and Perovskite solar cells), it can also be applied to other types of photovoltaic cells, such as Si, CIGS, GaAs cells, and so on.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

JIS C 1609-1, *Illuminance meters – Part 1: General measuring instruments*

DIN 5032-7, *Photometry – Part 7: Classification of illuminance meters and luminance meters*

ISO/CIE 19476, *Characterization of the performance of illuminance meters and luminance meters*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
response time
time required for current to respond after a change is made to the applied voltage

Note 1 to entry: Response time is represented by τ in the formula $I(t) = I(0) + \Delta I\left(1 - \exp\left(-\frac{t}{\tau}\right)\right)$ for expressing change in current over time.

3.2
indoor primary reference photovoltaic cell
photovoltaic cell calibrated from a radiometer, standard detector, or standard indoor light that is traceable to SI units

3.3
indoor standard relative spectral responsivity
measure to define indoor spectral coincidence without relying on the device under test itself

3.4
indoor reference photovoltaic cell
photovoltaic cell used to adjust the intensity of the indoor light source

3.5
indoor spectral coincidence
measure of spectral matching between standard indoor light and the illumination source used for a measurement

Note 1 to entry: It is expressed as a ratio of short-circuit currents calculated from the spectral responsivity of the photovoltaic cell.

3.6
indoor secondary reference photovoltaic cell
photovoltaic cell calibrated from the indoor primary reference photovoltaic cell

3.7
indoor working reference photovoltaic cell
photovoltaic cell calibrated from the indoor secondary reference photovoltaic cell

3.8
standard indoor light
light source with a defined spectral distribution that is used when evaluating photovoltaic cells under indoor light

Note 1 to entry: It covers a variety of indoor light sources, and two types of standard indoor light are adopted in this document.

3.9
standard indoor illuminance
illuminance values used when evaluating photovoltaic cells under indoor light

Note 1 to entry: The standard indoor illuminance values are 50 lx, 200 lx and 1 000 lx.

3.10
fluorescent lamp
light source that operates by electrically exciting mercury vapour and then converting the luminescence generated into visible light using a phosphor

3.11
dye-sensitized solar cell
photovoltaic cell created by coating metal-oxide particles (such as titanium oxide or zinc oxide) with a molecular dye then immersing them in an ionically conductive electrolyte

3.12
illuminance
intensity of a light that illuminates a surface, as perceived by the human eye

Note 1 to entry: Illuminance is expressed in units of lux (lx).

3.13
correlated colour temperature
temperature of the black-body radiator whose CIE (u, v), or (u′, 2/3 v′), colour coordinate is closest to that of a light source

Note 1 to entry: See Ohno, Y., "Practical Use and Calculation of CCT and Duv", Leukos, 10:1, 47-55. (2013).

3.14
measurement delay time
interval of time between the changing of the applied voltage and the start of the current measurement when measuring an I-V curve by varying an externally applied voltage

3.15
white LED lamp
light source that produces white light by using a fluorescent substance to convert the wavelength of light generated by violet or ultraviolet LEDs

3.16
luminosity function
numerical representation of the relative sensitivity of the human eye to the different wavelengths of visible light

3.17
perovskite solar cell
photovoltaic cell containing a semiconductor with a perovskite structure composed of monovalent cations, divalent metal ions, and halogen ions

3.18
organic photovoltaic cell
photovoltaic cell containing an organic semiconductor or dye in the layers where light absorption and charge separation take place

3.19
maximum power point tracking
technique for finding the operating point (I-V or load characteristic) at which a device generates the maximum amount of electric energy under given photo-irradiation conditions

Note 1 to entry: It is typically used for adjusting a photovoltaic cell's optimal operating point under changing conditions such as weather and solar altitude angle, but it can also be utilized to determine the conversion efficiency of a cell when assessing its I-V curve is not feasible.

3.20
programmable reference cell system for irradiance adjustment by spectral measurement
method for adjusting the intensity of an illumination source through the formula

$$\int S_{\text{abs}}(\lambda) E_{\text{ref}}(\lambda) \text{d}\lambda = \int S_{\text{abs}}(\lambda) E_{\text{mes}}(\lambda) \text{d}\lambda ,$$

where $S_{\text{abs}}(\lambda)$ is the absolute spectral responsivity of the DUT, $E_{\text{mes}}(\lambda)$ is the absolute spectral irradiance of the illumination source, and $E_{\text{ref}}(\lambda)$ is the spectral irradiance of the standard light

4 Abbreviated terms

PV:	photovoltaic
DSC:	dye-sensitized solar cell
CIGS:	copper indium gallium selenide
GaAs:	gallium arsenide
c-Si:	crystalline silicon
a-Si:	amorphous silicon
LED:	light emitting diode
DUT:	device under test
CCT:	correlated colour temperature

OPV: organic photovoltaic cell

V_{oc}: open circuit voltage

I_{sc}: short circuit current

FF: fill factor

EQE: external quantum efficiency

PRISM: programmable reference cell system for irradiance adjustment by spectral measurement

MPPT: maximum power point tracking

I-V: current-voltage

SI: système international d'unités (international unit system)

5 Methods for measuring current-voltage characterization

5.1 General

IEC 60904-1 describes procedures for the measurement of current-voltage characteristics (I-V curves) of photovoltaic (PV) devices in natural or simulated sunlight. Efficiency is not directly an I-V parameter, but rather an additional quantity obtained from the maximum-power, the irradiance and the device area. For guidance on area measurement see Annex A.

5.2 Requirements

5.2.1 Device under test (DUT)

Define the area A (m^2) of the DUT used to calculate conversion efficiency. If the DUT is a photovoltaic cell, attach a shadow mask then measure the area of the mask's opening and use that as the area of the DUT. If the DUT is a module, use the area of the entire element (including nonconductive components) as the area of the DUT.

5.2.2 Illumination adjustment

For adjusting illuminance at the DUT described in 5.2.3, one of the three methods a) to c) shall be used.

a) Indoor reference photovoltaic-cell method: A method for adjusting the intensity of an illumination source by matching it to the calibrated value for an indoor reference photovoltaic cell. When performing spectral-mismatch correction, however, adjust the intensity to match the value obtained by dividing the calibrated value by the spectral-mismatch correction factor.

b) PRISM or spectroradiometer method: A method for adjusting the intensity of an illumination source through the formula $\int S_{abs}(\lambda)E_{ref}(\lambda)d\lambda = \int S_{abs}(\lambda)E_{mes}(\lambda)d\lambda$, where $S_{abs}(\lambda)$ is the absolute spectral responsivity of the test photovoltaic cell, $E_{mes}(\lambda)$ is the absolute spectral irradiance of the light source, and $E_{ref}(\lambda)$ is the spectral irradiance of the standard light, using a calibrated spectroradiometer, in accordance with ASTM G138-12 (2020) [1][1], for example.

c) Illuminometer method: A method for adjusting the intensity of an illumination source to match standard indoor illuminance by using an illuminometer calibrated according to JIS C 1609-1, DIN 5032-7, or ISO/CIE 19476. For this method of adjusting illuminance, the class of the light source should be restricted to Class-A or higher defined in 12.1.4.

Measure illuminance in the sample plane as measured by a reference device. If the reference device is an illuminometer, then the measured illuminance is the output of the illuminometer. If

[1] Numbers in square brackets refer to the Bibliography.

the reference device is a reference cell or PRISM then make the measured illuminance [$L_{mes} = L_{ref} \cdot I_{mes} / (M \cdot I_{cal})$] close to L_{ref} within 5 % by adjusting I_{mes}, where L_{ref} is the reference illuminance at which the reference cell is calibrated, I_{cal} is the calibrated short-circuit current of the reference cell at L_{ref}, I_{mes} is the measured short-circuit current, and M is the spectral-mismatch correction factor (if it is not applied, M = 1). If $L_{mes} \neq L_{ref}$ then measured current value shall be corrected by multiplying by L_{eff} / L_{mes}.

5.2.3 Measurement procedure

1) If necessary, allow the DUT to stabilize prior to measurement. IEC TR 63228 [2] describes stabilization for emerging PVs.
2) Regulate the temperature of the DUT to 25 °C ± 1 °C.
3) Illuminance at the DUT (L_{mes}) shall be adjusted to the illuminance to the standard indoor illuminance (L_{ref}) – 50 lx, 200 lx, or 1 000 lx – according to 5.2.2.
4) Determine the maximum output power (P_m) by sweeping the bias voltage while illuminating the DUT to perform I-V measurements.
   - Make a correction to the measured current (I) by multiplying by L_{eff} / L_{mes}.
   - When sweeping the bias voltage, set the measurement delay time to a value at least four times greater than the response time of the DUT.
   - If the response time is unknown, set the measurement delay time so that the difference in P_m values for the forward and reverse directions is 2 % or less. For slowly responding elements, adjust the measurement delay time in accordance with the response speed so that P_m variance is 2 % or less. In cases where P_m variance exceeds 2 %, record the P_m values and I-V characteristics for both the forward and reverse directions.
   - Measurement stability: Perform at least five measurements for both the forward and reverse directions, then verify that variation among those P_m values is 2 % or less. Variation among multiple measurement values is given by

$$\left(\frac{P_{m\_max} - P_{m\_min}}{P_{m\_average}} \right) \times 100 ,$$

     where

     P_{m_max} is the maximum P_m value;

     P_{m_min} is the minimum P_m value; and

     $P_{m\_average}$ is the average P_m value.

   - Use $P_{m\_average}$ as the maximum output (P_m).
5) Determine conversion efficiency η as given by

$$\eta = \frac{P_m}{G \cdot A}$$

   where A is the area of the DUT (m^2) and E is the irradiance per unit area (W/m^2) given by

$$G = \int E(\lambda) d\lambda$$

   where $E(\lambda)$ is the spectral irradiance ($W/m^2/nm$) of the illumination source.
6) Irradiance values for standard indoor illuminance are listed in Table 1.

Table 1 – Standard indoor illuminance

Illuminance (lx)	**Standard indoor light FL10** (mW/m²)	**Standard indoor light B4** (mW/m²)	**User light source, u**
1 000	3 076	3 132	$\int E_u(\lambda)\mathrm{d}\lambda$ (where $K_m \int E_u(\lambda)V(\lambda)\mathrm{d}\lambda = 1\,000$)
200	615	626	$\int E_u(\lambda)\mathrm{d}\lambda$ (where $K_m \int E_u(\lambda)V(\lambda)\mathrm{d}\lambda = 200$)
50	154	157	$\int E_u(\lambda)\mathrm{d}\lambda$ (where $K_m \int E_u(\lambda)V(\lambda)\mathrm{d}\lambda = 50$)

7) Recording results.

The information in Table 2 should be recorded.

Table 2 – Result record

Item	Subitem	Details
Test date		
Tested by		
Device under test	Type	
	Dimensions	
P_m		
Electrical characteristics		I_{sc}, V_{oc}, FF, V_{max}, I_{max}
Conversion efficiency		
P_m	a	Forward-direction P_m Reverse-direction P_m
Electrical characteristics	a	Forward-direction I_{sc}, V_{oc}, FF, V_{max}, I_{max} Reverse-direction I_{sc}, V_{oc}, FF, V_{max}, I_{max}
Conversion efficiency	a	Forward-direction η Reverse-direction η
I-V characteristic	a	Record on separate sheet
Standard indoor light	Type	
	Illuminance	
	Spectral irradiance b	Record on separate sheet
	Irradiance	
	Wavelength range b	
Indoor reference PV cell method (if using reference PV cell method)	Type	
	Calibration value	
	Calibration date	
PRISM method (if using PRISM method)	Spectral-response measurement system	
	Type	
	Calibration date	
	Spectroradiometer	
	Type	
	Calibration date	
Illuminometer method (if using illuminometer method)	Type	
	Calibration date	
I-V measurement device	Type	
	Calibration date	

a Record this data if P_m varies more than 2,0 % between the forward and reverse directions.

b Record this data only if a user-defined light source was used.

5.3 Important additional information

a) If there is considerable distance between the DUT and the I-V measuring device, perform the I-V measurement with the four-point probe method to eliminate the potential distortion of the result by the voltage drop in the cables.

b) Connect the electrodes of the DUT to the electrical characteristics measuring device using a lead wire or specialized jig for measuring electrical characteristics.

c) If there are large fluctuations during measurement and stable values cannot be obtained, include that information in the report.

d) To achieve the specified cell temperature, either directly regulate the DUT to 25 °C ± 1 °C or leave it in an environment that is 25 °C ± 1 °C until it reaches thermal equilibrium with that environment. It is recommended to use a DUT with an exposure area greater than 1 cm^2.

e) Use a shadow mask with slightly smaller dimensions than the DUT.

f) If highly accurate results are needed, it is recommended to use a Class-A illumination source and to adjust its intensity with either the reference-cell or PRISM methods.

g) When calculating spectral-mismatch correction with the reference-cell method or wavelength range with the PRISM method, use a wavelength range that is wider than that of the DUT's spectral responsivity.

NOTE Limiting calculations to the wavelength range of standard indoor light can lead to errors if the light source contains spectral components that fall outside the range specified for the standard indoor light and if the DUT is sensitive to light within that range.

