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Improving uncertainty of total luminous flux working standard lamps at National Institute of Standards (NIS) - Egypt

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KEYWORDS

Calibration, Spectral mismatch correction factor, Uncertainty, Total luminous flux, Working standard lamp, Integrating Sphere Photometer, Photometer quality factor

A B S T R A C T

In the present research, uncertainty of spectral mismatch correction factor of total luminous flux measurements are estimated for NIS working standard OSRAM lamps. Twenty one NIS working standard lamps have been seasoned and calibrated since 1969. The drift in the recalibration value during these years was between 0.3% to 0.6% depending on their wattages and their color temperatures. A set up based on 2.5meter NIS integrating sphere and NIS photometer LMT U1000 with uncertainty 4% and a group of NIS luminous flux standard lamps calibrated at National Physical Laboratory in England (NPL) with uncertainty 0.8% are used to measure the total luminous flux for twenty one NIS working standard lamps. The sphere photometer calibration factor (SCPF) is 0.15% with photometer quality factor $f_1^{'}$ is 6.25%. Another set up based on NIS Spectroradiometer ocean optics HR 2000 with uncertainty 4.7% and the photometric bench has been used for measuring the spectral power distribution of the lamps to determine the spectral mismatch correction factor and estimate the uncertainty due to this factor. This research demonstrates and realizes the process required to determine the spectral mismatch correction factor and to estimate the uncertainty due to it and recalibrated for NIS working standard OSRAM lamps to improve their total luminous flux measurements uncertainty. The spectral mismatch correction factors are varied from approximately 2% when using the 2400 K standard lamps to approximately 5.3% when using the 2750 K standard lamps. Also, the uncertainty estimation for spectral mismatch correction factors is varied from 0.00062 to 0.008511 depending on the correlated color temperature of the standard lamps.

Introduction

The integrating sphere as shown in Figure 1 is a device for measuring total luminous flux for any light source and its function is to spatially integrate radiant flux.

Light incident on a diffuse surface creates a virtual light source by reflection (IESNA, 1999). Items located inside the sphere, including baffles, lamps, and lamp sockets as shown in Figure 2 absorb some of the energy of the radiant source and decrease the throughput of the sphere. This decrease in throughput is best avoided by coating all possible surfaces with a highly reflective. As any part of the sphere surface sees all other parts of the sphere surface equally; the detector at any point on the surface can measure the total power in the entire sphere (Research paper No. 502, National Bureau of standards). In addition, the reflections from the coating added to the power of the lamp, lead to the fact that there is always more power inside a sphere than the lamp generates (IESNA, 1993).

In photometry, the comparison device is the photometer. Since no photometer perfectly matches the $V(\lambda)$ curve, we need to determine how closely we approach the $V(\lambda)$ curve. The output of a photometer is a single number; the integration over the spectral range is all done internally and one number comes out. In Figure 3 shows the LMT U1000 NIS photometer with 4% uncertainty.

Most photometers are calibrated using what is called the CIE Illuminant A, which is spectrally "smooth" light source, similar to a blackbody radiator operating at 2856K (Gaertner, 2007).

When the photometers measure light sources whose spectral distribution is different from the CIE Illuminant A, an error occurs due to the spectral mismatch of the photometers. This error is corrected by a spectral mismatch correction factor (Ohno, 1996).

An error occurs when a photometer measures a light source having a spectral power distribution different from the standard source for which the photometer was calibrated. In order to correct for such spectral mismatch error, the photometer must be characterized for its relative spectral responsivity. The spectral mismatch correction factor SCF is given by Gaertner (2007).

$$SCF = \frac{\int_{360}^{830\,nm} P_e^T(\lambda)\times V(\lambda)\,d\lambda \int_{all-wavelengths} P_e^S(\lambda)\times R(\lambda)\,d\lambda}{\int_{all-wavelengths} P_e^T(\lambda)\times R(\lambda)\,d\lambda \int_{360}^{830\,nm} P_e^S(\lambda)\times V(\lambda)\,d\lambda} \qquad (1)$$

where

$P_e^T(\lambda)$: is the relative spectral output of the test source.

