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RADIANCE MEASUREMENT – NOVEL SETUP AND SYSTEMATIC ERRORS OF COMMERCIAL SYSTEMS

Paper #L0602

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Abstract

Radiance is the quantity to express exposure and emission limits for incoherent broadband optical radiation to protect the retina, such as defined in the IEC 62471 series of standards. For a common setup, an aperture stop is located at an imaging lens and image irradiance (and therefore radiance) is averaged over a field stop, subtending an averaging angle of acceptance of for instance γ = 11 mrad. Commercial imaging radiance input optics are often called 'telescope'. We report on systematic errors of a radiance telescope for the case of sources with non-constant radiance profiles. The responsivity depends strongly on the location within the 11 mrad field of view. The calibration factor is an average, resulting in measured radiance values that are potentially a factor of 3 above the correct value, but that are also potentially too low. IEC 62471 also shows an alternative radiance measurement setup, where the field stop is placed at the source. Commercially this is often called 'field - of - view tube' or 'field - of - view attachment'. In case such a tube is used for an apparent source where the field stop cannot be placed at the source, for γ = 11 mrad we measured radiance values that are up to a factor of 10 too low. For γ = 1.7 mrad the factor is potentially as high as 400.

We also report on a radiance setup where the aperture stop is located at the focal plane of the imaging lens. The advantage is that for varying imaging distances (i.e. varying accommodation) the field stop diameter remains constant.

Introduction

Limits for optical broadband incoherent radiation to protect the retina are given in IEC 62471:2006 [1] in terms of radiance. The identical dosimetry concept is used in other standards and documents on the photobiological safety of lamps and products emitting broadband incoherent optical radiation: ICNIRP 2013 [2], IEC 62471-5 [3] and ANSI/IES RP-27 [4]. Associated additional standards and technical reports used in the lighting industry are IEC 62471-7 [5] and IEC TR 62778 [6] where for light sources, the assessment distance is generally given as 200 mm. For extended sources, also the laser limits to protect the retina can be expressed as radiance values, such as given in ICNIRP 2013 [7] and ANSI Z136.2-2022 [8].

The measurement requirements in these standards specify averaging angle of acceptances γ for the determination of radiance to be compared with the limits expressed as radiance. The angle of acceptance γ is a plane angle measured in mrad or rad, while the equivalent solid angle is measured in sr and can be referred as averaging field of view (averaging FOV).

It is a peculiarity of photobiological safety assessments that these averaging FOV are applied even for the case that the apparent source is smaller than the FOV, resulting in a much smaller averaged radiance than the actual physical radiance of the source. For the limits to protect against photochemically induced retinal injury (also referred to as blue light hazard) this is based on assumed eye movements, i.e. the averaging angle of acceptance reflects the extent of eye movements (for a discussion at a time when this concept was developed, see for instance [9]). However, an averaging angle of acceptance of 11 mrad is also defined for measurement of radiance to be compared against limits to protect against thermally induced retinal injury.

In this paper, we report on systematic errors of commercially available radiance input optics for spectroradiometers, as well as on a measurement setup where the aperture stop is located in the focal plane of the imaging lens, which results in a constant field stop diameter.

Details on radiance and photobiological safety limits are discussed in a free e-book to be published by Seibersdorf Laboratories Publishing in 2025 [10].

Systematic error: "telescope"

IEC 62471:2006 in figure 5.2 shows a setup to measure radiance, imaging a source with a lens onto the plane of the field stop. An aperture stop is located at the imaging lens, and the diameter of the circular field stop defines the averaging angle of acceptance γ. A detector, such as an integrating sphere as input optics for a spectrometer is located behind the field stop (Figure 1).

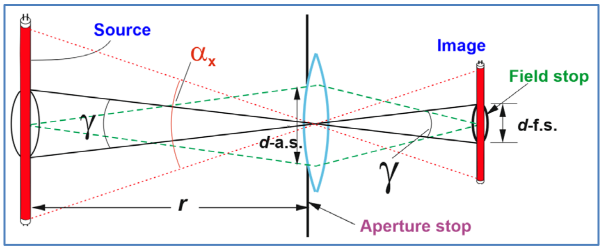

Figure 1. Imaging setup to measure radiance. Radiance is averaged over the angle subtended by the field stop.