6 Indoor reference photovoltaic cells

6.1 Requirements

6.1.1 Selecting indoor reference photovoltaic cells

Prepare a number of stable photovoltaic cells with the same spectral responsivity as the cell which will be measured, then use the following method to select a cell from among them.

a) Exclude any cells that have V_{oc}, I_{sc}, FF, and its appearance deviated drastically from the average of the group.

b) Measure the spectral responsivity of each cell under the illuminance selected for measurement, then choose the cell that is closest to the average spectral responsivity. Indoor secondary reference photovoltaic cells shall be cells that have less than ±2 % spectral-mismatch error (as calculated in Clause 10).

6.1.2 Calibrating indoor reference photovoltaic cells

a) Use one of the following methods to calibrate reference cells.

   1) Reference photovoltaic-cell method

      - Using an indoor primary reference photovoltaic cell that is traceable to SI units, calibrate the indoor secondary reference photovoltaic cell under the classified illumination source.
      - When calibrating, there is no need to perform a spectral-mismatch correction if the spectral-mismatch error between the indoor primary reference photovoltaic cell and the indoor secondary reference photovoltaic cell is within ±1 %.
      - If the spectral-mismatch error between the indoor primary reference photovoltaic cell and indoor secondary reference photovoltaic cell is greater than ±1 % when calibrating, perform the spectral-mismatch correction.

   2) Spectral-responsivity method

      - Using a spectral-responsivity measurement system that has a guaranteed accuracy of absolute values and is traceable to SI units, measure the spectral responsivity $S(\lambda)$ of the indoor secondary reference photovoltaic cell.
      - Using the standard indoor light's $E(\lambda)$ as defined in Clause 7, determine the calibration value (V_{cal}) given by

$$V_{cal} = \int S_{abs}(\lambda) E(\lambda) d\lambda$$

b) Recording results

Record the calibration results.

The information in Table 3 should be reported.

Table 3 – Calibration record

Item		Details
Calibration date		
Calibrated by		
Reference cell	Type	
	Size	
	Calibration value	
	Calibration method	
	Spectral-mismatch correction factor	
Primary reference cell	Type	
	Size	
	Calibration value	
	Calibration method	
	Calibration laboratory	
	Calibration value	
Standard indoor light	Type	
	Illuminance	
	Optical spectrum	
	Irradiance	
Measuring device used	Spectral-response measurement system	
	Calibration date	
	Spectroradiometer	
	Calibration date	

c) Inspections

Once per year, inspect and calibrate the device used for calibration and document a log of the inspection.

6.2 Important notes

If a stable secondary-reference cell with the same relative spectral responsivity as the DUT cannot be obtained, use a quasi-reference photovoltaic cell, the spectral responsivity of which is similar to the DUT with a stable photovoltaic cell, e.g., a Si photovoltaic cell combined with an appropriate optical filter.

NOTE The quasi-reference photovoltaic cell is explained in A.4.4.

7 Standard indoor light – Requirements

7.1 Standard indoor illuminance

Use the illuminance of standard indoor light (L_{ref}, 1 000 lx, 200 lx, or 50 lx) as the standard indoor illuminance.

When using an illuminance other than the above, record the light source and illuminance used for measurement.

7.2 Standard indoor light

Select one of the following.

a) CIE FL10 light source: the spectrum labelled "FL10" in Table 4 (fluorescent lamp with a correlated colour temperature of 5 000 K approximately, defined by CIE).

b) CIE LED-B4 light source: the spectrum labelled "B4" in Table 4 (LED lamp with a correlated colour temperature of 5 000 K approximately, defined by CIE).

c) U light source: a user-defined light source.

7.3 Spectral irradiance of standard indoor light

The spectral irradiance of each standard indoor light at 1 000 lx is indicated in Table 1 and Figure 1. For 50 lx and 200 lx illuminance, just divide each value by 20 and 5, respectively.

Table 4 – Spectral irradiance (mW/m²/nm) of standard indoor light at 1 000 lx

λ (nm)	FL10	B4		λ (nm)	FL10	B4		λ (nm)	FL10	B4		λ (nm)	FL10	B4
380	1,11	0,00		480	7,91	4,89		580	11,45	15,98		680	1,47	4,05
381	1,06	0,00		481	9,36	4,70		581	12,58	15,93		681	1,53	3,96
382	1,00	0,00		482	11,21	4,55		582	13,51	15,88		682	1,60	3,87
383	0,94	0,00		483	13,21	4,43		583	14,21	15,82		683	1,67	3,79
384	0,87	0,00		484	15,11	4,33		584	14,64	15,76		684	1,73	3,70
385	0,80	0,00		485	16,64	4,25		585	14,79	15,70		685	1,79	3,62
386	0,72	0,00		486	17,61	4,20		586	14,64	15,64		686	1,83	3,54
387	0,65	0,00		487	18,04	4,16		587	14,24	15,58		687	1,86	3,46
388	0,60	0,00		488	17,99	4,15		588	13,65	15,51		688	1,85	3,38
389	0,58	0,00		489	17,53	4,16		589	12,94	15,44		689	1,81	3,31
390	0,62	0,00		490	16,73	4,19		590	12,16	15,36		690	1,74	3,23
391	0,71	0,00		491	15,67	4,25		591	11,38	15,28		691	1,62	3,16
392	0,82	0,00		492	14,42	4,33		592	10,63	15,20		692	1,48	3,08
393	0,87	0,00		493	13,08	4,43		593	9,96	15,11		693	1,32	3,01
394	0,81	0,01		494	11,72	4,55		594	9,39	15,02		694	1,16	2,94
395	0,57	0,01		495	10,44	4,70		595	8,97	14,93		695	1,02	2,87
396	0,15	0,01		496	9,31	4,87		596	8,70	14,84		696	0,91	2,80
397	0,00	0,02		497	8,31	5,07		597	8,47	14,75		697	0,85	2,73
398	0,00	0,02		498	7,43	5,28		598	8,12	14,65		698	0,85	2,66
399	0,17	0,02		499	6,65	5,52		599	7,52	14,55		699	0,94	2,60
400	1,48	0,03		500	5,94	5,77		600	6,52	14,44		700	1,14	2,53
401	3,75	0,04		501	5,29	6,04		601	5,11	14,33		701	1,45	2,47

λ (nm)	FL10	B4		λ (nm)	FL10	B4		λ (nm)	FL10	B4		λ (nm)	FL10	B4
402	6,53	0,04		502	4,70	6,33		602	3,87	14,22		702	1,86	2,41
403	9,25	0,05		503	4,18	6,64		603	3,52	14,10		703	2,33	2,35
404	11,32	0,07		504	3,72	6,95		604	4,76	13,98		704	2,83	2,29
405	12,16	0,08		505	3,34	7,27		605	8,31	13,86		705	3,32	2,24
406	11,39	0,10		506	3,04	7,60		606	14,56	13,74		706	3,78	2,19
407	9,40	0,12		507	2,80	7,93		607	22,56	13,62		707	4,17	2,14
408	6,79	0,14		508	2,62	8,27		608	31,01	13,49		708	4,44	2,09
409	4,17	0,17		509	2,47	8,60		609	38,62	13,37		709	4,56	2,04
410	2,12	0,21		510	2,35	8,94		610	44,13	13,24		710	4,49	1,99
411	1,10	0,25		511	2,24	9,28		611	46,54	13,11		711	4,20	1,94
412	0,95	0,31		512	2,13	9,62		612	46,17	12,98		712	3,75	1,90
413	1,37	0,37		513	2,04	9,95		613	43,64	12,85		713	3,20	1,85
414	2,05	0,45		514	1,95	10,28		614	39,56	12,71		714	2,61	1,81
415	2,70	0,54		515	1,88	10,60		615	34,56	12,57		715	2,05	1,76
416	3,08	0,65		516	1,82	10,92		616	29,20	12,43		716	1,58	1,72
417	3,25	0,78		517	1,77	11,23		617	23,91	12,28		717	1,19	1,67
418	3,33	0,93		518	1,71	11,53		618	19,05	12,14		718	0,89	1,63
419	3,45	1,11		519	1,66	11,83		619	14,99	11,99		719	0,66	1,59
420	3,74	1,31		520	1,59	12,11		620	12,09	11,84		720	0,49	1,55
421	4,27	1,54		521	1,51	12,39		621	10,60	11,70		721	0,38	1,51
422	4,88	1,79		522	1,44	12,65		622	10,26	11,55		722	0,30	1,48
423	5,37	2,08		523	1,39	12,90		623	10,67	11,41		723	0,27	1,44
424	5,52	2,40		524	1,39	13,14		624	11,43	11,27		724	0,25	1,40
425	5,14	2,75		525	1,47	13,36		625	12,15	11,12		725	0,24	1,37
426	4,16	3,14		526	1,63	13,57		626	12,52	10,98		726	0,23	1,34
427	3,13	3,56		527	1,81	13,77		627	12,50	10,83		727	0,23	1,30
428	2,75	4,02		528	1,94	13,96		628	12,13	10,68		728	0,22	1,27
429	3,73	4,51		529	1,96	14,13		629	11,46	10,53		729	0,21	1,24
430	6,75	5,04		530	1,80	14,30		630	10,52	10,38		730	0,21	1,21
431	12,18	5,60		531	1,46	14,46		631	9,37	10,24		731	0,21	1,18
432	19,02	6,20		532	1,28	14,61		632	8,09	10,09		732	0,20	1,15
433	25,90	6,85		533	1,65	14,76		633	6,78	9,94		733	0,20	1,12
434	31,47	7,55		534	2,99	14,90		634	5,53	9,80		734	0,21	1,10
435	34,39	8,31		535	5,71	15,02		635	4,43	9,65		735	0,21	1,07
436	33,73	9,14		536	10,10	15,14		636	3,56	9,50		736	0,22	1,04
437	30,25	10,05		537	16,05	15,25		637	2,91	9,36		737	0,22	1,02
438	25,15	11,05		538	23,33	15,36		638	2,45	9,21		738	0,23	1,00
439	19,62	12,15		539	31,72	15,45		639	2,14	9,06		739	0,23	0,97
440	14,86	13,37		540	40,99	15,54		640	1,95	8,91		740	0,24	0,95
441	11,79	14,71		541	50,76	15,63		641	1,85	8,76		741	0,24	0,93
442	10,24	16,15		542	60,05	15,70		642	1,84	8,62		742	0,24	0,91
443	9,78	17,63		543	67,73	15,78		643	1,89	8,48		743	0,24	0,89
444	9,98	19,13		544	72,66	15,84		644	2,01	8,33		744	0,24	0,87

λ (nm)	FL10	B4		λ (nm)	FL10	B4		λ (nm)	FL10	B4		λ (nm)	FL10	B4
445	10,40	20,61		545	73,70	15,90		645	2,19	8,19		745	0,24	0,85
446	10,70	22,03		546	70,14	15,96		646	2,41	8,05		746	0,24	0,83
447	10,83	23,33		547	62,96	16,01		647	2,66	7,91		747	0,23	0,81
448	10,86	24,44		548	53,55	16,06		648	2,89	7,78		748	0,23	0,79
449	10,82	25,33		549	43,30	16,11		649	3,07	7,64		749	0,22	0,77
450	10,76	25,91		550	33,61	16,15		650	3,19	7,51		750	0,21	0,75
451	10,73	26,16		551	25,61	16,19		651	3,21	7,38		751	0,20	0,73
452	10,72	26,08		552	19,32	16,23		652	3,16	7,25		752	0,19	0,71
453	10,72	25,70		553	14,49	16,27		653	3,05	7,12		753	0,18	0,70
454	10,70	25,04		554	10,88	16,30		654	2,91	6,99		754	0,17	0,68
455	10,67	24,12		555	8,24	16,33		655	2,77	6,86		755	0,17	0,67
456	10,61	22,99		556	6,35	16,36		656	2,64	6,73		756	0,17	0,66
457	10,51	21,69		557	5,05	16,38		657	2,53	6,60		757	0,18	0,65
458	10,39	20,30		558	4,21	16,40		658	2,44	6,47		758	0,19	0,63
459	10,26	18,87		559	3,70	16,41		659	2,36	6,34		759	0,20	0,62
460	10,11	17,47		560	3,38	16,42		660	2,29	6,21		760	0,21	0,61
461	9,96	16,16		561	3,14	16,43		661	2,23	6,08		761	0,22	0,60
462	9,80	14,94		562	2,94	16,44		662	2,18	5,96		762	0,22	0,59
463	9,63	13,83		563	2,77	16,45		663	2,13	5,84		763	0,22	0,57
464	9,46	12,81		564	2,62	16,45		664	2,07	5,72		764	0,22	0,56
465	9,27	11,90		565	2,47	16,44		665	2,00	5,60		765	0,22	0,55
466	9,07	11,10		566	2,32	16,44		666	1,91	5,49		766	0,21	0,54
467	8,87	10,38		567	2,18	16,42		667	1,81	5,37		767	0,20	0,53
468	8,67	9,74		568	2,09	16,41		668	1,71	5,26		768	0,19	0,52
469	8,47	9,16		569	2,07	16,39		669	1,61	5,16		769	0,18	0,51
470	8,29	8,62		570	2,14	16,36		670	1,52	5,05		770	0,17	0,50
471	8,13	8,11		571	2,34	16,34		671	1,45	4,95		771	0,16	0,49
472	7,96	7,62		572	2,69	16,31		672	1,41	4,84		772	0,15	0,48
473	7,78	7,16		573	3,21	16,27		673	1,37	4,74		773	0,14	0,47
474	7,56	6,74		574	3,92	16,24		674	1,36	4,64		774	0,13	0,46
475	7,29	6,34		575	4,86	16,20		675	1,35	4,54		775	0,12	0,45
476	6,98	5,98		576	6,03	16,16		676	1,35	4,44		776	0,11	0,44
477	6,73	5,66		577	7,35	16,12		677	1,37	4,34		777	0,11	0,44
478	6,71	5,37		578	8,76	16,08		678	1,39	4,24		778	0,10	0,43
479	7,05	5,11		579	10,15	16,03		679	1,42	4,14		779	0,10	0,43
												780	0,09	0,42