$P_e^S(\lambda)$: is the relative spectral output of the standard source.

$R(\lambda)$: is the relative spectral responsivity of the photometer.

$V(\lambda)$: is the spectral luminous efficiency function, which defines a photometric measurement.

Uncertainty of the determination of the spectral mismatch correction factor u(SCF) which can be determined regarding to Equation (1) and according to reference ISO, 1995 and Manal A. Haridy, 2008 by the following equation:

$$u^2 = \sum_{variable} \left(\frac{\partial SCF}{\partial\, variable}\right)\times u^2(variable) \qquad (2)$$

Hence we have

$$u^2(SCF) = \delta^2 P_{iS}\left(\frac{\partial SCF}{\partial P_{iS}}\right)^2 + \delta^2 P_{it}\left(\frac{\partial SCF}{\partial P_{it}}\right)^2 + \delta^2 R_i\left(\frac{\partial SCF}{\partial R_i}\right)^2 \qquad (3)$$

Where

P_{iS}**:** the summation of $P_e^S(\lambda)$ within the visible wavelengths range.

P_{it}**:** the summation of $P_e^T(\lambda)$ within the visible wavelengths range.

R_i**:** the summation of $R(\lambda)$ within the visible wavelengths range.

Then from equation (2) we have

$$u(SCF) = \sqrt{\delta^2 P_{iS}\left(\frac{\partial SCF}{\partial P_{iS}}\right)^2 + \delta^2 P_{it}\left(\frac{\partial SCF}{\partial P_{it}}\right)^2 + \delta^2 R_i\left(\frac{\partial SCF}{\partial R_i}\right)^2} \quad (4)$$

Methods and Experimental Set-up

Measurement Set-up of the total luminous flux for the lamps

The NIS photometer used is LMT U1000 with 4% uncertainty and the integrating sphere (El-Bialy *et al.*, 2012) used has a diameter of 2.5 meter and is coated internally with a uniform layer of barium sulfate ($BaSO_4$). The spectral quality factor $f_1{}'$ for the photometer has been determined for the sphere-photometer with value 6.25% (Manal A. Haridy, 2015a). The flux lamps are mounted in a base-up configuration at the center of this sphere into a lamp socket supported from the top of the sphere. Figure 4, shows the 2.5 meter diameter integrating sphere photometer at NIS, Egypt.

Measurement set up of the spectral power distribution of the lamps

Spectroradiometer was used to measure the relative spectral output of the lamps. The Set up of measuring the spectral power distribution lamps (Manal A. Haridy, 2015a) is in figure. 5. It measured directly using the photometric bench and the Spectroradiometer ocean optics HR 2000 at NIS with uncertainty 4.7% (Manal A. Haridy, 2015b).

Results and Analysis

The electrical control parameters of the NIS OSRAM total luminous flux standard and working for the measurements performed are given in the tables 1 to 7.

The following lamps are NIS total luminous flux working standard lamp of our laboratory in photometry and radiometry division at National Institute of standards (NIS). These lamps are in six groups depending on the values of their wattages. The lamps are 25 Watts, 40 Watts, 60 Watts, 75 Watts, 100 Watts, and 200 Watts. In 1967 (Kertil, 1969), the lamps were calibrated in vertical, cap-up position. The values of luminous flux and lamp current were obtained after the lamps had been burning on a direct current supply at the test voltage for 5 minutes at least. The precision of the lamp current was estimated to be better than ±0.03% for the 25 W lamps and better than ±0.07% for all other types of lamps. The values of lumens may be regarded as precise to within ±0.7% for 25 W lamps and ±1.0% for all other types of lamps. As the lamps have been preliminarily aged and selected by the OSRAM Lamp Company, no additional ageing of the lamps has been done in NIS laboratory (Kertil, 1969). After recalibrated these lamps by using the NIS OSRAM total luminous flux standard (calibrated at NPL in England) with uncertainty 0.8%, the drift from the previous calibration in 1969 (Kertil, 1969) in percentage were added to the following tables.