A round robin test conducted in Austria showed that at least one type of commercially available radiance entrance optics (telescope), specifically designed and marketed as photobiological safety spectroradiometer component, apparently suffers from a varying responsivity across the FOV. We recently borrowed the telescope and performed additional measurements to characterise the responsivity more accurately, with equivalent results to the earlier measurements performed by a Photometry test house in Vienna. As shown in Figure 2, the telescope features an imaging lens and field stops (with varying diameters, on wheels). The focus, i.e. the source distance that is imaged onto the field stop, can be adjusted. Depending on the image distance, a particular field stop is chosen automatically to realise a certain averaging angle, such as 11 mrad. This part of the design is consistent with a classic imaging system as also shown in IEC 62471:2006. What is special is that the optical connection of the telescope with the spectrometer is made by a quartz fibre bundle and a lens is located between the field stop and the entrance plane of the fibre bundle.

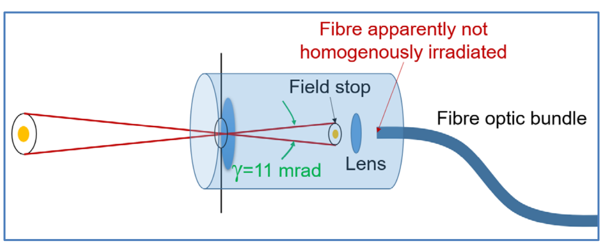

Figure 2. Greatly simplified concept of a commercial radiance telescope marketed as photobiological safety spectroradiometer input optics, which suffers from a systematic error for non-homogeneous radiance profiles.

As will be quantified below, it appears that the placement of the lens between field stop and fibre optic bundle leads to an unevenly irradiated fibre optic bundle, resulting in a variation of the responsivity across the field stop. Calibration is performed with a homogeneous spectral radiance source that is larger than the field of view. The diffuse emitter of the calibration source is imaged onto the field stop of the telescope. Because calibration is performed with a homogeneous calibration source (constant radiance across the diffuse emitter), the calibration factor is an average across the FOV. A homogeneous source of optical radiation that is larger than the FOV can be measured accurately. However, hotspots or inhomogeneities that are smaller than the FOV, or the entire source being smaller than the FOV, result in a systematic error: for a source or a hotspot that is in the centre of the averaging FOV the measured radiance value is significantly higher than the correctly measured radiance. Figure 3 shows the relative responsivity across the 11 mrad measurement angle of acceptance, determined by imaging a laser module (Kyocera LaserLight SMD) with a phosphor diffusor to result in a white broadband emission spectrum with a source emission extent of less than 0.5 mm. This source was located at 1 meter distance from the telescope, resulting in a source angular subtense of approximately 0.5 mrad. The laser module was translated horizontally and vertically, normal to the axis to the telescope. In Figure 3, the translation extent off the centre is given in mm, so that the FOV of 11 mrad is equivalent to a translation of ± 5.5 mm. For the measurements, the spectroradiometer was set to a wavelength of 524 nm.

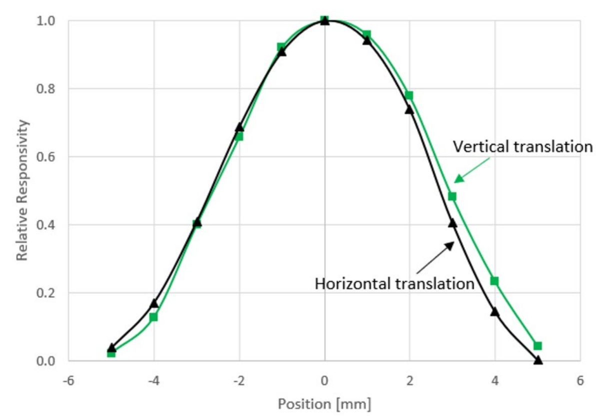

Figure 3. Example of a strongly varying responsivity across the FOV of a telescope radiance entrance optic, resulting in a significant systematic error for non-constant radiance sources.

For the round robin test, three different laboratories (two of them accredited test houses) in Austria compared the results for a descrete imaging radiance setup assembled with a lens and a field stop (γ = 11 mrad) placed on an integrating sphere. For a white LED emitter subtending an angle smaller than 11 mrad, the maximum difference was 6 %; for the Seibersdorf Laboratories accredited test house compared with the Photometry accredited test house in Vienna, the difference was less than 1 %. When the same LED was measured with the commercial telescope, the measured radiance was a factor of 1.63 higher than with the discrete setups, even though the measured LED was not significantly smaller than 11 mrad.