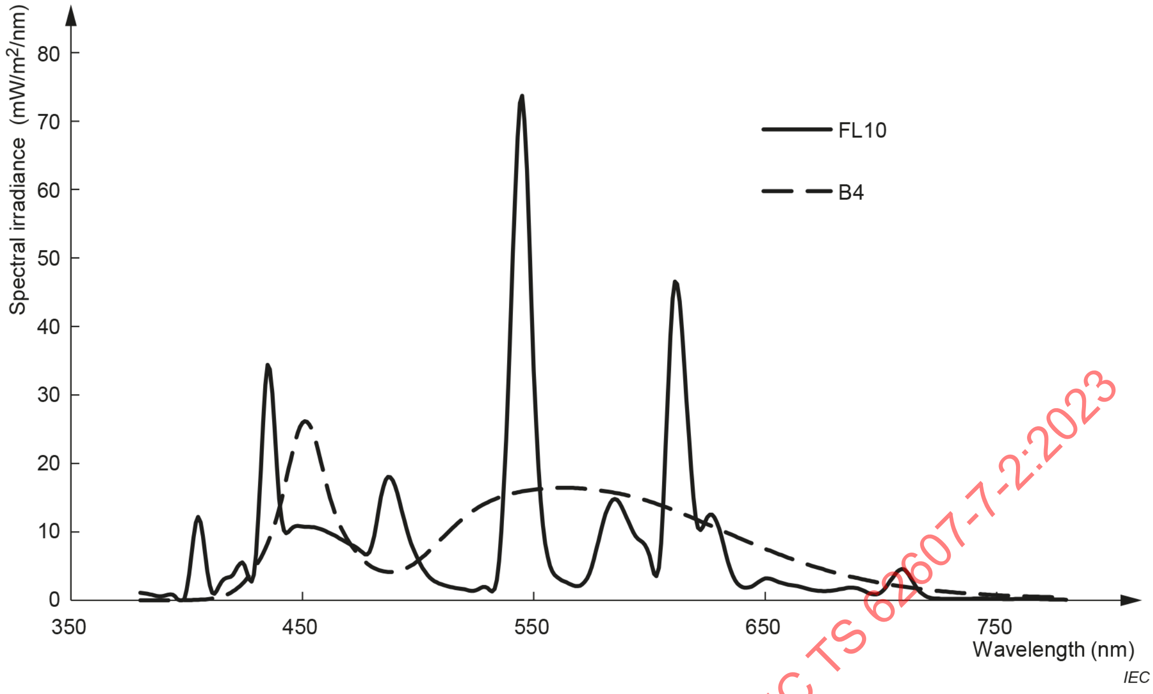

Figure 1 – Spectral irradiance of standard indoor light at 1 000 lx

8 Traceability

8.1 Description – General

Most of IEC 60904-4 can be applied by replacing reference solar devices to indoor reference photovoltaic cells and standard test conditions (STC) to standard evaluation conditions described in this document.

8.2 Calibration chain example

A calibration chain example is shown in Figure 2 for each illumination adjusting method.

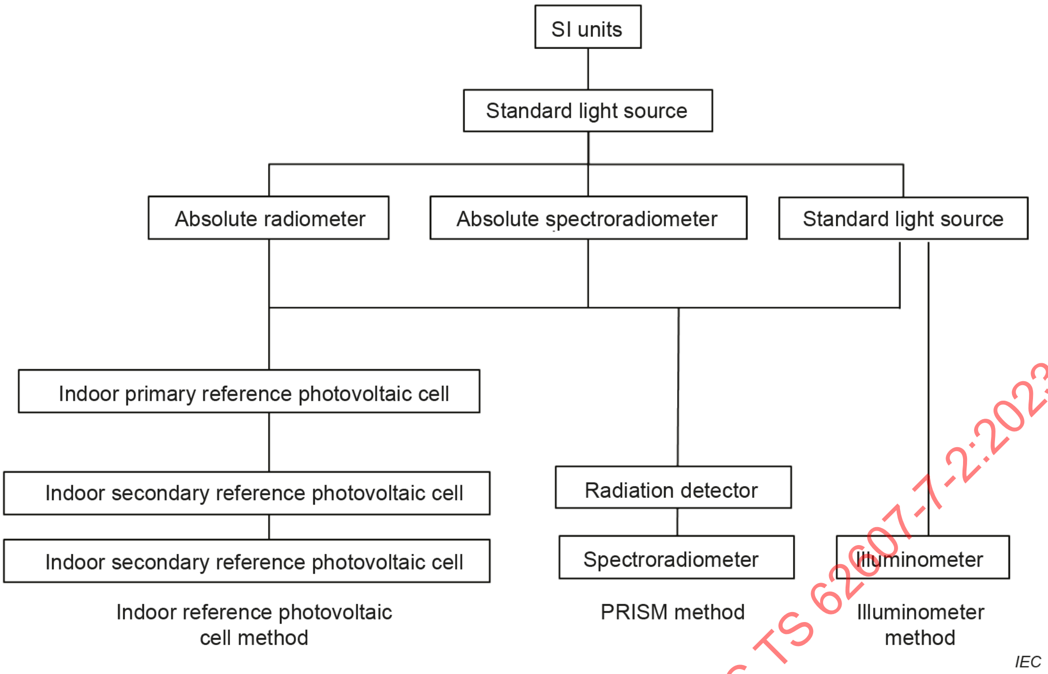

Figure 2 – Calibration chain example

9 Temperature correction

9.1 Requirements

None.

9.2 Temperature of the DUT

When conducting evaluations of photovoltaic cells under indoor light, regulate the temperature of the DUT to 25 °C ± 1 °C before taking measurements. Temperature correction is not necessary. If an evaluation is performed at a different temperature, record the temperature.

10 Spectral-mismatch correction

10.1 Requirements

10.1.1 Indoor reference photovoltaic-cell method

a) Measure the spectral irradiance $E_{mes}(\lambda)$ of the illumination source.

b) Measure the relative spectral responsivity $S_{mes}(\lambda)$ of the DUT.

c) Measure the relative spectral responsivity $S_{ref}(\lambda)$ of the reference photovoltaic cell calibrated using standard indoor illuminance.

d) Calculate the spectral-mismatch correction factor M as given by

$$\mathrm{M} = \frac{\int E_{ref}(\lambda) S_{ref}(\lambda) \mathrm{d}\lambda \int E_{mes}(\lambda) S_{mes}(\lambda) \mathrm{d}\lambda}{\int E_{mes}(\lambda) S_{ref}(\lambda) \mathrm{d}\lambda \int E_{ref}(\lambda) S_{mes}(\lambda) \mathrm{d}\lambda}$$

NOTE $E_{ref}(\lambda)$ is the spectral irradiance of the standard indoor light.

10.1.2 Recording results

a) Record the spectroradiometer and model of spectral-response measurement system used for measurement, the calibration date, and illumination conditions such as angle of light reception.

b) Record the type of standard indoor light and illuminance selected.

c) Record the model and $E_{mes}(\lambda)$ of the illumination source.

d) Record the name and $S_{mes}(\lambda)$ of the DUT.

e) Record the name and $S_{ref}(\lambda)$ of the indoor reference photovoltaic cell.

f) Record the spectral-mismatch correction factor M.

g) Record the measurement date.

10.2 Important additional information

a) When adjusting light intensity with the indoor reference photovoltaic-cell method, it is recommended to perform spectral-mismatch correction if the spectral-mismatch error (M − 1) is greater than ±2 %.

b) Even if the DUT is an element with a nonlinear response, as long as it is verified to have no fluctuations in its relative spectral responsivity, then the responsivity as measured with an arbitrary bias light (or with no bias light at all) can be used.

11 Spectral responsivity

11.1 Requirements

11.1.1 Spectral responsivity, $S(\lambda)$

Measurement methods differ for linear and nonlinear DUTs as defined in Clause 13.

a) Nonlinear DUT

Determine the spectral responsivity $S_{abs}(\lambda)$ under standard indoor illuminance. Use differential spectral responsivity to determine the $S_{abs}(\lambda)$ that corresponds to standard indoor illuminance in accordance with IEC 60904-8. However, replace the STC values in IEC 60904-8 with standard indoor illuminance as the illumination conditions.

b) Linear DUT

Measure $S_{abs}(\lambda)$ using an arbitrary bias light that falls within the range of short-circuit currents verified to be linear (or using no bias light at all).

11.1.2 Measurement methods

Measure spectral responsivity under the white bias light using one of the following methods.

a) Lock-in amplifier method

Illuminate the DUT with both the bias light and a chopped monochromatic light, then detect the signal coming from the DUT with a lock-in amplifier.

b) Steady state method

Detect variations in steady-state short-circuit current under monochromatic light using a DC detector.

11.2 Important notes

The spectral responsivity $S_{abs}(\lambda)$ used in this document is the absolute spectral responsivity that can be calculated from the short-circuit current I_{sc} generated when the cell is illuminated with light that has a spectral irradiance $E_{mes}(\lambda)$ similar to the standard indoor illuminance, as given by

$$I_{sc} = \int S_{abs}(\lambda) E_{mes}(\lambda) d\lambda$$

Keep the following points in mind when working with unstable elements or elements with slow response characteristics.

a) Spectral responsivity can vary according to chopping frequency, so conduct testing with low frequency if possible.

b) When measuring an unstable photovoltaic cell, carry out any necessary preparation beforehand such as exposing the cell to the illumination that will be used for testing. Perform measurements after confirming that the variation in short-circuit current over a 2 h period is within ±2 %.

12 Illumination sources

12.1 Requirements

12.1.1 Indoor spectral coincidence

Determine the indoor spectral coincidence of the illumination source as given by the worst value of

$$\frac{\int E_{mes}(\lambda) S_k(\lambda) d\lambda}{\int E_{ref}(\lambda) S_k(\lambda) d\lambda}$$

where

$E_{ref}(\lambda)$ is the spectral irradiance of standard indoor light CIE FL10/ CIE LED-B4 with standard indoor illuminance. $S_k(\lambda)$ (k = PV-1, −2, −3, −4, −5) are the relative standard spectral responsivities listed in Table 6, and $E_{mes}(\lambda)$ is the spectral irradiance of the illumination source with standard indoor illuminance as given by

$1000 = K_m \int E_{mes}(\lambda) V(\lambda) d\lambda$ (with 1 000-lx illuminance), and

$200 = K_m \int E_{mes}(\lambda) V(\lambda) d\lambda$ (with 200-lx illuminance),

where $V(\lambda)$ is the luminosity function characteristic and K_m is the maximum luminous efficacy (683 lm/W). The worst value means the value whose deviation from 1 is the largest.

When performing calculations, use a wavelength range that is wider than the spectral responsivity of the DUT.

12.1.2 Illuminance non-uniformity

a) If the illumination contains a single illumination source:

Measure for illuminance non-uniformity (%) as given by

$$\left(\frac{I_{max} - I_{min}}{I_{max} + I_{min}}\right) \times 100$$

where

I_{max} is the maximum illuminance value within the illuminated area, and

I_{min} is the minimum illuminance value within the illuminated area.

Use a stable DUT or a general-purpose photodetector to perform the measurement.

The photodetection area should be no more than 1/10 the area of the DUT. Measure at least 17 points.

b) If the illumination contains multiple illumination sources:

Measure for illuminance non-uniformity (%) as given by

$$\left(\frac{I_{max} - I_{min}}{I_{max} + I_{min}}\right) \times 100$$

where

I_{max} is the maximum value within the area irradiated by the illumination source, and

I_{min} is the minimum value within the area irradiated by the illumination source.

Perform the measurement with either a stable DUT or a photodetector that is no more than 1/10 the size of the DUT and that matches all of the relative standard spectral responsivities listed in Table 6. Measure at least 17 points.

12.1.3 Temporal stability

Measure the stability of illuminance over time as given by

$$\frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

where

V_{max} is the maximum voltage, and

V_{min} is the minimum voltage during measurement.

Perform the measurement by connecting a resistor in series to either a reference cell or photodiode then reading the voltage at both ends of the resistor with an oscilloscope or similar instrument. Adjust the resistor and the element's area small enough so that the response speed of the measurement system follows the fluctuation of the light source over time, while the signal-to-noise ratio is larger than 20 dB.