Spectral mismatch correction factors (SCF) for NIS OSRAM total luminous flux standard and working for the measurements are given in the tables 8 to table 14.

Uncertainty

Modern metrology practice in any field requires accurate estimation of uncertainties. The concept of uncertainty as a quantifiable attribute is relatively new in the history of measurement, although error and error analysis have long been a part of the practice of measurement science or metrology.

Table.1 The electrical control results of NIS total luminous flux standard lamps

NIS Standard Lamps	***SET Current***	***Voltage***	***Color temperature***	***Total luminous flux***
	(amperes)	***(Volts)***	***(Kelvin)***	***(lumen)***
NIS-E21	1.7869	102.1	2750	2587
NIS-E22	1.7991	101.6	2750	2597
NIS-E31	0.20482	91.9	2400	131.5
NIS-E32	0.20315	92.0	2400	130.8
NIS-E33	0.20382	92.4	2400	132.4

Table.2 The electrical control results of 25 Watt NIS total luminous flux working standard lamps

NIS Working Standard Lamps	***SET Current***	***Voltage***	***Power***	***Color temperature***	***Total luminous flux***
	(amperes)	***(Volts)***	***(Watts)***	***(Kelvin)***	***(lumen)***
NIS-F1	0.20345	90.7	25	2351	129.0±0.3%
NIS-F2	0.20362	90.3	25	2351	128.0±0.3%
NIS-F3	0.20484	91.0	25	2351	130.9±0.3%
NIS-F4	0.20435	91.0	25	2351	130.1±0.3%
NIS-F5	0.20319	90.4	25	2351	128.3±0.3%

Table.3 The electrical control results of 40 Watt NIS total luminous flux working standard lamps

NIS Working Standard Lamps	***SET Current***	***Voltage***	***Power***	***Color temperature***	***Total luminous flux***
	(amperes)	***(Volts)***	***(Watts)***	***(Kelvin)***	***(lumen)***
NIS-F7	0.37883	108.7	40	2693	423.1±0.3%
NIS-F9	0.38033	109.5	40	2693	428.8±0.3%

Table.4 The electrical control results of 60 Watt NIS total luminous flux working standard lamps

NIS Working Standard Lamps	***SET Current***	***Voltage***	***Power***	***Color temperature***	***Total luminous flux***
	(amperes)	***(Volts)***	***(Watts)***	***(Kelvin)***	***(lumen)***
NIS-F11	0.57724	108.5	60	2761	782.7±0.4%
NIS-F13	0.57850	108.2	60	2761	781.8±0.4%
NIS-F14	0.58203	109.4	60	2761	803.5±0.4%

Table.5 The electrical control results of 75 Watt NIS total luminous flux working standard lamps

NIS Working Standard Lamps	***SET Current***	***Voltage***	***Power***	***Color temperature***	***Total luminous flux***
	(amperes)	***(Volts)***	***(Watts)***	***(Kelvin)***	***(lumen)***
NIS-F16	0.70383	109.2	75	2737	960.2±0.4%
NIS-F17	0.70389	106.9	75	2737	924.4±0.4%
NIS-F18	0.71908	109.0	75	2737	973.7±0.4%
NIS-F20	0.71005	109.0	75	2737	969.4±0.4%

Table.6 The Electrical Control Results of 100 Watt NIS total luminous flux working standard lamps

NIS Working Standard Lamps	***SET Current***	***Voltage***	***Power***	***Color temperature***	***Total luminous flux***
	(amperes)	***(Volts)***	***(Watts)***	***(Kelvin)***	***(lumen)***
NIS-F23	0.90384	105.5	100	2788	1310±0.5%
NIS-F24	0.90491	106.6	100	2788	1342±0.5%
NIS-F25	0.90735	106.7	100	2788	1320±0.5%

