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EMPLOYMENT OF DEVELOPED INTEGRATING SPHERE PHOTOMETER SYSTEM TO REALIZE NIS SECONDARY AND WORKING STANDARDS LUMINOUS FLUX LAMPS AND UNCERTAINTY EVALUATION

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ABSTRACT

In the present research, the developed NIS integrating sphere photometer system was used to determine the total luminous flux and the ratio of the measuring values obtained by the integrating sphere photometer to the certified values for both NIS secondary and working standard lamps in the present study. The 2.5-m integrating sphere in the National Institute of Standards was equipped with the NIS photometer, LMT U1000, and a group of secondary standard lamps previously calibrated at the National Physical Laboratory, England. These were used to measure the total luminous flux of the NIS working standard lamps. A second arrangement for the measurement of the SPD of lamps included the NIS spectroradiometer (Ocean Optics HR 2000) and a photometric bench. The calculation of the spectral mismatch correction factor was required as well as the estimation of the uncertainty of that factor. Comparison of the Integrating sphere photometer measurements with the certified values for NIS secondary standard lamps showed results that differ from 0.0029 to 0.004, while it was found to vary between 0.0019 and 0.0055 for the NIS working standard lamps. The expanded uncertainty of the total luminous flux measurements was estimated at 1.49%, considering all the uncertainties in the determination of the luminous flux unit realization besides other factors. This comprehensive approach is effectively permitting the accurate measurement and calibration of luminous flux standards at NIS.

Keywords: total luminous flux measurements, secondary and working standard lamps, developed integrating sphere photometer, uncertainty.

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1. INTRODUCTION

Traceability to the SI unit by a National Metrology Institute NMI means that measurement results or standards are connected to specific references-usually national or international standards-by a chain of comparisons with quantified uncertainties. This connection allows a sample of interest to have its measurement results connected with the desired references such that confidence in the accuracy of measurements is achieved. When establishing traceability, metrological evidence must be collected in order to document the complete traceability chain and quantify associated uncertainties at each step. The ultimate reference is usually the definition of the unit concerned in SI terms, and this may be realized by a national laboratory. This procedure reflects the hierarchical succession of comparisons back to the primary standards that give validity and consistency to the results of measurements in different uses. Traceability is indispensable in areas that need measurements to be very accurate, for it is only then, with traceability, there can be standardization and comparisons on an international basis, instilling confidence in the measurements that are made [1,2]. Nowadays, goods and services are produced under a quality system, with people placing greater emphasis on quality rather than just cost when making purchasing decisions [3]. In the modern economy, calibration and testing activities are crucial for ensuring the quality of goods, services, and purchasing decisions. It's estimated that in industrialized countries, measurement-related activities account for about 4% of the gross domestic product [4]. Consequently, clients of laboratories are increasingly concerned with the quality of the measurement data they purchase. Presently, even though a prevalent approach to ensuring the quality of their product in the prevailing scenario involves registration of a quality system, it has come out eminently that such an approach does not fully meet the requirements of the testing and calibration activities. Gap has been fulfilled by ISO 17025 entitled 'General Requirements for the Competence of Testing and Calibration Laboratories' as the globally accepted standard for laboratory accreditation. ISO 17025 accreditation means that a laboratory has implemented a quality system and, beyond that, is competent to carry out tests and calibrations, including measurement uncertainty claims and traceability to the International System of Units, the SI. The international trade requires the elimination or reduction of technical barriers to trade, thus assurance that measurements are consistent and comparable across borders. Although this may be so, it has been particularly crucial and important for calibration laboratories, which are very important in ensuring the reliability and accuracy of measurements that are made in commerce. In fact, there have been several incidences when results from accredited

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laboratories outperform those from their unaccredited counterparts during interlaboratory comparisons, thus commanding further confidence to clients and stakeholders who require their services. To this regard, ISO 17025 accreditation helps instill trust in measurement and calibration to meet the broader goals of global commerce and scientific progress. [5, 6]. The purpose of a total luminous flux comparison is to compare the lumen magnitude values maintained by each participating NMI. The results from the participating NMIs will be used to establish a link to the results of the CCPR-K4 comparison [7] and determine the degree of equivalence among the participating NMIs. The measurement of a light source's total luminous flux is commonly conducted using either a goniophotometer or an integrating sphere [8-11]. Traditionally, goniophotometers are employed to establish the unit for total luminous flux [12]. The luminous flux of test lamps is determined using a substitution method using the NIS integrating sphere photometer as shown in Figure-1. First, the standard lamp is measured, followed by the test lamp, continuing this process until all standard and test lamps are measured. This sequence should be completed within a day and can be repeated on another day if necessary. Measuring the standard lamps before and after the test lamps ensures that the sphere's condition remains unchanged during the measurements. The total flux of test lamp Φ_t is given by Equation (1)