12.1.4 Light source classification

Light sources are classified as either SA, A, B, or C according to their spectral coincidence, amount of uneven illuminance, and stability over time.

To be assigned to a particular class, a light source shall meet all the requirements for that class.

Table 5 – Light source classification

Class	SA	A	B	C
Spectral coincidence	0,95 to 1,05	0,75 to 1,25	0,6 to 1,4	0,4 to 2,0
Non-uniformity	within ±2 %	within ±2 %	within ±5 %	within ±10 %
Temporal stability	within ±0,5 %	within ±0,5 %	within ±2 %	within ±10 %

12.1.5 Indoor standard relative spectral responsivity

Indoor standard relative spectral responsivity values are indicated in Table 6 and Figure 3.

Table 6 – Indoor standard relative spectral responsivity (%)

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	*λ* (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
300	0,0	0,0	0,0	0,0	22,7	750	0,0	0,0	49,9	92,6	92,1
301	0,0	0,0	0,0	0,0	23,1	751	0,0	0,0	47,0	92,8	92,2
302	0,0	0,0	0,0	0,0	23,3	752	0,0	0,0	44,1	92,9	92,3
303	0,0	0,0	0,0	0,0	23,6	753	0,0	0,0	41,3	93,0	92,5
304	0,0	0,0	0,0	0,0	23,9	754	0,0	0,0	38,5	93,1	92,6
305	0,0	0,0	0,0	0,0	24,2	755	0,0	0,0	35,7	93,3	92,7
306	0,0	0,0	0,0	0,0	24,5	756	0,0	0,0	33,1	93,4	92,8
307	0,0	0,0	0,0	0,0	24,7	757	0,0	0,0	30,5	93,5	92,9
308	0,0	0,0	0,0	0,0	24,9	758	0,0	0,0	28,0	93,6	93,0
309	0,0	0,0	0,0	0,0	25,2	759	0,0	0,0	25,7	93,8	93,1
310	0,0	0,0	0,0	0,0	25,4	760	0,0	0,0	23,4	93,9	93,2
311	0,0	0,0	0,0	0,0	25,6	761	0,0	0,0	21,3	94,0	93,4
312	0,0	0,0	0,0	0,0	25,8	762	0,0	0,0	19,2	94,1	93,4
313	0,0	0,0	0,0	0,0	26,0	763	0,0	0,0	17,3	94,2	93,5
314	0,0	0,0	0,0	0,0	26,2	764	0,0	0,0	15,6	94,4	93,6
315	0,0	0,0	0,0	0,0	26,4	765	0,0	0,0	13,9	94,5	93,7
316	0,0	0,0	0,0	0,0	26,6	766	0,0	0,0	12,4	94,6	93,8
317	0,0	0,0	0,0	0,0	26,7	767	0,0	0,0	11,0	94,7	93,9
318	0,0	0,0	0,0	0,0	26,9	768	0,0	0,0	9,7	94,9	94,0
319	0,0	0,0	0,0	0,0	27,0	769	0,0	0,0	8,5	95,0	94,1
320	0,0	0,0	0,0	0,0	27,2	770	0,0	0,0	7,5	95,1	94,2
321	0,0	0,0	0,0	0,0	27,4	771	0,0	0,0	6,5	95,2	94,3
322	0,0	0,0	0,0	0,0	27,5	772	0,0	0,0	5,7	95,4	94,4
323	0,0	0,0	0,0	0,0	27,6	773	0,0	0,0	4,9	95,5	94,5
324	0,0	0,0	0,0	0,0	27,8	774	0,0	0,0	4,2	95,6	94,6
325	0,0	0,0	0,0	0,0	27,9	775	0,0	0,0	3,6	95,7	94,6
326	0,0	0,0	0,0	0,0	28,0	776	0,0	0,0	3,1	95,9	94,7
327	0,0	0,0	0,0	0,0	28,1	777	0,0	0,0	2,6	96,0	94,8
328	0,0	0,0	0,0	0,0	28,2	778	0,0	0,0	2,2	96,1	94,9
329	0,0	0,0	0,0	0,0	28,3	779	0,0	0,0	1,9	96,2	95,1
330	0,0	0,0	0,0	0,0	28,4	780	0,0	0,0	1,6	96,3	95,2
331	0,0	0,0	0,0	0,0	28,5	781	0,0	0,0	1,3	96,5	95,3
332	0,0	0,0	0,0	0,0	28,6	782	0,0	0,0	1,1	96,6	95,3
333	0,0	0,0	0,0	0,0	28,7	783	0,0	0,0	0,9	96,7	95,4
334	0,0	0,0	0,0	0,0	28,8	784	0,0	0,0	0,7	96,8	95,5
335	0,0	0,0	0,0	0,0	28,9	785	0,0	0,0	0,6	97,0	95,5
336	0,0	0,0	0,0	0,0	29,0	786	0,0	0,0	0,5	97,1	95,6
337	0,0	0,0	0,0	0,0	29,1	787	0,0	0,0	0,4	97,2	95,7
338	0,0	0,0	0,0	0,0	29,1	788	0,0	0,0	0,3	97,3	95,8
339	0,0	0,0	0,0	0,0	29,2	789	0,0	0,0	0,3	97,5	95,8
340	0,0	0,0	0,0	0,0	29,2	790	0,0	0,0	0,2	97,6	95,9
341	0,0	0,0	0,0	0,0	29,3	791	0,0	0,0	0,2	97,7	96,0

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
342	0,0	0,0	0,0	0,0	29,3	792	0,0	0,0	0,1	97,8	96,1
343	0,0	0,0	0,0	0,0	29,3	793	0,0	0,0	0,1	98,0	96,2
344	0,0	0,0	0,0	0,0	29,3	794	0,0	0,0	0,1	98,1	96,3
345	0,0	0,0	0,0	0,0	29,3	795	0,0	0,0	0,1	98,2	96,4
346	0,0	0,0	0,0	0,0	29,3	796	0,0	0,0	0,0	98,3	96,4
347	0,0	0,0	0,0	0,0	29,2	797	0,0	0,0	0,0	98,4	96,5
348	0,0	0,0	0,0	0,0	29,2	798	0,0	0,0	0,0	98,6	96,6
349	0,0	0,0	0,0	0,0	29,1	799	0,0	0,0	0,0	98,7	96,7
350	0,0	0,0	0,0	0,0	29,1	800	0,0	0,0	0,0	98,8	96,8
351	0,0	0,0	0,0	0,0	29,1	801	0,0	0,0	0,0	98,9	96,9
352	0,0	0,0	0,0	0,0	29,1	802	0,0	0,0	0,0	99,0	96,9
353	0,0	0,0	0,0	0,0	29,1	803	0,0	0,0	0,0	99,1	97,0
354	0,0	0,0	0,0	0,0	29,2	804	0,0	0,0	0,0	99,3	97,1
355	0,1	0,0	0,0	0,0	29,2	805	0,0	0,0	0,0	99,4	97,2
356	0,1	0,1	0,1	0,0	29,2	806	0,0	0,0	0,0	99,5	97,3
357	0,1	0,1	0,1	0,1	29,3	807	0,0	0,0	0,0	99,6	97,4
358	0,1	0,1	0,1	0,1	29,5	808	0,0	0,0	0,0	99,7	97,4
359	0,1	0,1	0,1	0,1	29,6	809	0,0	0,0	0,0	99,7	97,5
360	0,2	0,1	0,1	0,1	29,7	810	0,0	0,0	0,0	99,8	97,6
361	0,2	0,2	0,2	0,1	29,8	811	0,0	0,0	0,0	99,9	97,7
362	0,3	0,2	0,2	0,2	30,1	812	0,0	0,0	0,0	99,9	97,8
363	0,3	0,3	0,3	0,2	30,4	813	0,0	0,0	0,0	100	97,8
364	0,4	0,3	0,3	0,2	30,7	814	0,0	0,0	0,0	100	97,9
365	0,5	0,4	0,4	0,3	30,9	815	0,0	0,0	0,0	100	98,0
366	0,6	0,5	0,5	0,4	31,2	816	0,0	0,0	0,0	100	98,0
367	0,7	0,6	0,6	0,4	31,6	817	0,0	0,0	0,0	99,9	98,1
368	0,9	0,7	0,7	0,5	31,9	818	0,0	0,0	0,0	99,8	98,2
369	1,0	0,9	0,9	0,6	32,3	819	0,0	0,0	0,0	99,7	98,3
370	1,2	1,0	1,1	0,8	32,6	820	0,0	0,0	0,0	99,6	98,3
371	1,5	1,2	1,2	0,9	32,9	821	0,0	0,0	0,0	99,4	98,4
372	1,7	1,5	1,5	1,1	33,3	822	0,0	0,0	0,0	99,1	98,4
373	2,0	1,7	1,7	1,3	33,6	823	0,0	0,0	0,0	98,8	98,5
374	2,4	2,0	2,0	1,5	34,0	824	0,0	0,0	0,0	98,4	98,5
375	2,8	2,4	2,4	1,8	34,3	825	0,0	0,0	0,0	98,0	98,6
376	3,3	2,8	2,8	2,1	34,7	826	0,0	0,0	0,0	97,5	98,6
377	3,8	3,2	3,2	2,4	35,0	827	0,0	0,0	0,0	96,8	98,7
378	4,4	3,7	3,7	2,8	35,3	828	0,0	0,0	0,0	96,2	98,8
379	5,1	4,3	4,2	3,2	35,6	829	0,0	0,0	0,0	95,4	98,8
380	5,8	4,9	4,8	3,7	35,9	830	0,0	0,0	0,0	94,5	98,9
381	6,7	5,6	5,5	4,2	36,2	831	0,0	0,0	0,0	93,5	99,0
382	7,6	6,3	6,2	4,8	36,5	832	0,0	0,0	0,0	92,3	99,0
383	8,6	7,2	7,0	5,4	36,8	833	0,0	0,0	0,0	91,1	99,1
384	9,7	8,1	7,8	6,1	37,0	834	0,0	0,0	0,0	89,7	99,1

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
385	10,9	9,1	8,8	6,9	37,3	835	0,0	0,0	0,0	88,2	99,1
386	12,1	10,2	9,8	7,7	37,6	836	0,0	0,0	0,0	86,6	99,2
387	13,5	11,3	10,8	8,6	37,9	837	0,0	0,0	0,0	84,9	99,2
388	15,0	12,6	12,0	9,5	38,1	838	0,0	0,0	0,0	83,0	99,3
389	16,6	13,9	13,2	10,5	38,4	839	0,0	0,0	0,0	81,0	99,3
390	18,3	15,3	14,4	11,5	38,7	840	0,0	0,0	0,0	78,9	99,3
391	20,0	16,8	15,8	12,7	38,9	841	0,0	0,0	0,0	76,6	99,4
392	21,9	18,3	17,2	13,8	39,2	842	0,0	0,0	0,0	74,3	99,4
393	23,8	20,0	18,6	15,1	39,4	843	0,0	0,0	0,0	71,8	99,4
394	25,8	21,6	20,1	16,3	39,6	844	0,0	0,0	0,0	69,3	99,5
395	27,9	23,4	21,7	17,7	39,9	845	0,0	0,0	0,0	66,6	99,5
396	30,1	25,2	23,3	19,0	40,1	846	0,0	0,0	0,0	63,9	99,5
397	32,3	27,0	24,9	20,4	40,3	847	0,0	0,0	0,0	61,1	99,6
398	34,5	28,9	26,5	21,8	40,5	848	0,0	0,0	0,0	58,3	99,6
399	36,8	30,8	28,2	23,3	40,8	849	0,0	0,0	0,0	55,4	99,7
400	39,1	32,7	29,8	24,7	41,0	850	0,0	0,0	0,0	52,5	99,7
401	41,4	34,7	31,5	26,2	41,2	851	0,0	0,0	0,0	49,6	99,7
402	43,7	36,6	33,1	27,6	41,4	852	0,0	0,0	0,0	46,7	99,8
403	46,0	38,5	34,8	29,1	41,6	853	0,0	0,0	0,0	43,8	99,8
404	48,2	40,4	36,4	30,5	41,8	854	0,0	0,0	0,0	41,0	99,8
405	50,5	42,3	38,0	31,9	42,1	855	0,0	0,0	0,0	38,2	99,9
406	52,7	44,1	39,5	33,3	42,3	856	0,0	0,0	0,0	35,5	99,9
407	54,8	45,9	41,0	34,7	42,5	857	0,0	0,0	0,0	32,8	99,9
408	56,9	47,7	42,5	36,0	42,7	858	0,0	0,0	0,0	30,3	99,9
409	58,9	49,4	43,9	37,3	42,9	859	0,0	0,0	0,0	27,8	100
410	60,9	51,0	45,2	38,5	43,1	860	0,0	0,0	0,0	25,5	100
411	62,8	52,6	46,5	39,7	43,3	861	0,0	0,0	0,0	23,2	100
412	64,5	54,1	47,7	40,8	43,5	862	0,0	0,0	0,0	21,1	100
413	66,2	55,5	48,9	41,9	43,7	863	0,0	0,0	0,0	19,1	100
414	67,8	56,8	50,0	42,9	43,9	864	0,0	0,0	0,0	17,2	100
415	69,4	58,1	51,0	43,9	44,1	865	0,0	0,0	0,0	15,4	100
416	70,8	59,3	52,0	44,8	44,3	866	0,0	0,0	0,0	13,8	99,9
417	72,1	60,4	52,9	45,6	44,5	867	0,0	0,0	0,0	12,3	99,9
418	73,4	61,5	53,7	46,4	44,7	868	0,0	0,0	0,0	10,9	99,9
419	74,5	62,4	54,5	47,1	44,9	869	0,0	0,0	0,0	9,6	99,9
420	75,6	63,3	55,2	47,8	45,1	870	0,0	0,0	0,0	8,5	99,9
421	76,6	64,2	55,9	48,4	45,3	871	0,0	0,0	0,0	7,4	99,9
422	77,5	64,9	56,5	49,0	45,5	872	0,0	0,0	0,0	6,5	99,9
423	78,3	65,6	57,0	49,5	45,7	873	0,0	0,0	0,0	5,6	99,9
424	79,1	66,3	57,5	50,0	45,9	874	0,0	0,0	0,0	4,8	99,9
425	79,8	66,9	58,0	50,5	46,1	875	0,0	0,0	0,0	4,2	99,9
426	80,5	67,4	58,4	50,9	46,3	876	0,0	0,0	0,0	3,6	99,8
427	81,1	67,9	58,8	51,3	46,5	877	0,0	0,0	0,0	3,0	99,8