To complement the earlier round robin test and characterise the maximum systematic error, the laser module was measured at 1 meter distance both with the commercial telescope, as well as with a discrete setup consisting of a 300 mm focal length lens with a 7 mm aperture stop at the lens, and an integrating sphere with a field stop of 4.58 mm which for an imaging distance of 429 mm resulted in an averaging angle of acceptance equal to 10.7 mrad. The spectroradiometers were a Flame-S-XR1-ES as well as a Bentham DMC150V. Between the two spectroradiometers, for the discrete setup, the difference was less than 2 %, so that we report the values of the Bentham spectroradiometer below. The radiance measured was equal to 710 W m^{-2} sr^{-1} (determined without spectral weighting). The radiance determined with the commercial telescope, for a setting of the averaging angle of acceptance of 11 mrad, was equal to 2576 W m^{-2} sr^{-1}, a factor of 3.7 higher than measured with the discrete setup. The factor of 3.7 difference can be substantiated by integrating the relative responsivity shown in Figure 3, assigning the responsivity values to quarters of concentric rings with 1 mm (or 1 mrad) width, and weighting the responsivity with the area of the respective ring relative to the area of a 11 mm disc. The sum represents the average responsivity. It is found that the peak responsivity in the centre of the FOV is a factor of 3.61 higher than the average responsivity. This compares very well with the experimentally found factor of 3.7 for the radiance measured for a small source located in the centre of the FOV, compared to the correct value.

Measurements were also performed with a homogenous radiance source, i.e. a diffusor with constant radiance. The measurement distance was 200 mm. For the discrete imaging setup, a 150 mm focal length lens was used. The measured radiance equalled 72.5 kW m^{-2} sr^{-1}. The radiance measured with the commercial telescope equalled 74.4 kW m^{-2} sr^{-1}, a difference of 3 %. This confirmed that the telescope was properly calibrated, and the calibration factor represents an average value.

The case of averaging over 11 mrad for a source that subtends an angle of less than 1 mrad is rather extreme. For such a source it is actually not necessary to determine radiance. A source where the total profile fits within 11 mrad can be characterised with an irradiance measurement, with an open FOV, where the measured irradiance is compared against the small source photochemical retinal limit that is expressed in terms of irradiance (also the thermal radiance limit of IEC 62471:2006, for emission durations of 10 s and longer can be converted to an irradiance limit, since the averaging angle of acceptance equals 11 mrad). However, it cannot be excluded that a user of the telescope performs measurements with the telescope, not realising that the source is a small source, and an irradiance measurement would suffice. More importantly, the overall extent of the source could be larger than 11 mrad and might be an array, or feature some highly irregular radiance profile with significant hotspots, so that it would not qualify as small source for the irradiance measurement with an open FOV. While location of a hotspot in the centre of the FOV results in a measured value that is significantly too large (resulting potentially in an overcritical safety classification), it is possible that the source is a ring assembly that fits within the 11 mrad FOV. In this case, the responsivity of the commercial telescope is less than the average responsivity that is related to the calibration, so that the measured value would be lower than the correct value, with the possibility of under-classifying a product.

Since CIE S009 was included in the scope of our accreditation in 2002 (IEC 62471:2006 is a 1:1 copy of CIE S009), our test house has been using a discrete setup, which is simple to implement and is also flexible. By placing the field stop at the entrance opening of an integrating sphere, a constant responsivity across the field stop is achieved. It is somewhat of a challenge to understand how commercial telescopes can be so widely used by test houses world-wide while the varying responsivity has not been identified and generally communicated, given that it is mandatory for every accredited test house to validate measurement equipment before using it for testing. The usage of commercial telescopes (the term is used by at least two equipment manufacturers for photobiological safety test equipment) is so widespread that a “telescope” was listed as mandatory measuring equipment for radiance measurements in the IECEE equipment list of 2011 for IEC 62471:2006 testing [11]. We would like to note that we find the term “telescope” somewhat inappropriate for an imaging system to determine radiance, where the object may be as close as 200 mm. In an IECEE audit of our test house, we even had non-compliance problems when the auditor did not accept our discrete imaging setup to qualify as a “telescope” as listed in the IECEE equipment list at the time. Following our input, the IECEE equipment list was amended [12] to refer to “Telescope or optical imaging system with imaging lens, aperture stop, detector, and field stop for spectral radiance measurement with field of view (1.7 mrad, 11 mrad, 100 mrad)”.

