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## **Comparison Study of Illuminance Measurements Emitted from Four Different Types of Gas Discharge Lamps and Uncertainty Evaluation**

Manal A. Haridy 1,\*

1 Photometry and Radiometry Division, National Institute of Standards (NIS), Giza, Egypt. \* Corresponding Author: <u>manal haridi@yahoo.com</u>

#### Abstract

The present work realized the detailed performance analysis of four types of gas discharge lamps (water vapor, helium, hydrogen, and mercury vapor) by measurement, calculation, and comparison of some of the main parameters' values of lighting. The lamps were characterized by their illuminance level and two significant indicators of safety and efficiency. The first parameter is the ratio between the UVA power and illuminance values given by K, critical in determining the lamp's safety. It gives the amount of UV radiation that comes out relative to the accessible light output-a very important single parameter to ensure that the lamp does not create a health hazard due to UV exposure. The second,  $\eta$ , describes the UVA irradiance related to the electrical power and gives information on how effectively the lamp turns electrical energy into UV radiation. Among the above parameters, an attempt has been made in the present study to find out the type of lamp that gives the best balance between safety and energy efficiency. Illuminance was measured by a setup with a Luxmeter, and another system based on a UVA/B silicon detector measured the irradiance in the UVA region. Data from these experiments were analyzed, putting much focus on the calculation and understanding of the uncertainty model. Such a model takes into consideration all the variables that could affect the accuracy of the measurements or overall results. The results indicate that hydrogen discharge lamps are far less dangerous compared to water vapor, helium, and mercury vapors. This study is concluded by proposing the use of hydrogen discharge lamps at a distance of at least 15 cm. Water vapour and helium discharge lamps should, therefore, be used only at a distance of 25 cm, and mercury vapour lamps should be operated over distances greater than 25 cm for the protection from Mercury in physics laboratories of all educational facilities during this spectrometer experiment. These recommendations of distances are, therefore, developed to minimize exposure in university and school students and instructors.

#### Keywords:

Illumination Levels, UVA Radiation, Irradiance, Human Health, water vapor, helium, hydrogen, and mercury vapor discharge lamps, Uncertainties.

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#### I. Introduction

The principle of operation of gas discharge lamps is based on passing an electric current through the gas. In this connection, such lamps usually contain one noble gas or their mixture: argon, neon, krypton, and xenon as the operating substance. Other lamps contain additional substances-mercury, sodium, or metal halides-that evaporate during the time the lamp operates and join the mixture of gases. When the electric current is turned on, the gas is ionized, meaning that some of the electrons are stripped from the atoms. This creates a plasma, which is a mixture of free electrons and positive ions. The electrons are attracted to the anode, while the positive ions are attracted to the cathode. As the electrons travel towards the anode, they collide with gas atoms and excite them. The excited atoms then emit photons of light as they return to their ground state. he color of light emitted by gas discharge lamps is determined not only by the type of gas used but also by the gas pressure

inside the lamp. Different gases, when ionized, produce different wavelengths of light, which appear as distinct colors. For instance, hydrogen discharge lamps emit a pinkish-red glow, while helium lamps produce a pale yellow to white light. Mercury vapor lamps, on the other hand, give off a bluish-white light, and certain configurations can also produce ultraviolet (UV) radiation. The pressure of the gas within the lamp also plays a significant role in determining the color and intensity of the emitted light. At lower pressures, the light tends to be dimmer and softer, whereas at higher pressures, the emitted light becomes more intense and may shift in color due to increased ionization of the gas particles. [1,2]. Gas discharge lamps are more efficient than incandescent lamps, but they are more expensive to make and more complex to operate. Most gas discharge lamps have negative resistance, which means that the resistance of the plasma decreases as the current flow increases. This can lead to a runaway current, which can damage the lamp or even cause a fire. To prevent this, gas discharge lamps usually require a ballast, which is called a ballast. A few gas discharge lamps also take a little time noticeably to achieve full brightness. However, despite these drawbacks, gas discharge lamps are replacing incandescent lamps in many applications because they are much more efficient. [3]. Different gases emit different colors of light, depending on their atomic structure. This is called the emission spectrum of a gas. CIE-the International Commission on Illumination-has designed the color rendering index, or CRI, a measure of how well a light source can reproduce the colors of an object. Many gas discharge lamps have a fairly low CRI, and the colors of objects they illuminate tend to look a little different compared with sunlight or other light sources with high CRI [4].