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
428	81,6	68,4	59,2	51,6	46,6	878	0,0	0,0	0,0	2,6	99,7
429	82,1	68,8	59,5	51,9	46,8	879	0,0	0,0	0,0	2,2	99,7
430	82,6	69,2	59,8	52,2	47,0	880	0,0	0,0	0,0	1,8	99,6
431	83,0	69,5	60,1	52,5	47,2	881	0,0	0,0	0,0	1,5	99,6
432	83,4	69,9	60,4	52,7	47,4	882	0,0	0,0	0,0	1,3	99,5
433	83,8	70,2	60,6	53,0	47,6	883	0,0	0,0	0,0	1,1	99,4
434	84,1	70,5	60,8	53,2	47,8	884	0,0	0,0	0,0	0,9	99,2
435	84,4	70,7	61,1	53,4	48,0	885	0,0	0,0	0,0	0,7	99,1
436	84,7	71,0	61,3	53,6	48,1	886	0,0	0,0	0,0	0,6	99,0
437	85,0	71,2	61,4	53,7	48,3	887	0,0	0,0	0,0	0,5	98,8
438	85,3	71,4	61,6	53,9	48,5	888	0,0	0,0	0,0	0,4	98,6
439	85,5	71,6	61,8	54,1	48,7	889	0,0	0,0	0,0	0,3	98,5
440	85,7	71,8	62,0	54,2	48,9	890	0,0	0,0	0,0	0,3	98,3
441	86,0	72,0	62,1	54,4	49,1	891	0,0	0,0	0,0	0,2	98,1
442	86,2	72,2	62,3	54,5	49,2	892	0,0	0,0	0,0	0,2	97,9
443	86,4	72,4	62,5	54,7	49,4	893	0,0	0,0	0,0	0,1	97,6
444	86,7	72,6	62,6	54,8	49,6	894	0,0	0,0	0,0	0,1	97,4
445	86,9	72,8	62,8	54,9	49,8	895	0,0	0,0	0,0	0,1	97,1
446	87,1	73,0	62,9	55,1	50,0	896	0,0	0,0	0,0	0,1	96,9
447	87,3	73,1	63,1	55,2	50,2	897	0,0	0,0	0,0	0,0	96,8
448	87,5	73,3	63,2	55,3	50,3	898	0,0	0,0	0,0	0,0	96,8
449	87,7	73,5	63,3	55,4	50,5	899	0,0	0,0	0,0	0,0	96,7
450	87,9	73,6	63,5	55,6	50,7	900	0,0	0,0	0,0	0,0	96,6
451	88,1	73,8	63,6	55,7	50,8	901	0,0	0,0	0,0	0,0	96,5
452	88,3	74,0	63,8	55,8	51,0	902	0,0	0,0	0,0	0,0	96,6
453	88,5	74,1	63,9	56,0	51,2	903	0,0	0,0	0,0	0,0	96,7
454	88,7	74,3	64,1	56,1	51,4	904	0,0	0,0	0,0	0,0	96,8
455	88,9	74,5	64,2	56,2	51,5	905	0,0	0,0	0,0	0,0	96,8
456	89,1	74,6	64,3	56,3	51,7	906	0,0	0,0	0,0	0,0	96,9
457	89,3	74,8	64,5	56,4	51,9	907	0,0	0,0	0,0	0,0	96,9
458	89,5	75,0	64,6	56,6	52,1	908	0,0	0,0	0,0	0,0	96,9
459	89,7	75,1	64,8	56,7	52,2	909	0,0	0,0	0,0	0,0	96,9
460	89,9	75,3	64,9	56,8	52,4	910	0,0	0,0	0,0	0,0	96,9
461	90,1	75,4	65,0	56,9	52,6	911	0,0	0,0	0,0	0,0	97,0
462	90,2	75,6	65,2	57,1	52,8	912	0,0	0,0	0,0	0,0	96,9
463	90,4	75,8	65,3	57,2	52,9	913	0,0	0,0	0,0	0,0	96,8
464	90,6	75,9	65,5	57,3	53,1	914	0,0	0,0	0,0	0,0	96,7
465	90,8	76,1	65,6	57,4	53,3	915	0,0	0,0	0,0	0,0	96,6
466	91,0	76,3	65,8	57,6	53,4	916	0,0	0,0	0,0	0,0	96,5
467	91,2	76,4	65,9	57,7	53,6	917	0,0	0,0	0,0	0,0	96,4
468	91,4	76,6	66,0	57,8	53,8	918	0,0	0,0	0,0	0,0	96,3
469	91,6	76,8	66,2	57,9	53,9	919	0,0	0,0	0,0	0,0	96,1
470	91,8	76,9	66,3	58,1	54,1	920	0,0	0,0	0,0	0,0	96,0

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
471	92,0	77,1	66,5	58,2	54,2	921	0,0	0,0	0,0	0,0	95,8
472	92,2	77,2	66,6	58,3	54,4	922	0,0	0,0	0,0	0,0	95,6
473	92,4	77,4	66,7	58,4	54,6	923	0,0	0,0	0,0	0,0	95,4
474	92,6	77,6	66,9	58,5	54,8	924	0,0	0,0	0,0	0,0	95,2
475	92,8	77,7	67,0	58,7	54,9	925	0,0	0,0	0,0	0,0	95,0
476	93,0	77,9	67,2	58,8	55,1	926	0,0	0,0	0,0	0,0	94,8
477	93,2	78,1	67,3	58,9	55,3	927	0,0	0,0	0,0	0,0	94,6
478	93,4	78,2	67,4	59,0	55,4	928	0,0	0,0	0,0	0,0	94,3
479	93,6	78,4	67,6	59,2	55,6	929	0,0	0,0	0,0	0,0	94,1
480	93,8	78,6	67,7	59,3	55,7	930	0,0	0,0	0,0	0,0	93,9
481	94,0	78,7	67,9	59,4	55,9	931	0,0	0,0	0,0	0,0	93,7
482	94,2	78,9	68,0	59,5	56,1	932	0,0	0,0	0,0	0,0	93,4
483	94,3	79,0	68,1	59,7	56,3	933	0,0	0,0	0,0	0,0	93,2
484	94,5	79,2	68,3	59,8	56,4	934	0,0	0,0	0,0	0,0	92,9
485	94,7	79,4	68,4	59,9	56,6	935	0,0	0,0	0,0	0,0	92,7
486	94,9	79,5	68,6	60,0	56,8	936	0,0	0,0	0,0	0,0	92,4
487	95,1	79,7	68,7	60,2	56,9	937	0,0	0,0	0,0	0,0	92,1
488	95,3	79,9	68,9	60,3	57,1	938	0,0	0,0	0,0	0,0	91,8
489	95,5	80,0	69,0	60,4	57,3	939	0,0	0,0	0,0	0,0	91,5
490	95,7	80,2	69,1	60,5	57,4	940	0,0	0,0	0,0	0,0	91,2
491	95,9	80,4	69,3	60,6	57,6	941	0,0	0,0	0,0	0,0	90,9
492	96,1	80,5	69,4	60,8	57,7	942	0,0	0,0	0,0	0,0	90,6
493	96,3	80,7	69,6	60,9	57,9	943	0,0	0,0	0,0	0,0	90,3
494	96,5	80,9	69,7	61,0	58,1	944	0,0	0,0	0,0	0,0	90,0
495	96,7	81,0	69,8	61,1	58,2	945	0,0	0,0	0,0	0,0	89,7
496	96,9	81,2	70,0	61,3	58,4	946	0,0	0,0	0,0	0,0	89,4
497	97,1	81,3	70,1	61,4	58,5	947	0,0	0,0	0,0	0,0	89,1
498	97,3	81,5	70,3	61,5	58,7	948	0,0	0,0	0,0	0,0	88,8
499	97,5	81,7	70,4	61,6	58,9	949	0,0	0,0	0,0	0,0	88,4
500	97,7	81,8	70,5	61,8	59,0	950	0,0	0,0	0,0	0,0	88,1
501	97,8	82,0	70,7	61,9	59,2	951	0,0	0,0	0,0	0,0	87,7
502	98,0	82,2	70,8	62,0	59,3	952	0,0	0,0	0,0	0,0	87,4
503	98,2	82,3	71,0	62,1	59,5	953	0,0	0,0	0,0	0,0	87,0
504	98,4	82,5	71,1	62,3	59,6	954	0,0	0,0	0,0	0,0	86,6
505	98,6	82,7	71,2	62,4	59,8	955	0,0	0,0	0,0	0,0	86,3
506	98,8	82,8	71,4	62,5	59,9	956	0,0	0,0	0,0	0,0	85,9
507	98,9	83,0	71,5	62,6	60,1	957	0,0	0,0	0,0	0,0	85,6
508	99,1	83,1	71,7	62,7	60,2	958	0,0	0,0	0,0	0,0	85,2
509	99,2	83,3	71,8	62,9	60,4	959	0,0	0,0	0,0	0,0	84,8
510	99,4	83,5	71,9	63,0	60,5	960	0,0	0,0	0,0	0,0	84,4
511	99,5	83,6	72,1	63,1	60,7	961	0,0	0,0	0,0	0,0	84,1
512	99,7	83,8	72,2	63,2	60,8	962	0,0	0,0	0,0	0,0	83,7
513	99,8	84,0	72,4	63,4	61,0	963	0,0	0,0	0,0	0,0	83,2