We summarize and conclude that - unless a commercial radiance equipment is identified that measures with sufficient accuracy - it is prudent and quite straight-forward to assemble and validate a discrete imaging system to perform radiance measurements with the required averaging FOV. As such a system can be calibrated without the imaging lens, using a spectral irradiance calibration lamp, there is even no need for a radiance calibration source.

Also, for a discrete setup, the dependence of the field stop diameter on image distance can be avoided with the focal plane setup as presented further below. The commercial telescope that was characterised as described here deals with different focusing distances (i.e. different image distances) by having a relatively large number of field stops with varying diameters on computer controlled wheels, which accounts for an angle of acceptance of up to 11 mrad in an appropriate way.

Additionally to the potential issue of a strongly varying responsivity of the telescope within the defined FOV as described above, there is another issue for some of the telescopes on the market: either the focus setting is fixed to 200 mm or, for telescopes where the focus can be adjusted, the field stops are set to result in the correct averaging angle of acceptance, such as 11 mrad, only for the focus setting of 200 mm. In case the focus is set to a more distant optical source (which is very common, see the following section), the image distance is smaller, and the given field stop results in an averaging angle larger than 11 mrad, resulting in an erroneously small averaged radiance value for non-homogenous sources. There is the apparent misunderstanding by some radiometry equipment manufacturers that the problem can be avoided by using what is referred to in IEC 62471 as alternative radiance method. As is discussed in the following section, this is an option only for the case that the optical source is accessible and the field stop can be placed in contact with the source of optical radiation.

Systematic error: "alternative method"

IEC 62471:2006 in figure 5.3 shows a radiance measurement setup that was called "alternative method", adapted here as shown in Figure 4. It is based on placing the field stop with an angular subtense of γ at the source of optical radiation.

Some measurement equipment manufacturers who specifically offer photobiological safety measurement equipment refer to this as "field of view tube", "aperture tube", but also "field-of-view attachment" or "field of view limiting optic".

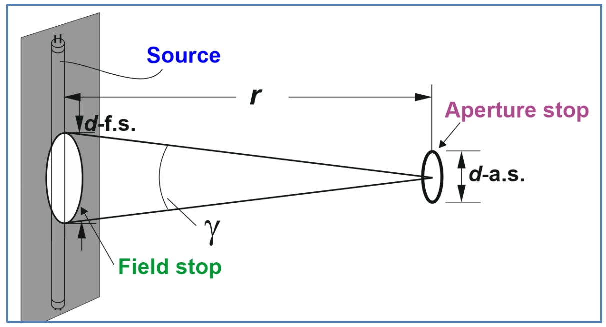

Figure 4. Schematic of a setup to measure radiance where the field stop is placed at the source of optical radiation, referred to as alternative method in IEC 62471:2006.

For example, a spectroradiometer manufacturer who uses a telescope (i.e. imaging setup) for averaging angle of acceptances up to 11 mrad supplies a FOV attachment for the irradiance input optics in order to achieve a 100 mrad field of view. This is basically a 200 mm long tube with a 20 mm field stop. Another spectroradiometer manufacturer, who has a telescope in the program where the field stops result in the correct γ only for an object (focus) distance of 200 mm, recommends using a field-of-view attachment for 1.7 mrad and 11 mrad FOV and in the respective quotation specifies a "200 mm working distance". This attachment fits onto an integrating sphere as input optics for measurement of spectral irradiance.

The so-called alternative radiance method is shown in Figure 4 (this term and the original figure were introduced by the first author of this paper for the development of CIE S009). The angle of acceptance γ is obtained by placing the circular field stop with diameter *d*-f.s. in contact with the source of optical radiation, at the measurement distance r relative to the aperture stop, so that $\gamma = d\text{-f.s.}/r$. A spectral irradiance measurement is performed by placing the detector (or input optics of the spectroradiometer) behind the aperture stop. In the following discussion we imply spectral radiance and spectral irradiance when referring to radiance and irradiance, respectively. Radiance is obtained by dividing the measured irradiance by the solid angle subtended by the field stop. It is vital to note that for the alternative radiance method, IEC 62471:2006 specifies "This set-up implies that the field stop can be placed sufficiently close to the apparent source to produce the required field of view." If the source of optical radiation is not accessible (which is very often the case), the alternative method yields erroneous results, as is shown below. From the information that is available from measurement equipment manufacturers it appears that often this significant limitation is either not appreciated, or at least it is apparently not generally communicated to the potential buyer and user of the measurement equipment.