Table.7 The electrical control results of 200 Watt NIS total luminous flux working standard lamps

NIS Working Standard Lamps	***SET Current***	***Voltage***	***Power***	***Color temperature***	***Total luminous flux***
	(amperes)	***(Volts)***	***(Watts)***	***(Kelvin)***	***(lumen)***
NIS-F26	1.7911	101.8	200	2790	2657±0.5%
NIS-F27	1.7853	101.4	200	2790	2626±0.6%
NIS-F29	1.7820	101.1	200	2790	2624±0.6%
NIS-F30	1.7923	100.3	200	2790	2615±0.6%

Table.8 Spectral Mismatch Correction Factors (SCF) for NIS Standard lamps

Lamp	***Spectral Mismatch Corrections Factor***
NIS-E21	0.979180
NIS-E22	0.980783
NIS-E24	0.980738
NIS-E31	0.977065
NIS-E32	0.979680
NIS-E33	0.974953

Table.9 Spectral Mismatch Correction Factors (SCF) for 25 W NIS-working standard lamps

Lamp	*Spectral Mismatch Correction Factor*
NIS-F1	0.979639452
NIS-F2	0.977285208
NIS-F3	0.979015634
NIS-F4	0.946634975
NIS-F5	0.978145455

Table.10 Spectral Mismatch Correction Factors (SCF) for 40 W NIS-working standard lamps

Lamp	*Spectral Mismatch Correction Factor*
NIS-F7	0.979594816
NIS-F9	0.979461724

Table.11 Spectral Mismatch Correction Factors (SCF) for 60 W NIS-working standard lamps

Lamp	*Spectral Mismatch Correction Factor*
NIS-F11	0.979767285
NIS-F13	0.976099438
NIS-F14	0.976099438

Table.12 Spectral Mismatch Correction Factors (SCF) for 75 W NIS-working standard lamps

Lamp	*Spectral Mismatch Correction Factor*
NIS-F16	0.975914508
NIS-F17	0.979594816
NIS-F18	0.980100622
NIS-F20	0.979810821

Table.13 Spectral Mismatch Correction Factors (SCF) for 100 W NIS-working standard lamps

Lamp	*Spectral Mismatch Correction Factor*
NIS-F23	0.980490576
NIS-F24	0.98081167
NIS-F25	0.980496927

Table.14 Spectral Mismatch Correction Factors (SCF) for 200 W NIS-working standard lamps

Lamp	***Spectral Mismatch Correction Factor***
NIS-F26	0.981043288
NIS-F27	0.981369928
NIS-F29	0.98074359
NIS-F30	0.97992139

Table.15 The uncertainty due to the spectral mismatch correction factor for 25 W NIS working standard lamps

Lamp	***NIS-E21***	***NIS-E22***	***NIS-E24***	***NIS-E31***	***NIS-E32***	***NIS-E33***
NIS-F1	0.001026822	0.001566688	0.001494572	0.008434087	0.008407382	0.008429052
NIS-F2	0.000987799	0.001547403	0.001469837	0.008404849	0.008379422	0.008400546
NIS-F3	0.00102323	0.001595753	0.001512079	0.008458741	0.008431926	0.008454036
NIS-F4	0.003716382	0.004042269	0.004009075	0.009185471	0.009165807	0.009178804
NIS-F5	0.001102514	0.001637259	0.001564979	0.00843464	0.008408631	0.008429338

Table.16 The uncertainty due to the spectral mismatch correction factor for 40 W NIS working standard lamps

Lamp	***NIS-E21***	***NIS-E22***	***NIS-E24***	***NIS-E31***	***NIS-E32***	***NIS-E33***
NIS-F7	0.000652696	0.001412292	0.001324225	0.008461807	0.008435222	0.008457498
NIS-F9	0.000641399	0.00141198	0.001322778	0.008464961	0.008438345	0.008460499

Table.17 The uncertainty due to the spectral mismatch correction factor for 60 W NIS working standard lamps