$$\Phi_t = \Phi_S \times \frac{y_t}{y_S} \times (SCF/\alpha) \quad (1)$$

where Φ_S is the total flux of the standard lamp, y_t is the signal for the test lamp, y_S is the signal for the standard lamp, SCF is the spectral correction factor, and α is the self-absorption [13, 14]. In this study, represents the measurement of total luminous flux and presents a comparison of the values obtained by the integrating sphere photometer against certified values for NIS luminous flux secondary and working standard lamps using a newly developed NIS integrating sphere photometer system. It is expected that this would constitute accurate, consistent measurements with maintained traceability to photometric standards. Reliability was checked by a 2.5-meter integrating sphere system, coupled with secondary standard lamps which were previously calibrated by the National Physical Laboratory (NPL). The spectral power distribution was measured, too, for applying spectral mismatch corrections, which would enhance precision. The values of the photometer are in good agreement with the certified values since discrepancies in measurement fell within 0.0019 and 0.0055, and the expanded uncertainty of the total luminous flux measurements calculated is 1.49%. This allows for increasing the accuracy and the reliability of luminous flux measures, but that enables international photometric standards. To achieve this, I utilize the newly developed NIS integrating sphere photometer system as shown in Figure1.

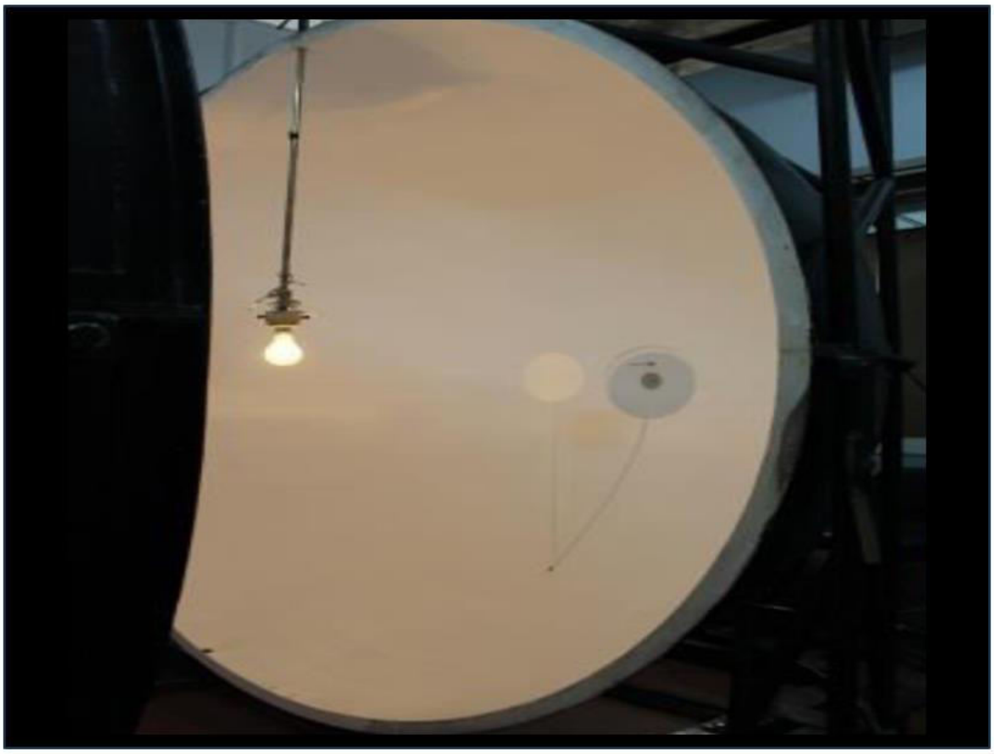

Figure-1. NIS 2.5 m integrating sphere photometer set up.