Examples of products where the source of optical radiation is accessible to place the field stop in contact with the source, and the alternative method is an accurate and simple method, are diffusely emitting (or transmitting) sources, provided that there is no lens part of the product, and the diffuse emitter is not recessed in the housing. We have measured the radiance of a recessed source, i.e. a diffuse emitter located at different distances relative to the exit window of the product, both with the alternative method as well as with the imaging method. An example for the alternative method applied to a recessed source is shown in Figure 5. The measurement distance was 200 mm relative to the exit window. For the alternative method (which is not appropriate to apply for such a source), the field stop was located at the exit window.

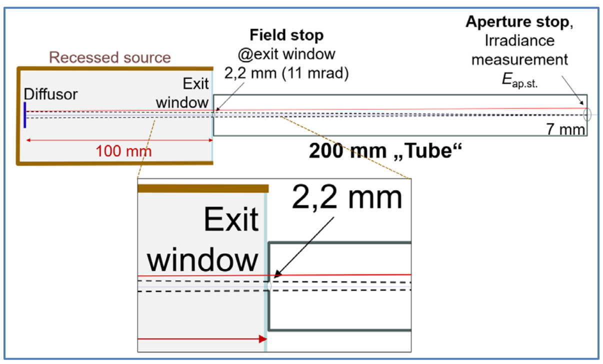

Figure 5. Schematic of the alternative radiance method, erroneously applied for the case that the source is not accessible. The drawing is made to scale.

That the field stop is not located at the diffusor has two effects which to a degree counteract each other: on the one hand, the solid angle from which the 7 mm aperture stop receives radiation (i.e. the actual field of view) is somewhat larger than the 11 mrad angle of acceptance defined by the field stop, because some rays outside of the 11 mrad angle of acceptance are incident on the 7 mm aperture stop. This leads to somewhat higher measured irradiance values compared to a well-defined FOV that is achieved by a field stop either at the source or in the image plane of an imaging radiance setup. On the other hand, the 2.2 mm field stop at the exit window blocks rays that for the imaging method would be included in the measurement, i.e. would pass through the aperture stop and are within the field of view of 11 mrad as defined by the field stop in the image plane. One example of such a ray is shown in the figure in red color, emanating from the top of the 11 mrad FOV at the diffusor and being incident on the top edge of the 7 mm aperture stop. The enlarged insert shows that this red ray is blocked by the 2.2 mm field stop. We note that the 2.2 mm field stop is significantly smaller than the 7 mm aperture stop. In this case, the effect of reducing the irradiance at the aperture stop by blocking rays that the imaging setup would include is more pronounced than the effect of the somewhat larger FOV increasing the irradiance at the aperture stop. This was shown by measurements performed with both the alternative and the imaging method, for varying depth of recess of the diffused source. For the case of an accessible source, i.e. the diffusor placed at the exit window, the difference of the measured radiance values for the alternative and the imaging method was only 3.3 %, confirming the equivalence and validity of the alternative method if the source is accessible. For increasing distance of the diffusor to the exit window, the (erroneous) radiance determined with the alternative method steadily decreased. For instance, for 12 cm recession distance, the radiance for the alternative method was a factor of 1.1 smaller than for the imaging method. For increasing recession distance, the radiance determined with the imaging method remained constant (within the measurement uncertainty), consistent with the radiometric rules associated to non-averaged radiance. We note that for this type of product, where the source is not accessible but does not feature a lens, the error associated to the alternative method is not great, except for large recess distances: for the case of a distance between diffusor and exit window of 70 cm, the error was a factor of 2.2.

The error is significantly larger for products with a projection (or magnifying) lens. Many products feature some type of lens, including simple and ubiquitous LEDs, such as shown in Figure 6, and more recent higher power models shown in Figure 7. The lens produces a magnified virtual image of the source, which in photobiological safety is referred to as “apparent source”.

Figure 6. For this classic type of LED, the half-spherical top of the housing constitutes a lens.