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
514	99,9	84,1	72,5	63,5	61,1	964	0,0	0,0	0,0	0,0	82,8
515	99,9	84,3	72,7	63,6	61,3	965	0,0	0,0	0,0	0,0	82,4
516	100	84,5	72,8	63,7	61,4	966	0,0	0,0	0,0	0,0	82,0
517	100	84,6	72,9	63,9	61,6	967	0,0	0,0	0,0	0,0	81,6
518	100	84,8	73,1	64,0	61,7	968	0,0	0,0	0,0	0,0	81,1
519	99,9	84,9	73,2	64,1	61,9	969	0,0	0,0	0,0	0,0	80,7
520	99,9	85,1	73,4	64,2	62,0	970	0,0	0,0	0,0	0,0	80,3
521	99,7	85,3	73,5	64,4	62,2	971	0,0	0,0	0,0	0,0	79,8
522	99,5	85,4	73,6	64,5	62,3	972	0,0	0,0	0,0	0,0	79,4
523	99,3	85,6	73,8	64,6	62,5	973	0,0	0,0	0,0	0,0	78,9
524	99,0	85,8	73,9	64,7	62,6	974	0,0	0,0	0,0	0,0	78,5
525	98,6	85,9	74,1	64,8	62,8	975	0,0	0,0	0,0	0,0	78,0
526	98,1	86,1	74,2	65,0	63,0	976	0,0	0,0	0,0	0,0	77,6
527	97,6	86,3	74,3	65,1	63,1	977	0,0	0,0	0,0	0,0	77,1
528	97,0	86,4	74,5	65,2	63,3	978	0,0	0,0	0,0	0,0	76,6
529	96,2	86,6	74,6	65,3	63,4	979	0,0	0,0	0,0	0,0	76,2
530	95,4	86,7	74,8	65,5	63,6	980	0,0	0,0	0,0	0,0	75,7
531	94,4	86,9	74,9	65,6	63,7	981	0,0	0,0	0,0	0,0	75,2
532	93,4	87,1	75,0	65,7	63,8	982	0,0	0,0	0,0	0,0	74,7
533	92,2	87,2	75,2	65,8	64,0	983	0,0	0,0	0,0	0,0	74,2
534	90,9	87,4	75,3	66,0	64,1	984	0,0	0,0	0,0	0,0	73,7
535	89,4	87,6	75,5	66,1	64,3	985	0,0	0,0	0,0	0,0	73,2
536	87,8	87,7	75,6	66,2	64,4	986	0,0	0,0	0,0	0,0	72,7
537	86,1	87,9	75,7	66,3	64,5	987	0,0	0,0	0,0	0,0	72,2
538	84,3	88,1	75,9	66,5	64,7	988	0,0	0,0	0,0	0,0	71,6
539	82,3	88,2	76,0	66,6	64,8	989	0,0	0,0	0,0	0,0	71,1
540	80,2	88,4	76,2	66,7	65,0	990	0,0	0,0	0,0	0,0	70,5
541	78,0	88,5	76,3	66,8	65,1	991	0,0	0,0	0,0	0,0	69,9
542	75,6	88,7	76,5	66,9	65,3	992	0,0	0,0	0,0	0,0	69,4
543	73,2	88,9	76,6	67,1	65,4	993	0,0	0,0	0,0	0,0	68,9
544	70,6	89,0	76,7	67,2	65,6	994	0,0	0,0	0,0	0,0	68,4
545	67,9	89,2	76,9	67,3	65,7	995	0,0	0,0	0,0	0,0	67,8
546	65,2	89,4	77,0	67,4	65,9	996	0,0	0,0	0,0	0,0	67,3
547	62,4	89,5	77,2	67,6	66,0	997	0,0	0,0	0,0	0,0	66,8
548	59,5	89,7	77,3	67,7	66,2	998	0,0	0,0	0,0	0,0	66,3
549	56,6	89,9	77,4	67,8	66,3	999	0,0	0,0	0,0	0,0	65,8
550	53,7	90,0	77,6	67,9	66,5	1 000	0,0	0,0	0,0	0,0	65,3
551	50,8	90,2	77,7	68,1	66,6	1 001	0,0	0,0	0,0	0,0	64,7
552	47,9	90,3	77,9	68,2	66,7	1 002	0,0	0,0	0,0	0,0	64,2
553	44,9	90,5	78,0	68,3	66,8	1 003	0,0	0,0	0,0	0,0	63,6
554	42,1	90,7	78,1	68,4	66,9	1 004	0,0	0,0	0,0	0,0	63,0
555	39,2	90,8	78,3	68,6	67,0	1 005	0,0	0,0	0,0	0,0	62,4
556	36,5	91,0	78,4	68,7	67,1	1 006	0,0	0,0	0,0	0,0	61,9

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
557	33,8	91,2	78,6	68,8	67,2	1 007	0,0	0,0	0,0	0,0	61,3
558	31,2	91,3	78,7	68,9	67,3	1 008	0,0	0,0	0,0	0,0	60,7
559	28,6	91,5	78,8	69,0	67,5	1 009	0,0	0,0	0,0	0,0	60,2
560	26,2	91,7	79,0	69,2	67,6	1 010	0,0	0,0	0,0	0,0	59,6
561	23,9	91,8	79,1	69,3	67,7	1 011	0,0	0,0	0,0	0,0	59,0
562	21,7	92,0	79,3	69,4	67,8	1 012	0,0	0,0	0,0	0,0	58,4
563	19,7	92,1	79,4	69,5	68,0	1 013	0,0	0,0	0,0	0,0	57,9
564	17,7	92,3	79,6	69,7	68,2	1 014	0,0	0,0	0,0	0,0	57,3
565	15,9	92,5	79,7	69,8	68,3	1 015	0,0	0,0	0,0	0,0	56,7
566	14,3	92,6	79,8	69,9	68,5	1 016	0,0	0,0	0,0	0,0	56,1
567	12,7	92,8	80,0	70,0	68,7	1 017	0,0	0,0	0,0	0,0	55,5
568	11,3	93,0	80,1	70,2	68,9	1 018	0,0	0,0	0,0	0,0	55,0
569	10,0	93,1	80,3	70,3	69,1	1 019	0,0	0,0	0,0	0,0	54,4
570	8,8	93,3	80,4	70,4	69,3	1 020	0,0	0,0	0,0	0,0	53,8
571	7,7	93,5	80,5	70,5	69,5	1 021	0,0	0,0	0,0	0,0	53,2
572	6,7	93,6	80,7	70,7	69,6	1 022	0,0	0,0	0,0	0,0	52,6
573	5,8	93,8	80,8	70,8	69,8	1 023	0,0	0,0	0,0	0,0	51,9
574	5,0	93,9	81,0	70,9	69,9	1 024	0,0	0,0	0,0	0,0	51,3
575	4,3	94,1	81,1	71,0	70,0	1 025	0,0	0,0	0,0	0,0	50,7
576	3,7	94,3	81,2	71,1	70,2	1 026	0,0	0,0	0,0	0,0	50,0
577	3,2	94,4	81,4	71,3	70,3	1 027	0,0	0,0	0,0	0,0	49,4
578	2,7	94,6	81,5	71,4	70,4	1 028	0,0	0,0	0,0	0,0	48,7
579	2,3	94,8	81,7	71,5	70,6	1 029	0,0	0,0	0,0	0,0	48,0
580	1,9	94,9	81,8	71,6	70,7	1 030	0,0	0,0	0,0	0,0	47,4
581	1,6	95,1	81,9	71,8	70,8	1 031	0,0	0,0	0,0	0,0	46,7
582	1,3	95,3	82,1	71,9	71,0	1 032	0,0	0,0	0,0	0,0	46,0
583	1,1	95,4	82,2	72,0	71,1	1 033	0,0	0,0	0,0	0,0	45,3
584	0,9	95,6	82,4	72,1	71,3	1 034	0,0	0,0	0,0	0,0	44,6
585	0,8	95,7	82,5	72,3	71,4	1 035	0,0	0,0	0,0	0,0	43,9
586	0,6	95,9	82,6	72,4	71,5	1 036	0,0	0,0	0,0	0,0	43,2
587	0,5	96,1	82,8	72,5	71,7	1 037	0,0	0,0	0,0	0,0	42,5
588	0,4	96,2	82,9	72,6	71,8	1 038	0,0	0,0	0,0	0,0	41,8
589	0,3	96,4	83,1	72,8	72,0	1 039	0,0	0,0	0,0	0,0	41,0
590	0,3	96,6	83,2	72,9	72,1	1 040	0,0	0,0	0,0	0,0	40,3
591	0,2	96,7	83,4	73,0	72,3	1 041	0,0	0,0	0,0	0,0	39,6
592	0,2	96,9	83,5	73,1	72,4	1 042	0,0	0,0	0,0	0,0	38,9
593	0,1	97,1	83,6	73,2	72,6	1 043	0,0	0,0	0,0	0,0	38,1
594	0,1	97,2	83,8	73,4	72,7	1 044	0,0	0,0	0,0	0,0	37,4
595	0,1	97,4	83,9	73,5	72,8	1 045	0,0	0,0	0,0	0,0	36,6
596	0,1	97,5	84,1	73,6	73,0	1 046	0,0	0,0	0,0	0,0	35,9
597	0,1	97,7	84,2	73,7	73,1	1 047	0,0	0,0	0,0	0,0	35,2
598	0,0	97,9	84,3	73,9	73,3	1 048	0,0	0,0	0,0	0,0	34,5
599	0,0	98,0	84,5	74,0	73,4	1 049	0,0	0,0	0,0	0,0	33,8

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
600	0,0	98,2	84,6	74,1	73,6	1 050	0,0	0,0	0,0	0,0	33,1
601	0,0	98,3	84,8	74,2	73,7	1 051	0,0	0,0	0,0	0,0	32,4
602	0,0	98,5	84,9	74,4	73,9	1 052	0,0	0,0	0,0	0,0	31,8
603	0,0	98,6	85,0	74,5	74,0	1 053	0,0	0,0	0,0	0,0	31,2
604	0,0	98,8	85,2	74,6	74,1	1 054	0,0	0,0	0,0	0,0	30,6
605	0,0	98,9	85,3	74,7	74,3	1 055	0,0	0,0	0,0	0,0	29,9
606	0,0	99,1	85,5	74,9	74,4	1 056	0,0	0,0	0,0	0,0	29,3
607	0,0	99,2	85,6	75,0	74,6	1 057	0,0	0,0	0,0	0,0	28,8
608	0,0	99,4	85,7	75,1	74,7	1 058	0,0	0,0	0,0	0,0	28,2
609	0,0	99,5	85,9	75,2	74,8	1 059	0,0	0,0	0,0	0,0	27,7
610	0,0	99,6	86,0	75,3	75,0	1 060	0,0	0,0	0,0	0,0	27,1
611	0,0	99,7	86,2	75,5	75,1	1 061	0,0	0,0	0,0	0,0	26,5
612	0,0	99,8	86,3	75,6	75,3	1 062	0,0	0,0	0,0	0,0	26,1
613	0,0	99,9	86,5	75,7	75,4	1 063	0,0	0,0	0,0	0,0	25,6
614	0,0	99,9	86,6	75,8	75,5	1 064	0,0	0,0	0,0	0,0	25,1
615	0,0	100	86,7	76,0	75,6	1 065	0,0	0,0	0,0	0,0	24,7
616	0,0	100	86,9	76,1	75,8	1 066	0,0	0,0	0,0	0,0	24,2
617	0,0	100	87,0	76,2	75,9	1 067	0,0	0,0	0,0	0,0	23,8
618	0,0	99,9	87,2	76,3	76,0	1 068	0,0	0,0	0,0	0,0	23,3
619	0,0	99,9	87,3	76,5	76,1	1 069	0,0	0,0	0,0	0,0	22,9
620	0,0	99,8	87,4	76,6	76,3	1 070	0,0	0,0	0,0	0,0	22,5
621	0,0	99,6	87,6	76,7	76,4	1 071	0,0	0,0	0,0	0,0	22,1
622	0,0	99,4	87,7	76,8	76,5	1 072	0,0	0,0	0,0	0,0	21,7
623	0,0	99,1	87,9	77,0	76,6	1 073	0,0	0,0	0,0	0,0	21,3
624	0,0	98,8	88,0	77,1	76,8	1 074	0,0	0,0	0,0	0,0	20,9
625	0,0	98,3	88,1	77,2	76,9	1 075	0,0	0,0	0,0	0,0	20,5
626	0,0	97,9	88,3	77,3	77,0	1 076	0,0	0,0	0,0	0,0	20,1
627	0,0	97,3	88,4	77,4	77,1	1 077	0,0	0,0	0,0	0,0	19,7
628	0,0	96,6	88,6	77,6	77,2	1 078	0,0	0,0	0,0	0,0	19,4
629	0,0	95,9	88,7	77,7	77,3	1 079	0,0	0,0	0,0	0,0	19,0
630	0,0	95,0	88,8	77,8	77,5	1 080	0,0	0,0	0,0	0,0	18,6
631	0,0	94,0	89,0	77,9	77,6	1 081	0,0	0,0	0,0	0,0	18,3
632	0,0	92,9	89,1	78,1	77,7	1 082	0,0	0,0	0,0	0,0	17,9
633	0,0	91,7	89,3	78,2	77,8	1 083	0,0	0,0	0,0	0,0	17,6
634	0,0	90,4	89,4	78,3	78,0	1 084	0,0	0,0	0,0	0,0	17,2
635	0,0	88,9	89,5	78,4	78,1	1 085	0,0	0,0	0,0	0,0	16,9
636	0,0	87,3	89,7	78,6	78,3	1 086	0,0	0,0	0,0	0,0	16,5
637	0,0	85,6	89,8	78,7	78,4	1 087	0,0	0,0	0,0	0,0	16,2
638	0,0	83,7	90,0	78,8	78,5	1 088	0,0	0,0	0,0	0,0	15,9
639	0,0	81,7	90,1	78,9	78,7	1 089	0,0	0,0	0,0	0,0	15,6
640	0,0	79,6	90,3	79,1	78,8	1 090	0,0	0,0	0,0	0,0	15,3
641	0,0	77,4	90,4	79,2	79,0	1 091	0,0	0,0	0,0	0,0	15,0
642	0,0	75,0	90,5	79,3	79,1	1 092	0,0	0,0	0,0	0,0	14,7