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2. EXPERIMENTS AND MEASUREMENTS

2.1 Integrating Sphere Facilities

The NIS integrating sphere system measures the absolute luminous flux of each lamp, which is essential for basic photometric and radiometric measurements. It consists of an integrating sphere of 2.5 meters, an LMT U1000 photometer, a stable power source, and standard luminous flux reference sources. This set is controlled and monitored using the LabVIEW PID algorithm, hence managing the instruments' coordination with high precision. It comes with a cosine-corrected photometer containing a V(λ) filter, which allows for direct measurement of luminous flux. The inner surface of the integrating sphere is coated with Barium Sulphate paint, which allows for 97% diffuse reflectance to enable homogeneous distribution of light. A compensating 100 W tungsten lamp neutralizes the self-absorption processes, and with the aid of a temperature sensor, the internal air temperature is maintained at about 25+1°C, guaranteeing the accuracy of the measurement. The LabVIEW PID algorithm enhances the performance of a system through minimization of errors, hence a real-time control and automation of instruments. The design is all-inclusive, ensuring high precision in luminous flux measurement and further improving the reliability of photometric tests and calibration.[15].

2.2 Measurement Set Up of the Spectral Power Distribution of the Lamps

The relative spectral output of the lamps was measured by means of the Spectroradiometer Ocean Optics HR 2000, having an uncertainty of 4.7% at NIS [16,17]. Figures 2 and 3 are the NIS secondary and working standards lamps of total luminous flux measurements. These measurements were conducted directly using both the photometric bench and the spectroradiometer, ensuring precise and reliable data collection for establishing luminous flux standards. The integration of these tools allows for accurate assessment of the lamps' spectral output, critical for maintaining high standards in photometric measurements and ensuring consistency across various applications.

Figure-2. NIS luminous flux secondary standards lamps.

Figure 3. NIS luminous flux working standards lamps.

3. RESULTS AND DISCUSSIONS

In this research, utilizing a developed integrating sphere photometer system to recalibrate NIS secondary and working standards for luminous flux lamps involves a comprehensive process that includes the meticulous calibration of the photometer system to ensure accurate measurements. The system is constructed with a highly reflective coating to facilitate uniform light distribution and is calibrated using reference lamps with known luminous flux values. Recalibrating NIS secondary standards begins with selecting stable and reproducible lamps and developing a standardized measurement protocol that specifies lamp positioning, power supply specifications, and environmental conditions. Multiple measurements of these lamps provide a robust data set to establish the standards. Working standards are developed by transferring luminous flux values from the NIS standards to working standard lamps, ensuring consistency through periodic verification and validation. Assessing uncertainty involves identifying all potential sources, quantifying them statistically, and combining them to determine overall measurement uncertainty. Detailed documentation of procedures, calibration data, and uncertainty calculations is maintained for traceability, and a comprehensive report is compiled to include all relevant

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data, methodologies, and conclusions. This thorough approach ensures accurate, reliable luminous flux measurements and a clear understanding of associated uncertainties, supporting a wide range of lighting and photometry applications. Figures 4 and 5 depict the spectral power distribution (SPD) of the NIS luminous flux secondary and working standards lamps. These figures provide a detailed visual representation of the distribution of power across different wavelengths of light emitted by the lamps. By illustrating the SPD, Figures 4 and 5 allow for a comprehensive analysis of the lamps' spectral characteristics, which is crucial for understanding their performance and ensuring their suitability as standards. The SPD information helps in verifying that the lamps meet the required spectral qualities for accurate luminous flux measurements, thereby reinforcing their reliability as secondary and working standards. This detailed spectral analysis is essential for calibrating photometric instruments and maintaining the high precision needed for various lighting and photometric applications.