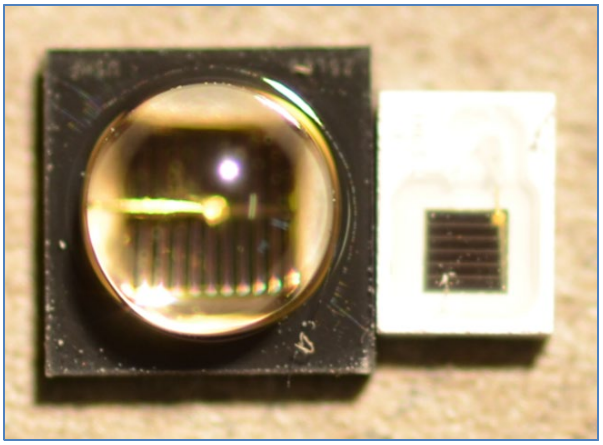

Figure 7. Photograph of two types of LEDs, one with and one without a lens as part of the product. The emitting die in both cases has dimensions of 1 mm × 1 mm.

The ray diagram of such a source, imaged by an eye or an imaging radiance measurement setup is shown in Figure 8.

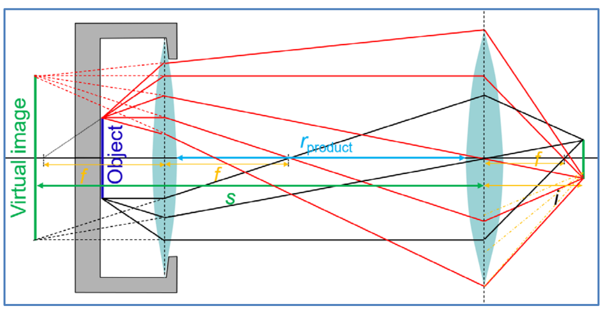

Figure 8. A lens as part of the product results in a virtual enlarged image when one 'looks into' the product, such as with the eye or with an imaging radiance measurement setup, shown on the right-hand side of the figure.

The location of the virtual image, i.e. the 'apparent source' is behind the product. This apparent source is located at the optical object distance s which is imaged by the eye, or the radiance imaging setup, to form a sharp image in the image plane (image distance i). For the eye, the distance s is the accommodation distance. Note that the product distance $r_{product}$ for IEC 62471:2006 would, for instance, be 200 mm for non-GLS lamps. It is clear that the apparent source in this case is not accessible, and for the alternative method (if erroneously applied) the closest the field stop can be placed is the lens of the product. The most common case for a projected source is that the emitting element is placed in the focal plane of the projection lens. This produces the smallest divergence of the emitted beam and is the principle of, for instance, a lighthouse, but also of many other luminaires and light sources. The location of the apparent source in this case is at infinity behind the product. For distances close to the product (within the "flash distance"), the angular subtense of the apparent source is equal to the extent of the source divided by the focal length of the projection lens (for details see for instance [10]).

To characterize the difference between the imaging radiance method and the (incorrectly applied) alternative radiance method, we have placed the LaserLight module at the focal plane of a number of projection lenses. The angle subtended by the field stop for all setups was 11 mrad and the measurement distance was 200 mm. For the case of projection lens focal lengths of 70 mm and 150 mm, the LaserLight source with an approximate emission dimension of 0.33 mm subtended an angle less than 11 mrad. For the imaging method, the averaged radiance was equal to 285.0 kW m^{-2} sr^{-1} for the 70 mm focal length lens and equal to 59.3 kW m^{-2} sr^{-1} for the 150 mm focal length lens. Due to the apparent source angular subtense being considerably less than 11 mrad, the respective sources qualify as small source. Therefore, additionally, an irradiance measurement was performed with an unrestricted 'open' FOV, i.e. no field stop at the projection lens). Dividing this irradiance by the solid angle that is associated to the averaging angle of 11 mrad resulted in an averaged radiance value that was a factor of less than 1 % larger than the radiance value obtained with the imaging setup (the measurement was corrected for reflection losses of the imaging lens). However, for the alternative method, placing the 2.2 mm field stop at the projection lens and performing the irradiance measurement at 200 mm distance, the obtained radiance for the $f = 70$ mm projection lens was a factor of 10.9 smaller than the correct average radiance measured with the imaging setup. For the 150 mm focal length lens the difference (i.e. the error) was a factor of 10.1. This error was basically the same as the factor between the irradiance measured at 200 mm distance with an open FOV vs. a field stop of 2.2 mm placed at the projection lens. This factor can be explained considering that the emitted beam of light is relatively well collimated and the 2.2 mm field stop reduces the power that passes through the 7 mm aperture stop by a factor of $7^2/2.2^2 = 10.1$.

