ILSC ® 2013 Conference Proceedings

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Reference information for this proceedings paper

Title: *The radiance of the sun, A 1 mW Laser Pointer and a phosphor emitter*

Author: *Schulmeister K*

Proceeding of the International Laser Safety Conference, March 18-21 2013, Orlando, Florida
Page 371-378

Published by the Laser Institute of America, 2013
Orlando, Florida, USA www.lia.org

THE RADIANCE OF THE SUN, A 1 mW LASER POINTER AND A PHOSPHOR EMITTER

Paper #P107

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Abstract

The upcoming new edition of IEC 60825-1 allows to treat the light output which replaces traditional light sources by laser powered emissions, and that do not exceed a certain radiance, to be assessed under IEC 62471 (the lamp safety standard series). Since lamps (at distances where they can be hazardous) are all extended sources, the exposure and emission limits for the retina are specified in terms of radiance. Radiance has very attractive properties for extended sources, but is not intended to be applied to characterize point sources.

During the discussion in the standard committee TC76, the level of radiance of a 1 mW laser pointer (which is known to be safe) was discussed. However, the calculation of radiance for safety purposes needs to consider a proper choice of source size and averaging due to the small beam diameter. The concept of radiance is discussed as applied to the sun, a 1 mW laser pointer and a laser illuminated phosphor, as well as the current and new exposure limit for broadband radiation.

Introduction

The international laser safety standard IEC 60825-1 [1] is currently revised to be published as Edition 3 at the end of 2013 [2].

A significant amendment was prompted by blue laser sources being used to produce white light by adding a phosphor (the same principle used to produce white LEDs based on blue LED chip) as well as laser radiation being used in cinema projectors. The emitted optical radiation of such systems is also either broadband (phosphor) or at least multi-wavelength, as well as either diffuse (phosphor) or extended sources (projectors). However, because the radiation is produced by a laser beam, the product falls under IEC 60825-1 (in the same way as a product, where *no* laser beam is emitted, such as a DVD player or burner, falls in the scope of IEC 60825-1 and needs to be classified according to IEC 60825-1).

The problem was dealt with by WG1 of IEC TC 76 by allowing (according to the current CDV of the third edition of IEC 60825-1) that the emitted light is treated under IEC 62471 [3] when the radiance of the product is below (1 $MW{\cdot}m^{-2}{\cdot}sr^{-1}$)/$\alpha$, where α is the angular subtense of the apparent source specified in radian (limited to values between 0.005 rad and 0.1 rad). The requirement is also that these products need to be designed to function as conventional light sources. If there is no "normal" laser radiation accessible, these products will be classified as Class 1, where the optical radiation that functions as light source is "neglected"; this optical radiation will be assessed under the IEC 62471 series of standards (a specific safety standard for this kind of products is under development).

For a source of, for instance, 5 mrad angular subtense, the abovementioned maximum radiance, for which IEC 62471 can be applied, equals 200 MW m^{-2} sr^{-1} (unweighted). It is noted that the updated broadband incoherent radiation exposure limit for retinal thermal injury for 0.25 exposure duration (draft ICNIRP [4], draft IEC 62471 [5]) for a 5 mrad source equals 5.7 MW m^{-2} sr^{-1}. The value of 200 MW m^{-2} sr^{-1} is a factor of 35 higher than the broadband exposure limit for 0.25 s, which is also the AEL for RG3 under the draft 2nd edition of IEC 62471. This ratio of 35 remains the same also for larger sources, since the dependence in both is 1/α. This clearly shows that the value given in IEC 60825-1 of (1 $MW{\cdot}m^{-2}{\cdot}sr^{-1}$)/$\alpha$, (200 MW m^{-2} sr^{-1} for 0.005 mrad) is not a safety limit; thus the products that approach that value will be RG3 under the current as well as under the upcoming edition of IEC 62471. As will be also discussed further below, the broadband exposure limit for 0.25 s exposure duration is somewhat conservative, as it is based on a 7 mm pupil diameter (that is prudent to assume for pulsed sources, but is conservative for many cw sources), as well as that there is a somewhat larger reduction factor (between injury threshold and exposure limit) for the 0.25 s exposure duration as compared to the milli-second range (due to the different dependence on exposure duration of thresholds and exposure limits, see for instance [6]). It thus depends greatly on the pupil diameter of what the risk for injury is for sources exceeding the exposure limit and approaching the radiance value given in CDV IEC 60825-1 – for very small pupils, such as 2 mm, the risk for injury will still be negligible; for pupils of for instance 5 mm diameter and a factor of 35 above the 7 mm exposure limit, the injury threshold for retinal injury might be exceeded also for the human case. However, product risk analysis of high brightness light sources is not the topic of this paper.