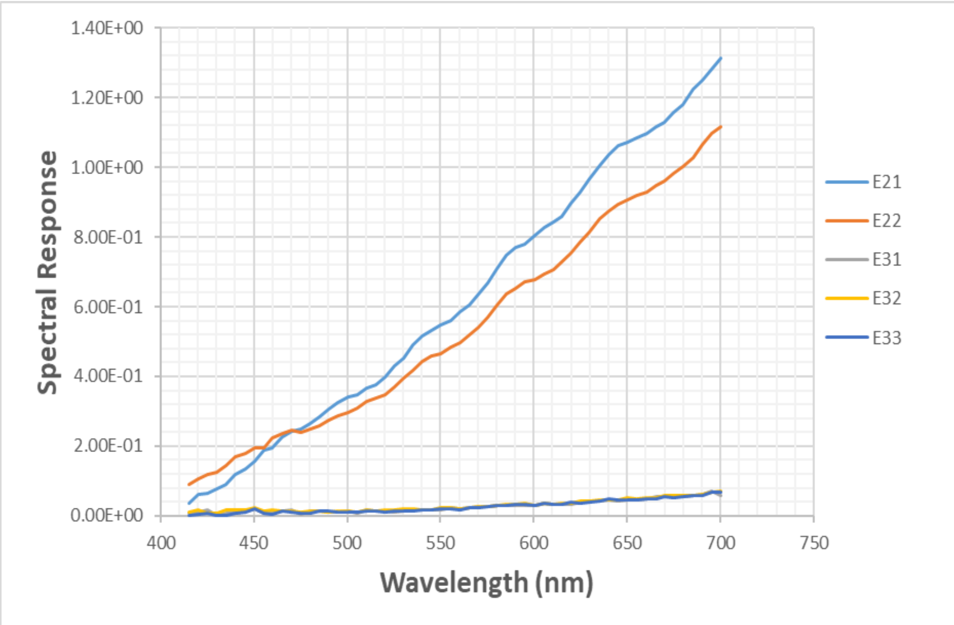

Figure-4. Spectral power distribution of NIS luminous flux secondary standards lamps.

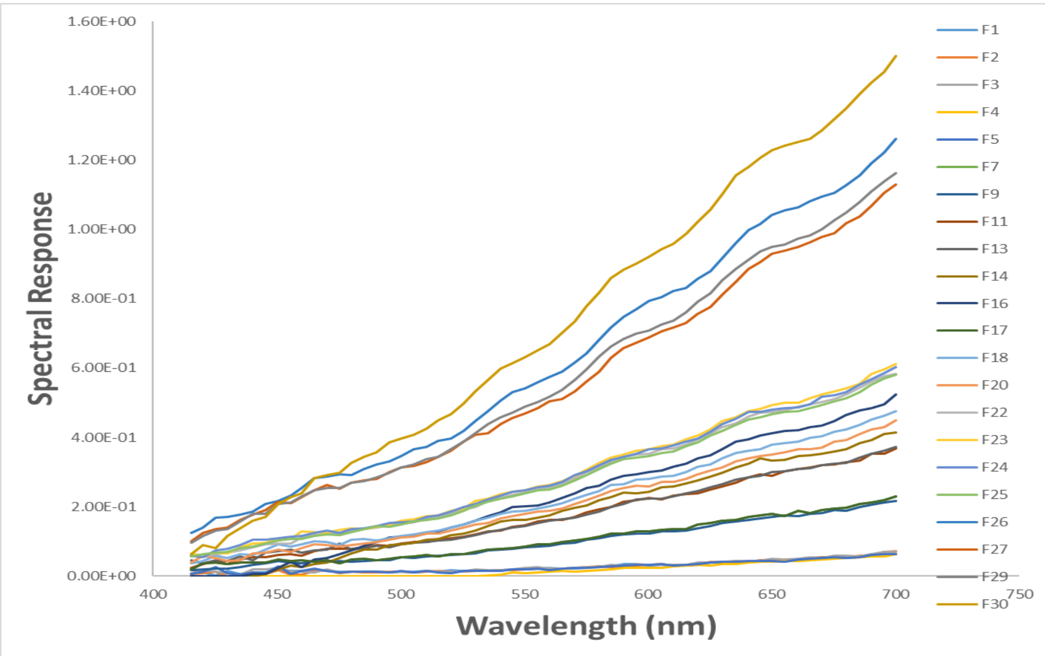

Figure-5. Spectral power distribution of NIS luminous flux working standards lamps.