Lamp	***NIS-E21***	***NIS-E22***	***NIS-E24***	***NIS-E31***	***NIS-E32***	***NIS-E33***
NIS-F11	0.000650361	0.001417763	0.001329863	0.008472442	0.008445819	0.008468153
NIS-F13	0.000654458	0.001404091	0.001318666	0.008452655	0.008425973	0.008448218
NIS-F14	0.000640718	0.00148423	0.001396649	0.008515111	0.008488704	0.008510651

Table.18 The uncertainty due to the spectral mismatch correction factor for 75 W NIS working standard lamps

Lamp	***NIS-E21***	***NIS-E22***	***NIS-E24***	***NIS-E31***	***NIS-E32***	***NIS-E33***
NIS-F16	0.000649526	0.001488923	0.001401156	0.008513561	0.008487184	0.008509052
NIS-F17	0.000652696	0.001412292	0.001324225	0.008461807	0.008435222	0.008457498
NIS-F18	0.000625208	0.001402376	0.001314894	0.008471445	0.008444622	0.008467054
NIS-F20	0.000626989	0.001413728	0.001324586	0.008479423	0.008452603	0.00847496

Table.19 The uncertainty due to the spectral mismatch correction factor for 100 W NIS working standard lamps

Lamp	*NIS-E21*	*NIS-E22*	*NIS-E24*	*NIS-E31*	*NIS-E32*	*NIS-E33*
NIS-F23	0.000629725	0.001392791	0.001304176	0.008464322	0.008437461	0.008460049
NIS-F24	0.000629884	0.001394793	0.001307317	0.008468961	0.008442123	0.008464705
NIS-F25	0.000626782	0.001396933	0.00130769	0.008469084	0.008442165	0.008464739

Table.20 The uncertainty due to the spectral mismatch correction factor for 200 W NIS working standard lamps

Lamp	*NIS-E21*	*NIS-E22*	*NIS-E24*	*NIS-E31*	*NIS-E32*	*NIS-E33*
NIS-F26	0.000637661	0.001396617	0.001310173	0.008470128	0.008443209	0.008465765
NIS-F27	0.000652429	0.001372065	0.001285219	0.008442318	0.008415249	0.008437957
NIS-F29	0.000626627	0.001395604	0.001307062	0.008470655	0.008443747	0.008466317
NIS-F30	0.000621836	0.00141283	0.001324353	0.008484127	0.008457279	0.008479792

Figure.1 The NIS integrating sphere photometer system (2.5meter diameter)

Figure.2 The Lamp baffle, the photometer port, and the lamp holder of the 2.5 integrating sphere system