Gas discharge lamps are widely used in physics laboratories for various purposes involving light generation, including spectrometry, spectroscopy, and laser pumping. They are also used in a wide range of lighting applications, from street lights to indoor lighting. Due to their unique appearance, gas discharge lamps are often used by quacks and con artists to create illusions. However, this does not mean that gas discharge lamps are not useful or important. In fact, they are an essential part of many modern technologies. [5]. The gas discharge lamp consists of a tube of two metal electrodes-an anode and a cathode-with gas inside it. The principle of operation consists of the application of voltage to the electrodes for the creation of a breakdown of gas into electrons and positive ions, hence creating plasma emitting light. The color can be varied depending on the type of gas used. It works on the principle of ionizing the gas into a sea of electrons colliding with the gas atoms to maintain a plasma that emits light. They produce white, red, blue, and even ultraviolet colors. Such lamps have applications on streets, in commercials, and in industries. [6]. Helium discharge lamp produces pale yellow color and Mercury vapor lamp produce blue light [7]. Light is all around us and it affects our health in many ways. The type of light source we use and the amount of UV radiation it emits can have a big impact on our eyes and our overall health. For example, too much exposure to UV radiation can cause sunburn, premature skin aging, and skin cancer. It can also damage our eyes and increase the risk of cataracts and macular degeneration. On the other hand, exposure to bright light can help to regulate our circadian rhythms and improve our mood and energy levels. It can also help to improve our vision and cognitive function. When choosing light sources for our homes and workplaces, it is important to consider the spectrum of light they emit and the amount of UV radiation they produce. We should also try to get enough exposure to bright light during the day, especially in the morning. [8]. All gas discharge lamps emit some UV radiation, which is the most harmful type of radiation. UV radiation can damage valuable objects and cause health problems for people. Therefore, it is important to choose the right type of lighting for different situations. For example, if you are lighting an area where important or valuable objects are kept, you should choose a type of lighting that emits very little or no UV radiation. You should also choose a type of lighting that provides the right level of illumination for the activities that will be taking place in the area. For example, if you are lighting a workspace, you will need a different type of lighting than if you are lighting a museum display. By understanding the basics of UV radiation and illumination levels, you can choose the right type of lighting for any situation [9]. Ultraviolet radiation is a form of nonionizing radiation since it does not even have enough energy to ionize atoms. Objects can be heated and produce UV radiation, such as the sun, or UV can be produced by passing electrical current through gases which produce UV light. There are three categories of UV light based on wavelength: UVA (315-400 nm), UVB (280-315 nm), and UVC (100-280 nm). UVC radiation possesses the most significant health risks, which cause sunburn, skin cancer, damage to the eyes, and weakening of the body's immune system, making a person easily acquire diseases. [10-12].

The relation of the intensity of the tested lamp and the amount of light it produces - the illuminance - is expressed by the following equation:

$$E = \frac{I\cos\theta}{d^2} \tag{1}$$

where

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E: illuminance.

I: intensity of lamps' tested.

d : distance from the surface of the detector to the tested lamp.

 $\Theta$ : angle between the direction of emission and the normal of the receiving surface [13].

Spectral irradiance in the portion of ultraviolet radiation in class A is basically defined as the power of electromagnetic radiation divided by area in ( $W/m^2/nm$ ) hence.

$$I_{\lambda}(\lambda) = \int_{\lambda_1}^{\lambda_2} I_i(\lambda) d\lambda$$
<sup>(2)</sup>

where,

 $I_{\lambda}(\lambda)$  : spectral irradiance in  $(W/m^2/nm)$ .

 $I_i(\lambda)$ : intensity.

The spectral power distribution (SPD) of a light source tells us how much power is emitted at each wavelength of light. It is a measure of the light source's spectrum, which is the range of wavelengths of light that it emits. The SPD is important for understanding how a light source will be perceived by humans and how it can be used for different applications [14].

The following formula will be useful in determining and calculating ultraviolet radiation in class A [10]:

$$\eta = \frac{\int_{\lambda_1}^{\lambda_2} E_{irr}(\lambda) d\lambda}{P}$$
(3)

Where,

 $E_{irr}(\lambda)$ : ultraviolet irradiance.

P: electrical power of lamp.