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The electrical control parameters for the NIS OSRAM total luminous flux secondary standard and working measurements are detailed in Tables 1 to 7, inclusive. These tables present in exact detail the electrical settings and conditions employed during calibration and measurement so that any interested party can appreciate the transparency and reproducibility of the experimental setup. At the Photometry and Radiometry Division of the National Institute of Standards (NIS), our laboratory is currently using several lamps as the working standards for total luminous flux measurements. In this regard, a set of lamps was divided into six groups, according to watt ratings of 25 Watts, 40 Watts, 60 Watts, 75 Watts, 100 Watts, and 200 Watts. This categorization assists in making a comprehensive judgment about luminous flux over an enormous range of output. We are able to cover several applications and needs in this respect. The choice of such wattage groups becomes vital in so far as making the measurements both reliable and as accurate as possible. Every category allows us to glimpse a different performance nature that adds to constructing a sound structure for luminous flux standards. With a range of wattages, we can obtain more information about how different lamp types behave for individual operational parameters, thus enabling further refinement of our calibration processes. The electrical control parameters in the tables provide very important means for reducing the uncertainty of measurement. Recording settings and conditions allows subsequent measurements to reproduce with high accuracy. Thus, the record contributes to the integrity of luminous flux standards. This reflects a holistic approach whereby NIS is committed to offering high-quality calibration services that ensure the accuracy and reliability of the photometric measurements are maintained across various applications. [18].

Table-1. The NIS total luminous flux secondary standard lamps.

NIS Secondary Standard Lamps	Integrating sphere (IS) Photometer Certificate value (Lumen)	Integrating sphere (IS) Photometer (Lumen)
Standard -E21	2587	2594.7
Standard -E22	2597	2604.8
Standard -E31	131.5	132.1
Standard -E32	130.8	131.3
Standard -E33	132.4	132.9

Table-2. The NIS total luminous flux 25 watt working standard lamps.

NIS Standard Lamps	Integrating sphere (IS) Photometer Certificate value (Lumen)	Integrating sphere (IS) Photometer (Lumen)
W-Standard -F1	129	129.4
W-Standard -F2	128	128.4
W-Standard -F3	130	131.3
W-Standard -F4	130	130.5

Table-3. The NIS total luminous flux 40 watt working standard lamps.

NIS Standard Lamps	Integrating sphere (IS) Photometer Certificate value (Lumen)	Integrating sphere (IS) Photometer (Lumen)
W-Standard -F6	423.1	424.3
W-Standard -F7	428.8	430

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Table-4. The NIS total luminous flux 60 watt working standard lamps.

NIS Standard Lamps	Integrating sphere (IS) Photometer Certificate value (Lumen)	Integrating sphere (IS) Photometer (Lumen)
W-Standard -F11	782.7	784.8
W-Standard -F13	781.8	783.9
W-Standard -F14	803.5	805.7

Table-5. The NIS total luminous flux 75 watt working standard lamps.

NIS Standard Lamps	Integrating sphere (IS) Photometer Certificate value (Lumen)	Integrating sphere (IS) Photometer (Lumen)
W-Standard -F16	960	961.8
W-Standard -F17	924.4	926.1
W-Standard -F18	973.7	975.6
W-Standard -F20	969	973.3

Table-6. The NIS total luminous flux 100 watt working standard lamps.

NIS Standard Lamps	Integrating sphere (IS) Photometer Certificate value (Lumen)	Integrating sphere (IS) Photometer (Lumen)
W-Standard -F23	1310	1315.5
W-Standard -F24	1342	1346.7
W-Standard -F25	1320	1324.6

Table-7. The NIS total luminous flux 200 watt working standard lamps.

NIS Standard Lamps	Integrating sphere (IS) Photometer Certificate value (Lumen)	Integrating sphere (IS) Photometer (Lumen)
W-Standard -F26	2657	2670.3
W-Standard -F27	2626	2669.8
W-Standard -F30	2615	2628.7

Figures 6 and 7 illustrate the ratio of the integrating sphere photometer values to the certified values for the NIS luminous flux secondary and working standards lamps. These figures provide a visual comparison that highlights the accuracy and consistency of the IS photometer measurements against the established certified standards. By comparing these ratios, one can assess the reliability of the IS photometer system in maintaining the precise luminous flux values required for NIS standards. This comparison is essential for validating the performance of the photometer system and ensuring that the measurements align with the rigorous standards set by NIS, thereby reinforcing the credibility and accuracy of the luminous flux measurements for both secondary and working standards lamps.