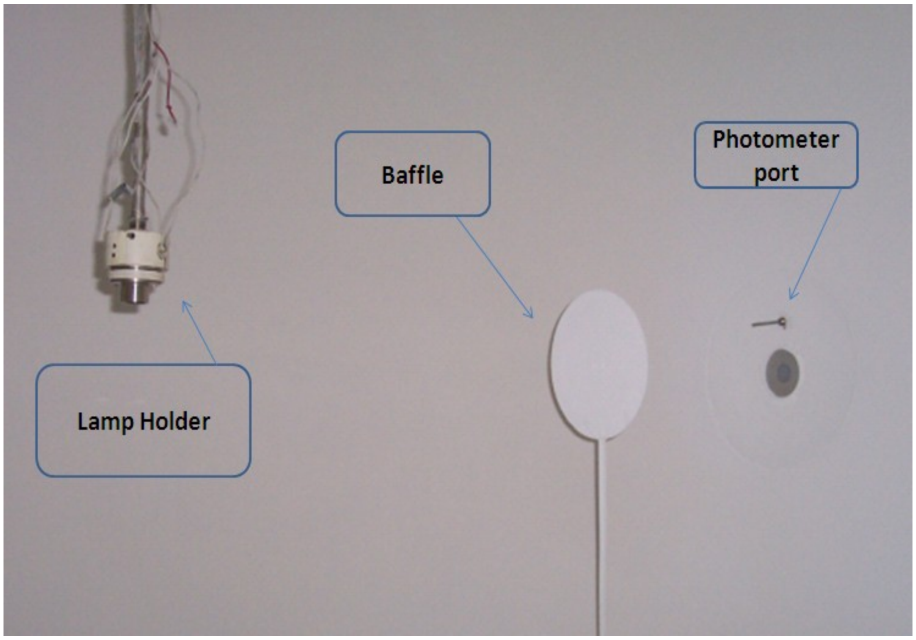


Figure.3 The LMT U1000 NIS photometer

Figure.4 The NIS integrating sphere photometer system set up for the luminous flux measurement

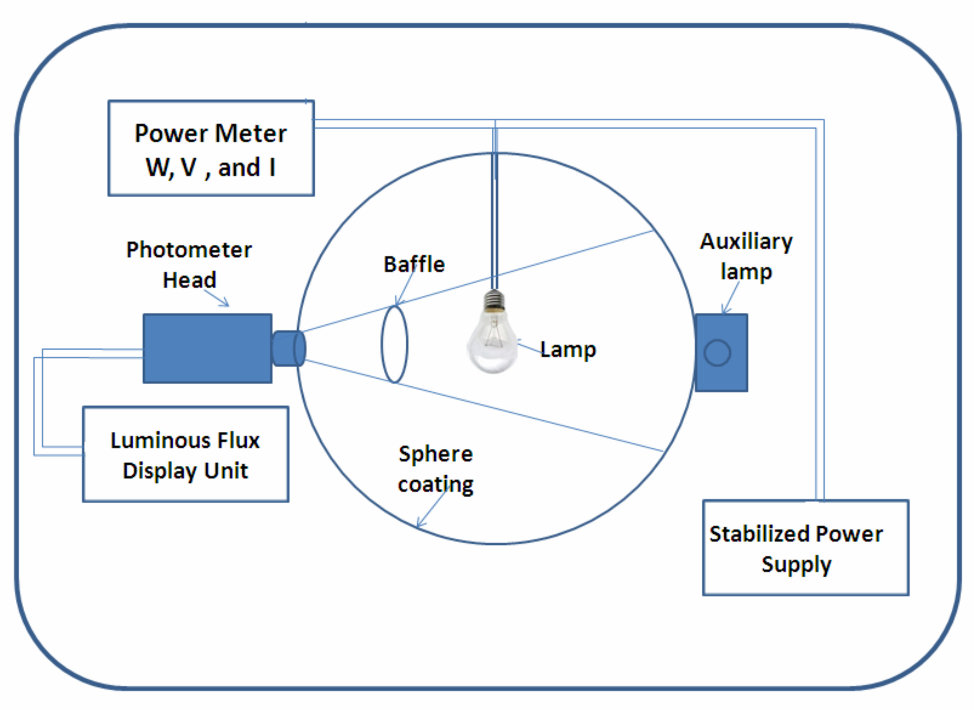
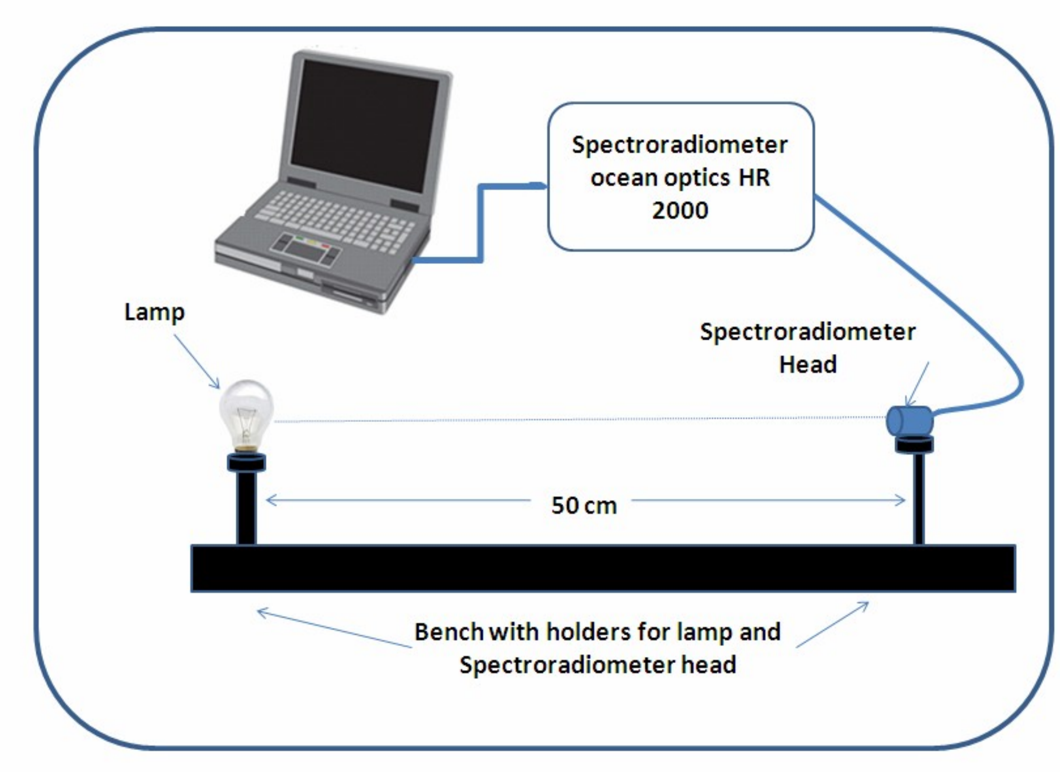