Identification of the safe parameter, K, will then be required in order to make a better comparative study between two different artificial light sources.

$$K = \frac{\int_{\lambda_1}^{\lambda_2} E_{irr}(\lambda) d\lambda}{k_m \int_{400nm}^{800nm} E_{irr}(\lambda) d\lambda V(\lambda) d\lambda}$$
(4)

 $E_{irr}(\lambda)$ : spectral distribution of radiant flux W/nm $V(\lambda)$ : CIE response curve.

 $k_m$ : photometric constant =  $\frac{683 lm/W}{W}$ 

This parameter can help us choose an artificial light source that emits less UV radiation. The equation above can be used to calculate the safe parameter, which depends on how far away the light source is from the area where people will be exposed to the light. The higher the safe parameter, the more UV radiation people will be exposed to. It is important to choose a light source with a low safe parameter for applications where people will be close to the light source, such as in a workspace. [10]

$$K = \frac{\int_{\lambda_1}^{\lambda_2} I_{\lambda}(\lambda) d\lambda}{k_m \int_{380nm}^{780nm} I_{\lambda}(\lambda) d\lambda V(\lambda) d\lambda}$$
(5)

This work has assessed the relations between UV and illuminance emissions from four kinds of gas discharge lamps-water vapor, helium, hydrogen, and mercury vapor-through data comparison obtained by a series of precision measurements. In this paper, interest is in learning how the various gas discharge lamps emit ultraviolet (UV) radiation related to their visible light output quantified by illuminance. For each of these lamp types, detailed measurements of illuminance and UVA irradiance were done under controlled conditions. Illuminance is, by definition, the amount of visible light reaching the human eye. It was measured using a Luxmeter, while the UVA irradiance was measured by means of a silicon detector designed for the UVA region of the spectrum. These two parameters were fundamental in determining the ratio of visible light and UV radiation, which was one of the main issues related to the setting of the safety and efficiency of the lamps. [15,16].

#### II. Experimental Method:

The gas discharge lamps (spectrum tubes) manufactured by Electro-Technic Products. Inc. are specifically designed using high-quality research-grade gases and vapors to produce bright, well-defined spectral lines, as illustrated in Figure 1. These lamps are engineered to deliver optimal intensity and sharp line resolution, making them ideal for use in student-grade spectrometers equipped with diffraction gratings of around 200 lines/mm (5000 lines/inch). The gas pressure inside the spectrum tubes is carefully regulated to ensure the best possible brightness and clarity of the spectral lines. However, the ideal pressure for producing high-quality spectral lines does not always align with the pressure that ensures maximum operational life. In some cases, particularly with gases like helium used in cold cathode display signs, the tubes can operate continuously with minimal degradation in the quality of the spectral lines. On the other hand, gases such as hydrogen and water vapor require more careful processing to maintain both spectral clarity and extended tube life. Electro-Technic's Model SP-200 Spectrum Tube Power Supply is specifically designed to energize these spectrum tubes, ensuring stable and consistent power for optimal performance. To further extend the lifespan of the tubes, the manufacturer uses pure nickel electrodes and takes meticulous care in the processing stages. This attention to detail, along with the use of the best research-grade gases, helps to enhance the service life and maintain the high-quality spectral output that these tubes are known for. This makes them valuable tools in educational and research settings where precise and reliable spectral analysis is required.



Figure 1. Four types of gas discharge lamps: water vapor, helium, hydrogen, and mercury vapor.

Wavelength	Color
420 nm	Violet
440 nm	Violet
490 nm	Blue
670 nm	Red

Table 1. Emission Spectra of Hydrogen discharge lamps

wavelength	Color
400 nm	Violet
450 nm	Blue
455 nm	Blue
480 nm	Blue
500 nm	Green
510 nm	Green
585 nm	Yellow
670 nm	Red

Table 2. Emission Spectra of Helium discharge lan	nps
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Wavelength	Color
430 nm	Violet
440 nm	Violet
490 nm	Blue
520 nm	Green
540 nm	Green
550 nm	Green
560 nm	Green
605 nm	Red
610 nm	Red
665 nm	Red

Table 3. Emission Spectra of Water Vapor discharge lamps

Wavelength	Color
450 nm	Violet
460 nm	Violet
500 nm	Green
505 nm	Green
560 nm	Green
590 nm	Yellow
610 nm	Red
625 nm	Red
660 nm	Red
680 nm	Red
720 nm	Red
730 nm	Red

Table 4. Emission Spectra of Mercury Vapor discharge lamps.