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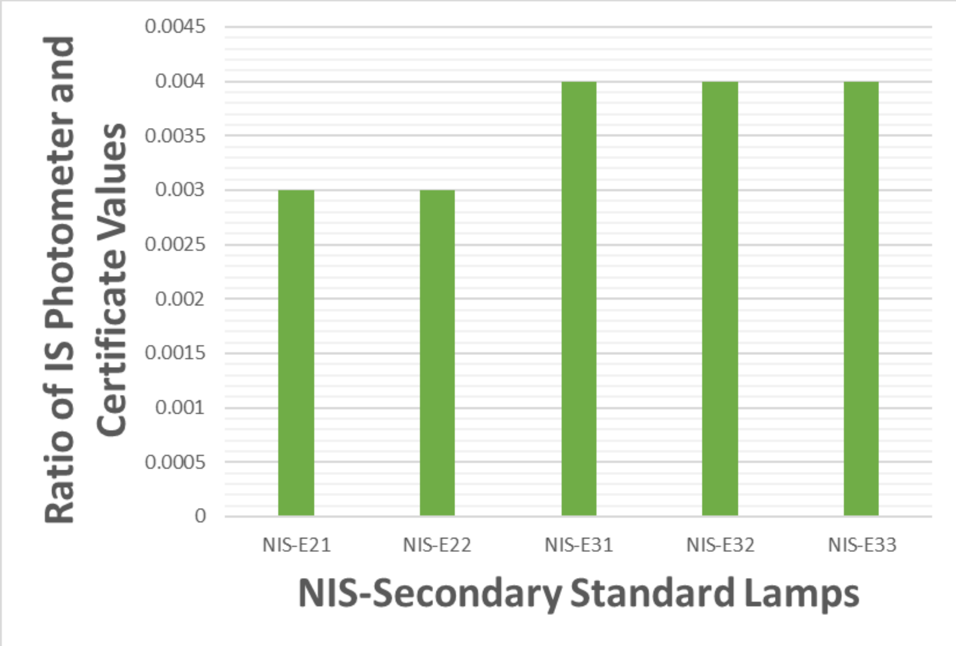

Figure-6. Ratio of Integrating sphere (IS) Photometer (Lumen) and Certified Values for NIS luminous flux secondary standards lamps.

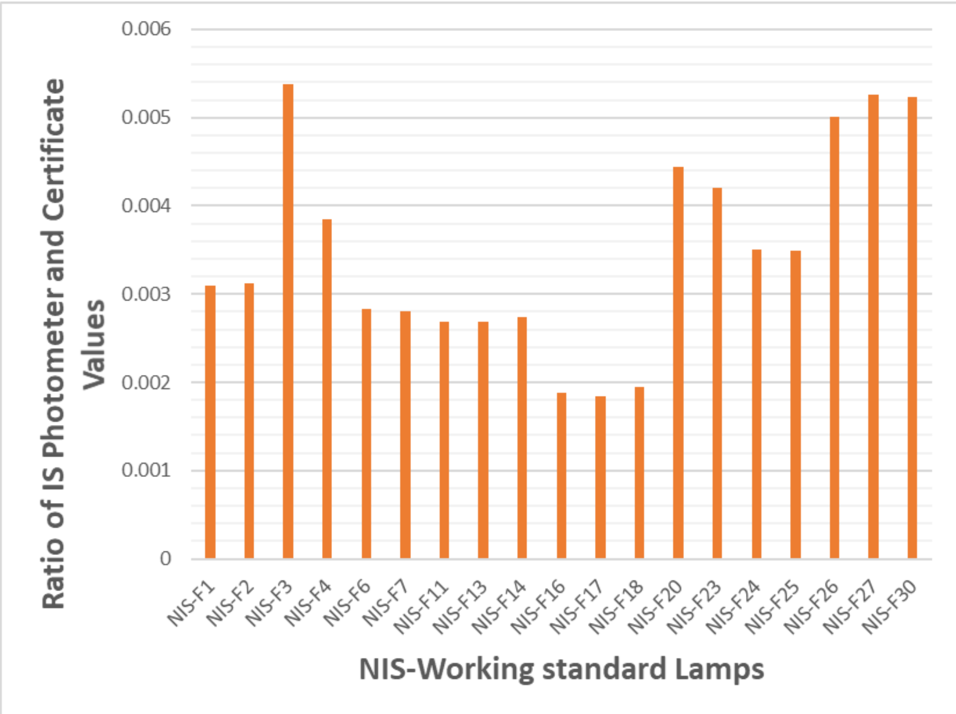

Figure-7. Ratio of Integrating sphere (IS) Photometer (Lumen) and certified values for NIS luminous flux working standards lamps.