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
643	0,0	72,6	90,7	79,4	79,2	1 093	0,0	0,0	0,0	0,0	14,4
644	0,0	70,0	90,8	79,5	79,3	1 094	0,0	0,0	0,0	0,0	14,1
645	0,0	67,4	91,0	79,7	79,5	1 095	0,0	0,0	0,0	0,0	13,8
646	0,0	64,6	91,1	79,8	79,6	1 096	0,0	0,0	0,0	0,0	13,5
647	0,0	61,8	91,2	79,9	79,7	1 097	0,0	0,0	0,0	0,0	13,3
648	0,0	59,0	91,4	80,0	79,8	1 098	0,0	0,0	0,0	0,0	13,0
649	0,0	56,1	91,5	80,2	80,0	1 099	0,0	0,0	0,0	0,0	12,7
650	0,0	53,2	91,7	80,3	80,1	1 100	0,0	0,0	0,0	0,0	12,4
651	0,0	50,3	91,8	80,4	80,3	1 101	0,0	0,0	0,0	0,0	12,2
652	0,0	47,4	91,9	80,5	80,4	1 102	0,0	0,0	0,0	0,0	11,9
653	0,0	44,5	92,1	80,7	80,5	1 103	0,0	0,0	0,0	0,0	11,7
654	0,0	41,6	92,2	80,8	80,7	1 104	0,0	0,0	0,0	0,0	11,4
655	0,0	38,8	92,4	80,9	80,8	1 105	0,0	0,0	0,0	0,0	11,2
656	0,0	36,0	92,5	81,0	80,9	1 106	0,0	0,0	0,0	0,0	10,9
657	0,0	33,4	92,6	81,2	81,0	1 107	0,0	0,0	0,0	0,0	10,7
658	0,0	30,8	92,8	81,3	81,2	1 108	0,0	0,0	0,0	0,0	10,4
659	0,0	28,3	92,9	81,4	81,3	1 109	0,0	0,0	0,0	0,0	10,2
660	0,0	25,9	93,1	81,5	81,4	1 110	0,0	0,0	0,0	0,0	9,9
661	0,0	23,6	93,2	81,6	81,6	1 111	0,0	0,0	0,0	0,0	9,7
662	0,0	21,5	93,3	81,8	81,7	1 112	0,0	0,0	0,0	0,0	9,5
663	0,0	19,4	93,5	81,9	81,8	1 113	0,0	0,0	0,0	0,0	9,2
664	0,0	17,5	93,6	82,0	82,0	1 114	0,0	0,0	0,0	0,0	9,0
665	0,0	15,7	93,8	82,1	82,1	1 115	0,0	0,0	0,0	0,0	8,8
666	0,0	14,1	93,9	82,3	82,2	1 116	0,0	0,0	0,0	0,0	8,6
667	0,0	12,5	94,1	82,4	82,3	1 117	0,0	0,0	0,0	0,0	8,3
668	0,0	11,1	94,2	82,5	82,4	1 118	0,0	0,0	0,0	0,0	8,1
669	0,0	9,8	94,3	82,6	82,6	1 119	0,0	0,0	0,0	0,0	7,9
670	0,0	8,6	94,5	82,8	82,7	1 120	0,0	0,0	0,0	0,0	7,7
671	0,0	7,6	94,6	82,9	82,8	1 121	0,0	0,0	0,0	0,0	7,5
672	0,0	6,6	94,8	83,0	82,9	1 122	0,0	0,0	0,0	0,0	7,3
673	0,0	5,7	94,9	83,1	83,0	1 123	0,0	0,0	0,0	0,0	7,1
674	0,0	4,9	95,0	83,3	83,2	1 124	0,0	0,0	0,0	0,0	6,9
675	0,0	4,3	95,2	83,4	83,3	1 125	0,0	0,0	0,0	0,0	6,7
676	0,0	3,7	95,3	83,5	83,4	1 126	0,0	0,0	0,0	0,0	6,4
677	0,0	3,1	95,5	83,6	83,5	1 127	0,0	0,0	0,0	0,0	6,2
678	0,0	2,6	95,6	83,7	83,7	1 128	0,0	0,0	0,0	0,0	6,0
679	0,0	2,2	95,7	83,9	83,8	1 129	0,0	0,0	0,0	0,0	5,8
680	0,0	1,9	95,9	84,0	83,9	1 130	0,0	0,0	0,0	0,0	5,6
681	0,0	1,6	96,0	84,1	84,1	1 131	0,0	0,0	0,0	0,0	5,4
682	0,0	1,3	96,2	84,2	84,2	1 132	0,0	0,0	0,0	0,0	5,3
683	0,0	1,1	96,3	84,4	84,3	1 133	0,0	0,0	0,0	0,0	5,1
684	0,0	0,9	96,4	84,5	84,4	1 134	0,0	0,0	0,0	0,0	4,9
685	0,0	0,7	96,6	84,6	84,6	1 135	0,0	0,0	0,0	0,0	4,7

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
686	0,0	0,6	96,7	84,7	84,7	1 136	0,0	0,0	0,0	0,0	4,5
687	0,0	0,5	96,9	84,9	84,9	1 137	0,0	0,0	0,0	0,0	4,4
688	0,0	0,4	97,0	85,0	85,0	1 138	0,0	0,0	0,0	0,0	4,2
689	0,0	0,3	97,2	85,1	85,2	1 139	0,0	0,0	0,0	0,0	4,0
690	0,0	0,3	97,3	85,2	85,4	1 140	0,0	0,0	0,0	0,0	3,9
691	0,0	0,2	97,4	85,4	85,5	1 141	0,0	0,0	0,0	0,0	3,7
692	0,0	0,2	97,6	85,5	85,6	1 142	0,0	0,0	0,0	0,0	3,6
693	0,0	0,1	97,7	85,6	85,7	1 143	0,0	0,0	0,0	0,0	3,4
694	0,0	0,1	97,9	85,7	85,8	1 144	0,0	0,0	0,0	0,0	3,3
695	0,0	0,1	98,0	85,8	85,9	1 145	0,0	0,0	0,0	0,0	3,2
696	0,0	0,1	98,1	86,0	86,0	1 146	0,0	0,0	0,0	0,0	3,0
697	0,0	0,1	98,3	86,1	86,1	1 147	0,0	0,0	0,0	0,0	2,9
698	0,0	0,0	98,4	86,2	86,3	1 148	0,0	0,0	0,0	0,0	2,8
699	0,0	0,0	98,5	86,3	86,4	1 149	0,0	0,0	0,0	0,0	2,6
700	0,0	0,0	98,7	86,5	86,5	1 150	0,0	0,0	0,0	0,0	2,5
701	0,0	0,0	98,8	86,6	86,6	1 151	0,0	0,0	0,0	0,0	2,4
702	0,0	0,0	98,9	86,7	86,7	1 152	0,0	0,0	0,0	0,0	2,3
703	0,0	0,0	99,1	86,8	86,9	1 153	0,0	0,0	0,0	0,0	2,1
704	0,0	0,0	99,2	87,0	87,0	1 154	0,0	0,0	0,0	0,0	2,0
705	0,0	0,0	99,3	87,1	87,1	1 155	0,0	0,0	0,0	0,0	1,9
706	0,0	0,0	99,4	87,2	87,3	1 156	0,0	0,0	0,0	0,0	1,8
707	0,0	0,0	99,5	87,3	87,4	1 157	0,0	0,0	0,0	0,0	1,7
708	0,0	0,0	99,6	87,5	87,5	1 158	0,0	0,0	0,0	0,0	1,6
709	0,0	0,0	99,7	87,6	87,6	1 159	0,0	0,0	0,0	0,0	1,5
710	0,0	0,0	99,8	87,7	87,7	1 160	0,0	0,0	0,0	0,0	1,4
711	0,0	0,0	99,9	87,8	87,8	1 161	0,0	0,0	0,0	0,0	1,3
712	0,0	0,0	99,9	87,9	88,0	1 162	0,0	0,0	0,0	0,0	1,2
713	0,0	0,0	100	88,1	88,1	1 163	0,0	0,0	0,0	0,0	1,1
714	0,0	0,0	100	88,2	88,2	1 164	0,0	0,0	0,0	0,0	1,0
715	0,0	0,0	100	88,3	88,3	1 165	0,0	0,0	0,0	0,0	0,9
716	0,0	0,0	100	88,4	88,4	1 166	0,0	0,0	0,0	0,0	0,8
717	0,0	0,0	99,9	88,6	88,5	1 167	0,0	0,0	0,0	0,0	0,7
718	0,0	0,0	99,8	88,7	88,6	1 168	0,0	0,0	0,0	0,0	0,6
719	0,0	0,0	99,7	88,8	88,7	1 169	0,0	0,0	0,0	0,0	0,5
720	0,0	0,0	99,5	88,9	88,8	1 170	0,0	0,0	0,0	0,0	0,4
721	0,0	0,0	99,2	89,1	88,9	1 171	0,0	0,0	0,0	0,0	0,4
722	0,0	0,0	98,9	89,2	89,1	1 172	0,0	0,0	0,0	0,0	0,3
723	0,0	0,0	98,6	89,3	89,2	1 173	0,0	0,0	0,0	0,0	0,3
724	0,0	0,0	98,1	89,4	89,3	1 174	0,0	0,0	0,0	0,0	0,3
725	0,0	0,0	97,6	89,6	89,4	1 175	0,0	0,0	0,0	0,0	0,3
726	0,0	0,0	97,0	89,7	89,5	1 176	0,0	0,0	0,0	0,0	0,2
727	0,0	0,0	96,4	89,8	89,6	1 177	0,0	0,0	0,0	0,0	0,2
728	0,0	0,0	95,6	89,9	89,7	1 178	0,0	0,0	0,0	0,0	0,2

λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5	λ (nm)	PV-1	PV-2	PV-3	PV-4	PV-5
729	0,0	0,0	94,7	90,0	89,8	1 179	0,0	0,0	0,0	0,0	0,2
730	0,0	0,0	93,7	90,2	89,9	1 180	0,0	0,0	0,0	0,0	0,2
731	0,0	0,0	92,6	90,3	89,9	1 181	0,0	0,0	0,0	0,0	0,2
732	0,0	0,0	91,4	90,4	90,1	1 182	0,0	0,0	0,0	0,0	0,2
733	0,0	0,0	90,0	90,5	90,2	1 183	0,0	0,0	0,0	0,0	0,2
734	0,0	0,0	88,5	90,7	90,3	1 184	0,0	0,0	0,0	0,0	0,2
735	0,0	0,0	86,9	90,8	90,4	1 185	0,0	0,0	0,0	0,0	0,2
736	0,0	0,0	85,2	90,9	90,5	1 186	0,0	0,0	0,0	0,0	0,2
737	0,0	0,0	83,3	91,0	90,6	1 187	0,0	0,0	0,0	0,0	0,2
738	0,0	0,0	81,3	91,2	90,7	1 188	0,0	0,0	0,0	0,0	0,2
739	0,0	0,0	79,2	91,3	90,9	1 189	0,0	0,0	0,0	0,0	0,1
740	0,0	0,0	77,0	91,4	91,0	1 190	0,0	0,0	0,0	0,0	0,1
741	0,0	0,0	74,6	91,5	91,1	1 191	0,0	0,0	0,0	0,0	0,1
742	0,0	0,0	72,2	91,7	91,2	1 192	0,0	0,0	0,0	0,0	0,6
743	0,0	0,0	69,6	91,8	91,3	1 193	0,0	0,0	0,0	0,0	0,5
744	0,0	0,0	66,9	91,9	91,5	1 194	0,0	0,0	0,0	0,0	0,5
745	0,0	0,0	64,2	92,0	91,6	1 195	0,0	0,0	0,0	0,0	0,5
746	0,0	0,0	61,4	92,1	91,7	1 196	0,0	0,0	0,0	0,0	0,5
747	0,0	0,0	58,6	92,3	91,8	1 197	0,0	0,0	0,0	0,0	0,4
748	0,0	0,0	55,7	92,4	91,9	1 198	0,0	0,0	0,0	0,0	0,4
749	0,0	0,0	52,8	92,5	92,0	1 199	0,0	0,0	0,0	0,0	0,4
						1 200	0,0	0,0	0,0	0,0	0,4

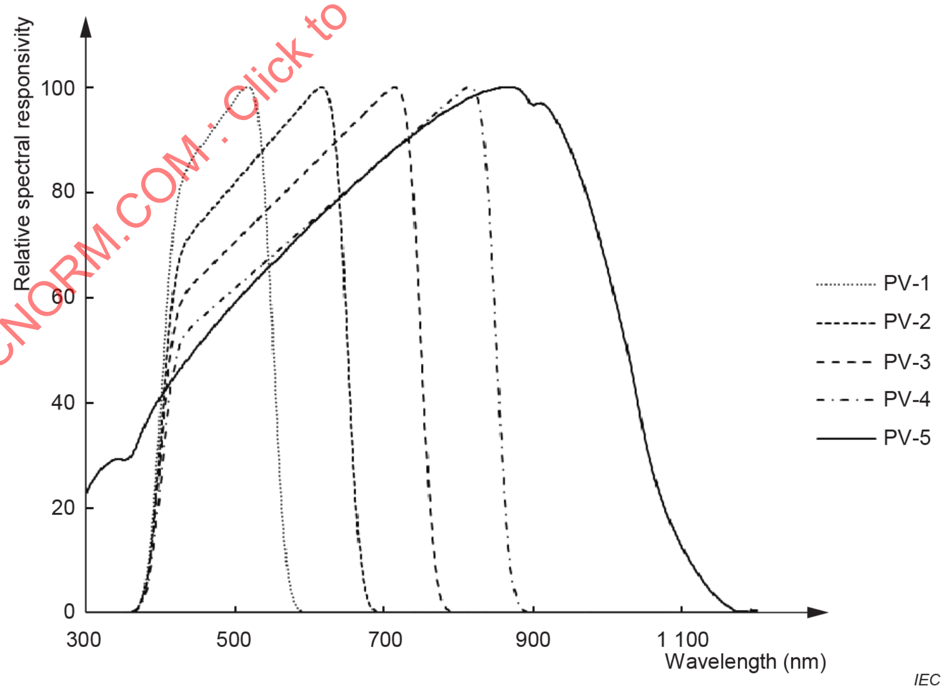

Figure 3 – Standard relative spectral responsivity

12.2 Illuminance non-uniformity

Illumination devices that comprise multiple light sources will also produce uneven colour in addition to variations in illuminance since each light source has a different spectral irradiance. To reduce the effects of this phenomenon, measure variation using the DUT itself.