This study compared the ultraviolet (UV) irradiance and illuminance of four different gas discharge lamps: water vapor, helium, hydrogen, and mercury vapor. The goal of the study was to evaluate the performance of the different lamps and to estimate the uncertainty of the measurements. [10,17,18]. The measurements for gas discharge lamps were made in a vertical geometry for comparable and consistent results of lamp types. Measurement for the above type of lamp determined several critical parameters for each type of lamp, including ultraviolet irradiance, the ratio of UVA irradiance to electrical power  $\eta$ , and the ratio of UVA power to luminous flux, K. These parameters were tested in various ranges so as to find out the performance and safety of the lamps under question. The tests were conducted in an air-conditioned room. The black box setup produced minimal disturbance due to outside lighting sources, thus enabling a more accurate measurement. The setup followed all the guidelines given by the International Commission on Non-Ionizing Radiation Protection, which gave the necessary safe exposure limits for UV. The surroundings in the black box were such that the light emissions from the lamps were isolated and correctly measured, be it visible or ultraviolet light. Moreover, the temperature within the testing surroundings was maintained strictly at  $(25 \pm 2)^{\circ}C$  [19, 20].

The Illuminance for each of the gas discharge lamps was measured through the use of a special light meter known as the Lux meter TM-201 Lux. This exact tool was mounted on a mobile stage, easily maneuverable and positionable at the same height as the artificial gas discharge lamps set up on the optical bench, as shown in Figure 2. The purpose was to ensure the proper and identical illuminance readings in all types of lamps, for which many measurements were carried out reliably on each type of lamp. Readings were taken at a number of distances in order for the full illuminance range to be covered for each lamp. After collection of the data, the various measurements were averaged through in order to capture more accurately the performance of each lamp. This helps to level off any anomalies or fluctuations in readings that might occur during the measurement process. The uncertainties of the light measurements were computed. This includes considering what could have gone wrong, like variables in the positioning of the light meter, the surrounding environment, and even the limitations of the Luxmeter device itself.

The photometric bench employed in this study was equipped with a Sper Scientific UVA/B Light Meter (Model 850009C), which had undergone calibration at the National Institute of Standards and Technology (NIST) in the USA. This calibration ensured the accuracy and reliability of the UVA measurements, making it a suitable choice for evaluating the ultraviolet emissions from the four types of gas discharge lamps under investigation. The UVA detector was mounted on a translation stage, allowing for precise positioning at the same height as the light sources on the optical bench, as illustrated in Figure 3. This alignment was critical for obtaining consistent and accurate irradiance measurements, as it minimized potential discrepancies caused by varying distances between the light source and the detector. Prior to taking measurements, each lamp was allowed to warm up for 15 minutes. This warm-up period ensured that the lamps reached their optimal operating conditions, stabilizing their output and providing more reliable data. During the measurement process, readings were taken multiple times for each lamp to account for any fluctuations in the output. After collecting all the data, the individual measurements were averaged to obtain a comprehensive representation of the UVA irradiance for each lamp type. The uncertainty associated with these measurements was also calculated. This assessment involved identifying and quantifying potential sources of error, such as variations in lamp output, positioning of the UVA detector, and environmental influences.



Figure 2. Illustrates a setup diagram for the measurement of illuminance of water vapor, helium, hydrogen, and mercury vapor filled four different gas discharge lamps.



Figure 3. Illustrates a set up diagram for measuring UVA irradiance for four types of gas discharge lamps: water vapor, helium, hydrogen, and mercury vapor.

#### III. Results and Discussions

Illuminance and UVA irradiance at distances of helium and mercury vapor discharge lamps were measured. Special attention was devoted to the 5 cm distance, which was treated as the closest possible exposure in physics laboratories for both students and instructors, especially during spectrometer experiments. The detailed analysis was made for a 5-cm distance to assess UV exposure at short-range. Among these, the UOH-Helium and UOH-Mercury vapor lamps are studied, both designed to emit most of their energy in the visible region. Although it is a predominantly visible light lamp, the energy may also be partially emitted in the ultraviolet region. At closer