4. UNCERTAINTY

Measurement uncertainty refers to the inherent doubt or variability that exists in any measurement result. Even when using precisely crafted instruments such as rulers, clocks, and thermometers, which are designed to provide accurate readings, there is always a certain level of uncertainty involved. This uncertainty arises from various factors. Firstly, the limitations of the measuring instruments themselves can introduce slight errors. No instrument can be perfect; they all have tolerances and precision limits. For instance, a ruler may be marked in millimeters, but the exact position of the markings and the observer's ability to align the object being measured can cause slight deviations. Secondly, environmental conditions can affect measurements. Temperature, humidity, and atmospheric pressure can influence the performance of measuring devices and the objects being measured. For example, a metal ruler may expand or contract slightly with temperature changes, altering the measurement slightly. Thirdly, the process of measurement involves human intervention, which introduces a potential source of error. Human perception and reaction times can lead to slight inaccuracies, such as when reading the level of a liquid in a graduated cylinder or timing an event with a stopwatch. Finally, even when automated systems are used to eliminate human error, there is still a degree of variability in the measurements due to the inherent properties of the materials and the measuring systems. Therefore, despite our best efforts and the use of high-quality instruments, every measurement carries with it a margin of doubt, reflecting the inherent uncertainty in the process. Understanding and accounting for this uncertainty is crucial in scientific and engineering practices, as it allows for more accurate interpretations and reliable results [19]. The best way of assessing and stating measurement uncertainty should be valid for any measurement and any input data. Moreover, the quantity that states the uncertainty should be directly calculable from its constituent parts. The GUM [20, 21] assumes that measurement results are corrected for all significant systematic effects and that every reasonable effort has been made to identify such effects. The uncertainty budget of total luminous flux measurements using developed NIS integrating sphere photometer system is 1.49.

5. CONCLUSIONS

The present study focuses on the determination of the total luminous flux and assessment of integrating sphere photometer measurements' accuracy compared with the certified values for both the NIS luminous flux secondary standard lamps and the working standard lamps. To achieve this, we utilize the newly developed NIS integrating sphere photometer system. Figures 4 and 5 show the spectral power distribution (SPD) of the NIS luminous flux secondary and working standards lamps. These visuals provide a detailed look at how power is distributed across various wavelengths of light emitted by the lamps. By presenting the SPD, these figures facilitate a thorough analysis of the lamps' spectral characteristics, which is vital for assessing their performance and ensuring they are suitable as standards. This SPD data is crucial for confirming that the lamps meet the necessary spectral qualities for precise luminous flux measurements, thus supporting their reliability as secondary and working standards. Such in-depth spectral analysis is fundamental for calibrating photometric instruments and maintaining the high precision required for various lighting and photometric applications.

Figures 6 and 7 present the ratio of the integrating sphere (IS) photometer values to the certified values for the NIS luminous flux secondary and working standards lamps. These figures offer a visual comparison that emphasizes the accuracy and consistency of the IS photometer measurements against the established certified standards. By examining these ratios, the reliability of the IS photometer system in maintaining the precise luminous flux values required by NIS standards can be assessed. This comparison is crucial for validating the photometer system's performance and ensuring that the measurements comply with the stringent standards set by NIS, thereby reinforcing the credibility and accuracy of the luminous flux measurements for both secondary and working standards lamps.

The uncertainties of the recalibration values of the NIS secondary working standards, measured by using the developed integrating sphere photometer system, were determined in tables 2-7 as within the dissemination of wattages and color temperatures between 0.3% and 0.6%, respectively. These NIS working standard lamps play a pivotal role in the daily functions of photometry laboratories. They are essential for accurately calibrating a wide array of lamps utilized across diverse industrial sectors. Their precise calibration ensures consistency and reliability in photometric measurements, thereby maintaining high standards in lighting quality and performance across industrial applications.

The comparison between the integrating sphere photometer values and the certified values for the NIS luminous flux secondary standards lamps showed a variation ranging from 0.0029 to 0.004. Similarly, for the NIS luminous flux working standards lamps, this comparison ranged from 0.0019 to 0.0055. These ratios illustrate the degree of correspondence between the measurements taken by the integrating sphere photometer and the officially certified values, indicating the accuracy and consistency of the photometric measurements relative to the established standards. This analysis is crucial for validating the reliability of the photometer system in maintaining precise luminous flux measurements for both secondary and working standards lamps, ensuring their suitability for various applications in lighting and photometry. The expanded uncertainty for total luminous flux measurements is 1.49%, which includes uncertainties associated with the realization of the unit.

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