It is noted that placing the field stop at the projection lens is not necessary in this case of the angular subtense of the apparent source being smaller than 11 mrad, where the small source blue light hazard limit can be compared against the irradiance measurement performed with an open FOV, resulting in a correct and accurate assessment. However, in case of lack of information of the user of commercial “FOV attachments” it could well be that alternative method is erroneously used even for the small-source situation, resulting in a rather extreme error of, for γ = 11 mrad, a factor of 10 of the measured radiance being too low. The factor for γ = 1.7 mrad is even more extreme: for a measurement distance (i.e. FOV attachment length) of 200 mm, the field stop diameter equals 0.34 mm. Since projected sources with angular substances of less than 11 mrad are associated to beam divergences of less then 11 mrad, the approximate reduction of the power that passes through a 7 mm aperture stop when applying the field stop equals $7^2/0.34^2 = 423$.

Additionally to the projections which resulted in small apparent source, a projection lens with a focal length of 20 mm was used to realize an apparent source angular subtense (50 % source radiance points) of 17.1 mrad, so that this assembly does not qualify as small source when the averaging angle of acceptance is 11 mrad. The radiance measured with the alternative method was still a value of 3.3 smaller than the correct value measured with an imaging setup. This highlights the potential drastic error that can be realized if the alternative method, i.e. a commercial “tube” or “FOV attachment” is applied for the case that the apparent source is not accessible, particularly if lenses are part of the product. This is the case for the majority of sources of optical radiation, both in terms of light sources such as LEDs as well as for luminaires.

Focal plane set-up

For the imaging setup shown above in Figure 1 (Figure 5.2 in IEC 62471:2006), the aperture stop is located at the imaging lens (usually, the distance between the aperture stop and the respective principle plane of the lens can be neglected). For different accommodation distances (i.e. different object distances), the image distance varies and consequently, a certain averaging angle of acceptance (such as 11 mrad) is achieved only if the diameter of the field stop is adjusted accordingly. This can be avoided by what we call the focal plane setup, or short FP setup. There is no established name for this setup and it is only mentioned in one sentence in the paragraph preceding figure B.6 in IEC TR 62471-4:2022 [13], without a discussion: “In the situation that the aperture stop is located at the focal point, the acceptance angle of the measurement and the aperture solid angle of the detector will remain constant.”. We studied this concept and experimentally characterized it as fully valid. It is valuable for the case of varying accommodation distances, because the diameter of the field stop remains constant. The method is discussed in detail in our free e-book [10], with the main figures reproduced here.

The measurement distance to the product (such as 200 mm) is determined from the location of the aperture stop, as is the case for the “classic” imaging setup. Figure 9 compares the FP setup with the “classic” imaging setup. The object distance is s, the image distance, i.e. the location of the field stop, is i.

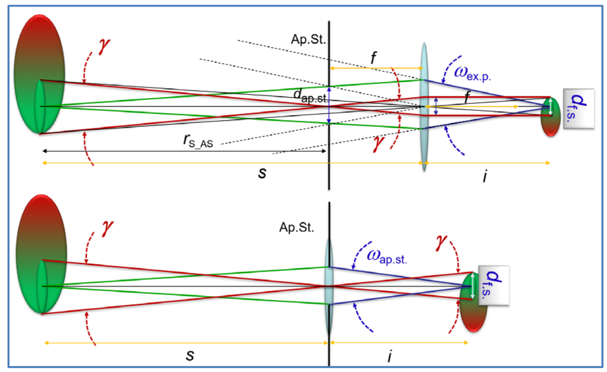

Figure 9. For the “focal plane” setup shown on the top, the aperture stop is located in the focal plane of the imaging lens. The lower part of the figure shows the classic imaging setup for the same measurement distance and averaging angle of acceptance.

For a given focal length f and averaging angle of acceptance γ, the diameter of the field stop $d_{\text{f.s.}}$ is given by $d_{\text{f.s.}} = \gamma \cdot f$. This field stop diameter is constant and independent of the accommodation and image distance (Figure 10), which often is a significant advantage over setups where the aperture stop is located at other positions.

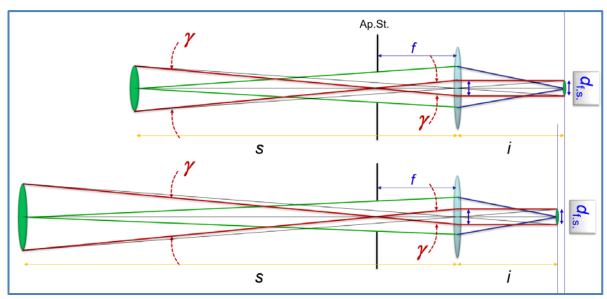

Figure 10. Example of two object and image distances for the FP setup, where a given averaging angle of acceptance is achieved by a constant field stop diameter.