distances, like 5 cm, UV content became more relevant for safety analysis. In this study, only UVA irradiance measurements that fell in the range of 5 cm to 25 cm from the hydrogen lamp were considered, as negligible UVA was detected at 15 cm. Similarly, very negligible amounts of UVA and UVB were measured at 25 cm from the mercury vapor discharge lamp, which points out that UV exposure decreases significantly with increased distance from the light source. Fig. 4 compares the UVA irradiance of the helium and mercury vapour discharge lamps as a function of distance from 5 cm to 25 cm. Measurements for each lamp were measured using a Sper Scientific UVA/B Light Meter, Model 850009C, calibrated from the NIST, USA at intervals from the central vertical axis at. The results obtained indicate that there is a marked difference in the UVA irradiance levels, with mercury vapor discharge lamps always being higher in UVA values compared to water vapor, hydrogen, and helium discharge lamps. This comparison is important since it considers the distance concerning UV exposure that people may get from gas discharge lamps, particularly in academic and laboratory uses. The UVA irradiance for the mercury vapour discharge lamps was remarkably higher; thus, appropriate safety precautions by maintaining a safe distance or using protective barriers to limit UV exposure in practical experiments should be considered.

Figure 5 shows Helium against Mercury Vapor Discharge Lamps Illuminance Level Comparison for Varying Distances The illuminance levels were measured from 5 cm to 25 cm distant from the vertical middle axis of the lamps. A Luxmeter TM-201Lux was utilized in order to take highly accurate and consistent data of the measured illuminance levels in the range of 2-160 lux depending on the distance from the light source for all lamps. The results obtained showed that the helium discharge lamps produced higher illuminance values than those of mercury vapor, water vapor, and hydrogen discharge lamps. At closer distances, such as 5 cm for example, this helium lamp provided substantially more visible light; hence, it was a better source where brighter light is required. With the increase in distance, there was a natural decrease in the amount of illuminance for all lamps; however, helium maintained the edge over the others throughout the range of distances taken at any rate and thus demonstrated its superior ability to emit visible radiation compared to the others. This result shows that helium lamps would provide bright and visible illumination more efficiently and thus could be more suitable for laboratory experiments that require high light intensities and involve optical instruments. While mercury vapor lamps, on the other hand, emit a much greater amount of UV radiation, their rather lower illuminance values indicate that they would prove less effective as a primary light source where visible light is important. The data obtained emphasize the consideration of both illuminance and UV emissions in choosing gas discharge lamps for specific uses to meet safety and lighting performance.







# Figure 5. Comparison measurements of Illuminance levels (Lux) between four types of gas discharge lamps: water vapor, helium, hydrogen, and mercury vapor at different distances.

It would be more relevant to examine the UVA irradiance vis-à-vis electrical power consumption,  $\eta$ . Figure 6 presents a histogram that compares the absolute UVA irradiance levels per watt ( $\eta$ ) of the water vapor, helium, hydrogen, and mercury vapor types of gas discharge lamps that were measured for distances between 5 cm and 25 cm. A spread in values from 0 to  $0.06 m^{-2}$ .



# Figure 6. Comparison measurements of UVA absolute irradiance levels per to electrical power (ŋ) between four types of gas discharge lamps: water vapor, helium, hydrogen, and mercury vapor at different distances.

A more meaningful comparison is afforded by the UVA concentration to illuminance ratio (K) which is very useful for characterizing radiation from the lamps. Figure 7: Histogram compares the UVA concentration to illuminance ratio (K) obtained for water vapor, helium, hydrogen, and mercury vapor gas discharge lamps measured at 5 - 25 cm distance oscillate from 0 to 0.9  $\mu$ W/lm.



Figure 7. UVA absolute irradiance levels per illuminance values (K) for four types of gas discharge lamps: water vapor, helium, hydrogen, and mercury vapor at different distances.

According to occupational exposure limited (OEL), occupational UVB and UVA exposure should be limited to an effective irradiance of  $3\mu W/m^2$  and  $1.04166 W/m^2$  in an 8 hr period, respectively [21,22].

#### IV. Uncertainty analysis

When you measure something, there is always some uncertainty about the accuracy of your measurement. This is because there are many factors that can affect the measurement, such as the quality of the measuring instrument, the skill of the person making the measurement, and the environmental conditions in which the measurement is made. It is important to report the uncertainty of your measurement so that other people can understand how reliable your measurement is. There are two main types of uncertainty. Type A uncertainty is caused by random errors, such as the variation in the readings of a measuring instrument. Type A uncertainty can be reduced by taking multiple measurements and averaging the results. Type B uncertainty is caused by systematic errors, such as the calibration of a measuring instrument being slightly off. Type B uncertainty cannot be reduced by taking multiple measurements. To evaluate the uncertainty of a measurement, it is important to identify all of the sources of uncertainty and to estimate the contribution of each source to the overall uncertainty. There are a number of different methods for evaluating uncertainty, depending on the type of measurement being made. Once the uncertainty of a measurement has been evaluated, it can be reported along with the measurement result. This allows other people to understand how reliable the measurement is and to compare it to other measurements.