If a stable DUT cannot be obtained for this measurement, use an element with a spectral-mismatch error within ±3 %. Also, the photodetection area of that element should be no more than 1/10 that of the DUT.

13 Nonlinearity

13.1 Requirements

a) Measurement method

Measure the short-circuit current I_{sc} of the DUT under at least five different illuminance conditions (L) ranging from 5 % to 110 % of the illuminance that will be used for measurement.

Use either a spectroradiometer or illuminometer to measure the illuminance. However, the device used to measure illuminance shall be verified as linear.

b) Criteria

An element is considered linear if it exhibits a deviance of 0,5 % or less as given by

$$\frac{K_{\text{max}} - K_{\text{min}}}{K_{\text{max}} + K_{\text{min}}}$$

where K_{max} and K_{min} are the minimum and maximum values for I/L.

13.2 Important notes

a) It is important that the spectroradiometer or illuminometer be positioned in the same location as the DUT.

b) If the spectrum of the illumination source fluctuates when a change is made to its intensity, perform spectral-mismatch correction.

Annex A
(informative)

Explanations of the provisions, descriptions, and other content in the standard main body of this document.

A.1 Purpose of this document

Applications in which photovoltaic cells are used under indoor lighting are expected to increase in the future. Although there are many types of indoor lighting – sunlight through windows, incandescent lighting, fluorescent lamps, LEDs, and so forth – the brightness of each is expressed in units of illuminance, which means that even under the same illuminance the efficiency of a given photovoltaic cell will vary depending on the light source. This document identifies two types of standard indoor light and establishes methods for evaluating photovoltaic cells under them [3][4].

A.2 Target of this document

Defined in this document are methods for evaluating the generating efficiency of photovoltaic cells under indoor light. Cells that generate electricity by absorbing direct sunlight are an extension of outdoor use, even if they are placed indoors. The indoor use of photovoltaic cells to generate electricity by receiving direct sunlight from outdoors is therefore outside the scope of this document, which is intended for evaluating the efficiency of photovoltaic cells used under indoor lighting at ordinary homes, offices, commercial facilities, and so on.

A.3 Issues discussed during deliberation

A.3.1 Adjusting light intensity with an illuminometer

Regarding the methods to adjust light intensity, some insisted that an illuminometer should be the first choice since illuminometers are often used to measure illuminance. However, the accuracy of illuminometers could deteriorate the measurement accuracy significantly due to its spectral and incident angle properties, and it was concluded that achieving sufficient accuracy with an illuminometer was difficult. Thus, this document requires the use of a General Class-AA illuminometer (as defined in JIS C 1609-1) and a Class-A or higher illumination source when an illuminometer is used. Therefore, a reference cell method and a PRISM method are included.

A.3.2 Indoor spectral coincidence

IEC 60904-9 defines spectral coincidence using the amount of deviation of the relative energy in each wavelength range. Although the possibility of using the same method to define spectral coincidence of AM1.5g was studied, it was decided to use a different method for the following reasons which are not an issue with sunshine.

– Because IEC 60904 uses the relatively flat and continuous spectrum of AM 1.5g as its reference light source, defining spectral coincidence using relative energy in certain wavelength ranges does not result in a significant error. For artificial indoor light sources, however, some light sources show steep bands in the spectrum and the relative energies vary by a large degree depending on how the wavelength ranges are chosen. Therefore, it is difficult to reduce this error using a method that uses the relative energy for each 100-nm or 50-nm range as used in IEC 60904.

– The same wavelength range cannot be applied for the two types of standard indoor lights, because it would make their relative energy values vary significantly.

– Many different shapes of spectral responsivities exist for organic photovoltaic cells and they appear in a narrower range of wavelengths than c-Si cells; as a result, the spectral responsivity of a DUT could cause large measurement errors in light intensity adjustment.

– In case the light intensity is adjusted with an illuminometer, the spectrum of the light source should be matched as closely as possible to that of the standard indoor light.

To solve these issues, an indoor spectral coincidence was defined that was calculated using the spectral responsivity of the DUT. Consequently, evaluation of spectral coincidence is conducted for each DUT. This method is inconvenient because the class of the illumination source cannot be determined without a DUT even if the light has a spectrum that is close enough to a standard indoor light. Therefore, five relative spectral-responsivity profiles were provided to calculate spectral coincidence of an illumination source with them. PV-1 through PV-4 are artificial EQE curves with cut-off wavelengths of 550 nm, 650 nm, 750 nm, and 850 nm, respectively. PV-5 is the spectral responsivity of a c-Si photovoltaic cell. By estimating the spectral coincidence of all five of these profiles, the class of the light source can be defined without relying on any specific DUT, presuming that the light source sufficiently resembles a standard indoor light for five very different cells.

A.3.3 Stability of a DUT (5.2.2)

It is not possible to evaluate a device correctly if its characteristics change during the measurement. Some photovoltaic cells (a-Si, OPV, DSC) have been reported to undergo an initial drift by illumination applied after fabrication, which eventually stabilize [5]. Standards such as IEC 61215 [6] and SEMI PV57-0622 [7] state that the cell should be subject to 43 kWh light soaking repeatedly until the change of its efficiency falls below 2 %. This light-induced decay is for photovoltaic cell evaluation for outdoor use, and it is not certain whether it can be applied or should be applied to indoor use in 1/100 or less illuminance. Therefore, this document only requires that the change be small at least during the measurement.

A.3.4 Maximum power (P_{max})

I-V measurements are commonly used to evaluate photovoltaic cells. Some cells, such as DSC and perovskite solar cells, show significantly different P_{max} values between a forward-bias scan (short-circuit condition to open-circuit condition) and a reverse-bias scan (open-circuit condition to short-circuit condition). There was much argument about how to handle this hysteresis. In this document, the conclusion is deferred by requiring small variation (hysteresis) among ten total measurements taken (five for each scan direction) according to SEMI PV57-0622 [7].

Quite a few theories have been proposed for why this hysteresis phenomenon occurs: ion conduction or other factors can cause slow response times of the cell, making suitable voltage sweeping rate too slow; or the applied voltage causes electrical charge to build up and discharge within the cell, creating an additional current to the photogenerated current. At present, however, the exact cause remains unknown. However, the reality is that some photovoltaic cells, such as perovskite solar cells, have drastically different current for forward and reverse scan reproducibly. For these cases, this document does not provide a clear solution, awiting further scientific investigations.

There was also a discussion about allowing P_{max} to be obtained by a maximum power point tracking (MPPT) method that uses an algorithm which considers response time appropriately. The MPPT method is widely used to adjust the load of a system so that P_{max} is continually maintained under changing power-generation conditions, such as when clouds reduce the amount of light that reaches an outdoor photovoltaic cell [8]. The method can also be used to determine the P_{max} under a fixed irradiation condition. Since this evaluation method is close to the actual condition in which a photovoltaic cell is used, it could be an efficient way to evaluate P_{max} without spending too much time on I-V measurements. However, there are not many cases of such evaluations, and it was concluded that it would be premature to include the method in this document. More data are needed on this topic.

A.4 Supplemental remarks on requirements

A.4.1 Requirements for the DUTs (5.2.1)

In the early stages of research, devices with small active area are fabricated and evaluated in general. In such cases, the cell area is often defined by the overlap area between the upper and lower electrodes. One typical example of a device that appears in many research papers is placing two stripe-shaped electrodes with 2 mm width into an orthogonal arrangement. Although this method is convenient, some problems have been reported: light diffused from outside of the device contributes to the generation of electricity, or the highly conductive buffer layer enlarges the effective active area of the device, both of which end up in overestimation of current. Furthermore, too small an active area can reduce the accuracy of area measurements.

A.4.2 Standard indoor light (Clause 7)

The relationships between the spectral irradiance $E(\lambda)$ of the illumination source, irradiance G (W/m^2), and illuminance E_v (lx) are expressed by Formulas (A.1) and (A.2).

Irradiance

$$G = \int E(\lambda)\mathrm{d}\lambda \tag{A.1}$$

Illuminance

$$E_\mathrm{v} = K_\mathrm{m}\int E(\lambda)V(\lambda)\mathrm{d}\lambda \tag{A.2}$$

where $V(\lambda)$ is the luminosity function and K_m = 683 lm/W.

Two light sources were defined with different spectral profiles as standard indoor lights. The two standard indoor lights have a correlated colour temperature of 5 000 K comprised of the illuminant defined by the CIE; the fluorescent lamp, and the white LED lamp.

The short-circuit current (I_sc) for each standard indoor light is calculated using the absolute spectral responsivity $S_\mathrm{abs}(\lambda)$ of the photovoltaic cell by Formula (A.3):

$$I_\mathrm{sc} = A\int S_\mathrm{abs}(\lambda)E(\lambda)\mathrm{d}\lambda \tag{A.3}$$

where A is the area of the DUT.

Formula (A.3) for determining short-circuit current using spectral responsivity and spectral irradiance is employed heavily throughout this document. Because this sort of spectral responsivity does not exist for multi-junction devices, they are outside the scope of this document.

A.4.3 Methods for adjusting illuminance (5.2.2)

A.4.3.1 General

The results of round-robin testing on OPVs for standard test conditions (STC) conducted by laboratories around the world have revealed a ±30 % deviation in conversion-efficiency values and the primary causes of error resulted from a short-circuit current deviation of ±22 % [9], which means light intensity adjustment is the most important issue. To reduce these variations, this document provides three different methods for adjusting light intensity.

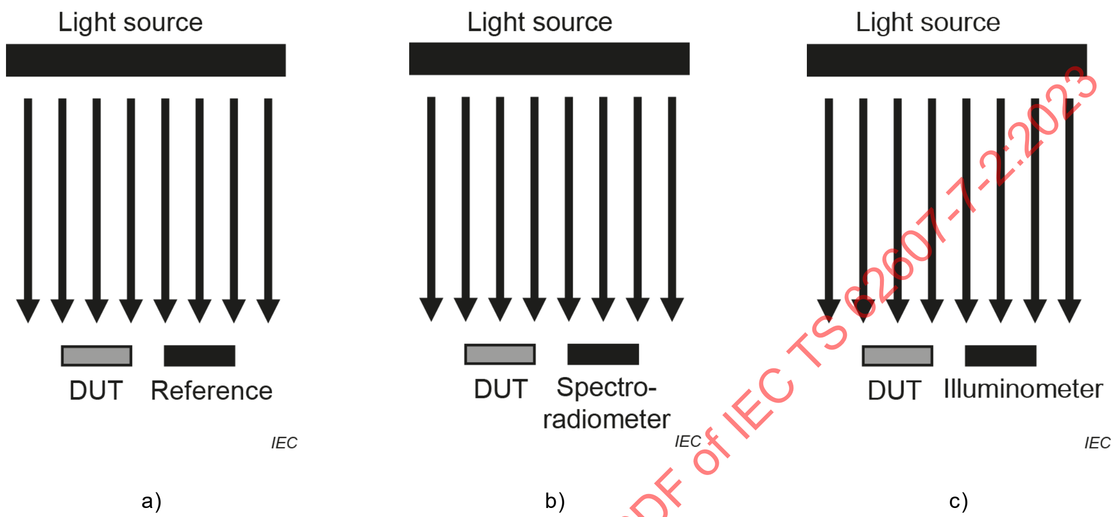

Figure A.1 – Configurations of illuminance adjusting methods described in a) A.4.3.2, b) A.4.3.3 and c) A.4.3.4

Reference [10] reported that measurements can be made with a relative accuracy of ±5 % or better if the light intensity of the illumination source can be adjusted using either the reference photovoltaic-cell method or PRISM method outlined in this document. The illuminometer method is for cases where ease-of-use is more important than accuracy.

Three illuminance adjusting methods (Figure A.1) described in this document are explained in detail in A.4.3.2, A.4.3.3 and A.4.3.4.

A.4.3.2 Indoor reference photovoltaic-cell method

This method is close to the IEC 60904 method. First, a photovoltaic cell with the same relative spectral responsivity as the DUT is selected and its short-circuit current under standard indoor light is calibrated as an indoor primary-reference photovoltaic cell. It is then used to calibrate an indoor secondary reference photovoltaic cell. Furthermore, an indoor working reference photovoltaic cell is calibrated with the secondary reference photovoltaic cell. One of these reference cells is used to adjust the intensity of the illumination source.

While this method allows the highest accuracy, it does require calibration for each standard indoor light when evaluating the efficiency of a photovoltaic cell under different types of standard indoor light.

It has been reported that the short-circuit current deviation among public laboratories is within ±1 % for c-Si photovoltaic cells as indicated in Figure 5 of reference [10] and the calibration values of reference cells for other types of photovoltaic cells (a-Si and µ-Si, for example) deviate by 4 % [11].