Summary

We summarize the main topics of this paper as follows.

The variation of the responsivity of a commercial imaging radiance device for spectroradiometers, marketed for photobiological safety testing, was characterized. This type of radiance input optics is frequently referred to as “telescope”. It was found that the responsivity in the center of the 11 mrad FOV is a factor of more than 3 higher than the responsivity averaged over the FOV (which is the basis of the calibration process). At the edges of the FOV, the responsivity is considerably lower than the average. For sources that are smaller than the FOV or have hotspots, or sources that are irregular such as arrays, the resulting measured radiance can be either significantly too large when the hotspot is in the center of the FOV, or significantly too small when source elements are located at the edge of the FOV.

While some telescopes feature a relatively large number of field stops in order to properly realize a given FOV for varying image distances, others feature the correct FOV, such as 11 mrad, only for the focus distance of 200 mm. When projected sources with distant apparent sources are properly focused, the resulting FOV becomes too large and the averaged radiance, for hotspots, too small.

Many equipment manufacturers offer a setup that realizes the “alternative radiance method” as given in IEC 62471:2006. These are for instance referred to as aperture tubes, or FOV-attachments. It is, however, apparently not appreciated, and often not properly communicated, that accurate radiance measurements are possible only if the field stop can be placed in contact with the optical location of the source, i.e. with the ”apparent source”. This is not possible if the source is recessed or if there is a lens part of the product. In such cases, only imaging setups (with constant responsivity across the field stop) can accurately determine radiance. We have shown that using the alternative radiance method and placing the field stop at the product’s projection lens, can, in the extreme, for an 11 mrad FOV result in radiance measurements that are a factor of 10 below the correct value, and for an 1.7 mrad FOV a factor of more than 400.

We have also briefly discussed an imaging radiance setup where the aperture stop is located in the focal plane of the imaging lens. We termed this setup the focal plane setup, or FP setup. It has the advantage of constant field stop diameters while varying the accommodation and therefore image distance. Details are discussed in the upcoming free e-book on optical broadband incoherent safety measurements and limits, to be published later on in the year.

References

All our ILSC proceeding papers can be downloaded from our website, with permission from the LIA.

https://laser-led-lamp-safety.seibersdorf-laboratories.at/home

[1] IEC 62471 (2006) Photobiological safety of lamps and lamp systems, IEC, Geneva.

[2] ICNIRP (2013) ICNIRP Guidelines on limits of exposure to incoherent visible and infrared radiation, Health Physics 105, 74-91.

[3] IEC 62471-5 (2015) Photobiological safety of lamps and lamp systems – Part 5 Image projectors, IEC, Geneva.

[4] ANSI/IES RP-27-20 (2020) Photobiological safety of lighting systems.

[5] IEC 62471-7 (2023) Photobiological safety of lamps and lamp systems – Part 7 Light sources and luminaires primarily emitting visible radiation, IEC, Geneva.

[6] IEC TR 62778 (2014) Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires, IEC, Geneva.

[7] ICNIRP (2013) ICNIRP Guidelines on limits of exposure to laser radiation of wavelengths between 180 nm and 1000 µm, Health Physics 105, 271 - 295.

[8] ANSI Z136.1 (2022) Safe Use of Lasers, Laser Institute of America, Orlando, USA.

[9] Schulmeister K. (2001) Concepts in dosimetry related to laser safety and optical radiation hazard evaluation, SPIE Vol. 4246, Proceedings of Laser and Noncoherent Light Ocular Effects: Epidemiology, Prevention, and Treatment III, pp 104-116.

[10] Schulmeister K. (2025) Optical Radiation - Radiometry and Safety Limits, Seibersdorf Laboratories Publishing, Seibersdorf, to be published 2025.

[11] IECEE (2011) Testing and measuring equipment IEC 62471:2006.

[12] IECEE (2025) Testing and measuring equipment IEC 62471:2006. https://www.iecee.org/certification/iec-standards/iec-624712006

[13] IEC TR 62471-4 (2022) Photobiological safety of lamps and lamp systems – Part 4: Measuring methods, IEC, Geneva.