Evaluation of the uncertainty is done by the Guide to the expression of uncertainty in Measurement (GUM) method. This method is adopted and described in details by International Organization for

Standardization (ISO). The standard uncertainty  $u(x_i)$  to be associated with input quantity is the estimated standard deviation of the mean [23, 24]

$$u(x_i) = s(\bar{X}) = \left(\frac{1}{n(n-1)}\sum_{k=1}^n (X_{i,k} - \bar{X})^2\right)^{1/2}$$

The combined standard uncertainty  $u(x_i)$  is obtained by combining the individual standard uncertainties  $u_i$  these can be evaluated as Type A and Type B. That is,

$$u_c^2(y) = \sum_{i=1}^N \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i)$$
(7)

Uncertainty model used for the determination of the UVA irradiance  $E_{UVA}(\lambda)$  is [15]

$$E_{UVA}(\lambda) = E_S(\lambda) + \delta E_l + \delta E_r \tag{8}$$

where,

 $E_s(\lambda)$  = uncertainty due to reference spectral irradiance UVA standard radiometer (obtained from the calibration certificate).

 $\delta E_1$  = uncertainty due to distance effect on the irradiance measurements (calculated by using the inverse square law).

 $\delta E_r$  = uncertainty due to repeatability of the measurements (standard deviation of repeated 5 times).

When reporting the results of a measurement, it is important to include the uncertainty of the measurement. This tells us how precise the measurement is. The uncertainty budgets for the illuminance and irradiance measurements are shown in Tables 1 and 2, respectively. The expanded uncertainties are calculated with a confidence level of 95% (coverage factor k=2). Finally, the UVA irradiance and illuminance measurements are calculated.

Uncertainty Component	Relative Standard Uncertainty (%)
Illuminance responsivity calibration of	6
standard photometer	
Distance measurements	0.015
Repeatability	0.020
Relative Expanded Uncertainty (k=2)	12

# Table 5. Uncertainty budget of illuminance measurements for four types of gas discharge lamps: water vapor, helium, hydrogen, and mercury vapor.

Uncertainty Component	Relative Standard Uncertainty (%)
Irradiance responsivity calibration of	5.2
standard radiometer	
Distance measurements	0.016
Repeatability	0.024
Relative Expanded Uncertainty (k=2)	10.4

 Table 6. Uncertainty budget of UVA irradiance measurements for four types of gas discharge lamps:

 water vapor, helium, hydrogen, and mercury vapor.

#### V. Conclusion

Illuminance and UVA emissions of water vapor, helium, hydrogen, and mercury vapor gas discharge lamps were measured between 5-25 cm. In this work, the main interest was the unwanted UVA output of these lamps. The main parameters considered are ultraviolet irradiance, UVA, the ratio of UVA irradiance to electrical power,  $\eta$ , and the ratio of UVA power to luminous flux, K. These parameters were measured and tested to assess the performance of the four categories of lamps at various distances. These results showed that the mercury vapor discharge lamps had the highest values of UVA irradiance, hence stronger emitters of ultraviolet radiation compared to the rest of the lamps. Of these, hydrogen discharge lamps placed 15 cm away proved to be the safest, in that they had smaller values of  $\eta$ , which means they emitted less UVA radiation concerning

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(6)

electrical power consumed. Smaller  $\eta$  values for hydrogen lamps make them much safer for human exposure, especially in educational institutions. Additionally, an uncertainty model that considered all influences on the measurement was added. The calculated uncertainty in absolute UVA irradiance measurements was 10.4% and the uncertainty in illuminance measurements was 12% at a 95% confidence interval (k = 2), as described in Tables 5 and 6. Based on the findings, hydrogen discharge lamps are recommended at 15-cm, water vapor and helium at 25-cm, and mercury vapor lamps at over 25-cm distances to ensure safety, especially in physics laboratories when carried out in experiments such as spectrometers.

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