Figure.5 Set up of measuring the spectral power distribution of NIS total luminous flux working standard lamps



It is now widely recognized that, when all of the known or suspected components of error have been evaluated and the appropriate corrections have been applied, there still remains an uncertainty about the corrections of the stated result, that is, a doubt about how well the result of the measurement represents the value of the quantity being measured.

Consistent estimation of uncertainty according to the methods described in the ISO Guide to the Expression of uncertainty in Measurements (ISO, 1995) is a major concern of modern metrology. This applies not only to the direct measurement of International System of Units quantities, but also to measurements derived from them.

All uncertainties are given as fractional uncertainties and as one standard deviation (coverage factor k=1). The relative expanded uncertainty (k=2) was obtained by assuring a normal distribution and multiplying the relative combined standard uncertainty by a coverage factor of k=2. NIS photometer LMT U1000 with uncertainty 4%, NIS Spectroradiometer with uncertainty 4.7% and NIS-standard lamps calibrated at National Physical Laboratory in England (NPL) with uncertainty 0.8%. Uncertainty of sphere calibration photometer factor (0.15%) and Photometer Spectral Quality Factor f_1' equal 6.25% (Manal A. Haridy, 2015a). The spectral mismatch correction factors are varied from approximately 2% when using the 2400 K standard lamps to approximately 5.3% when using the 2750 K standard lamps. Also, the uncertainty estimation for spectral mismatch correction factors are varied from 0.00062 to 0.008511 depending on the correlated color temperature of the standard lamps. Uncertainties due to spectral mismatch correction factors (SCF) for NIS OSRAM total luminous flux standard and working for the measurements are given in the tables 15 to 20.

Conclusion

The drift in the recalibration values for NIS working standards during these years was between 0.3% to 0.6% depending on their wattages and their color temperatures as in tables 2 to 7. The spectral mismatch correction factors are varied from approximately 2% when using the 2400 K standard lamps to approximately 5.3% when using the 2750 K standard lamps as in tables 8 to 14. Also, the uncertainty estimation for spectral mismatch correction factors are varied from 0.00062 to 0.008511 depending on the correlated color temperature of the standard lamps as in tables 15 to 20. These twenty one NIS working standard lamps are very important for the routine work in photometry laboratory to calibrate many lamps.

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