Radiance Principles

Radiance is a very "attractive" quantity for extended sources, as it is a measure of the irradiance level in the image plane of a system that images the source (such as the human eye), see for instance Sliney & Wolbarsht [7], Henderson & Schulmeister [8] and Schulmeister [9]. In the field of lighting, radiance is referred to as brightness (more correctly, luminance) when it is weighted with the luminous efficiency function $v(\lambda)$. Radiance (as long as the image it is not becoming smaller than the angular resolution of the imaging system) does not change with distance nor is changed by optical systems (assuming that there are no transmission and reflection losses). These properties and limitations will be discussed in detail further below.

Radiance L is defined as the power P per area A and solid angle Ω; θ is the angle between the normal to the surface and the solid angle cone (see Fig. 1 for the case that the solid angle cone is normal):

$$L = \frac{P}{A\,\Omega\,\cos\theta}$$

In the following, $\cos\theta$ is neglected because of central geometry and small angles and small areas relative to distances. Radiance, as is the case for irradiance, is in principle a kind of a power density (the strict definition of the quantity of power density, however, is standardized to be power per volume): while irradiance is power density in the sense of power per area, radiance also adds the angle from which the radiation is incident on the area element as an additional density, or concentration, dimension. It is thus power density, in the sense of power concentrated on an area and concentrated directionally (from where the power comes from or is emitted into when seen from the source).

The two "concentration-" or "density-factors" in the denominator are area and solid angle. It is of central importance to note that the vertex of the solid angle is at the area element, i.e. that these two quantities are a pair and the cone opens up away from the areal element, as shown in Fig 1.

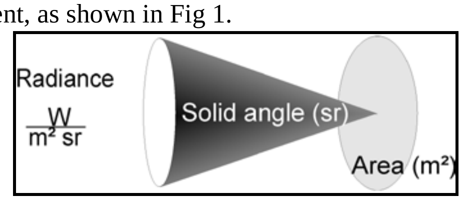

Figure 1. The concept of radiance.

For the case that the light field is not constant (not homogenous), the area element as well as the solid angle needs to be correspondingly small, otherwise it is the average radiance that is characterized and not the real radiance. In that pure and exact way, radiance would be associated to one light ray and the area element and solid angle element would tend towards infinitesimal small size. The properties of radiance, i.e. that radiance does not depend on distance and is not changed by optical elements, only apply if there is no averaging, i.e. to the real radiance.

These special properties of radiance stem from the principle that the product of the area and the solid angle remains constant in a (lossless) system. This quantity $A \times \Omega$ is referred to as etendue or throughput, where it is again emphasized that the vertex of the solid angle needs to be located at the area element as shown in Fig.1.

Radiance of the Sun

The determination and properties of radiance is discussed best with an example. For an extended source such as the sun, the radiance is usually measured in the following, simple way: the irradiance E in units of W m^{-2} at the earth surface is measured. Since we discuss the application of the retinal thermal exposure limit, we weight the spectral irradiance with the retinal thermal action spectrum $R(\lambda)$ where we already use the corrected version as published by ICNIRP [10] to obtain an effective irradiance of 520 W m^{-2} for the example of the ASTM G173-03 reference spectrum http://rredc.nrel.gov/solar/spectra/am1.5/. This is the irradiance that is incident on the imaging element, such as the cornea of the eye, and determines, together with the pupil diameter of the eye, how much power enters the eye. This intraocular power is then distributed over the image area A_{image}. The sun, as seen from the earth, as well as the retinal image as determined from the principle plane of an air-filled eye subtend a solid angle $\Omega = \alpha^2\pi/4$ were α is the angular subtense of the source (see Fig. 2). The angular subtense of the sun equals 10 mrad = 0.01 rad, so that the solid angle that is subtended by the sun equals $7.2 \cdot 10^{-5}$ sr.

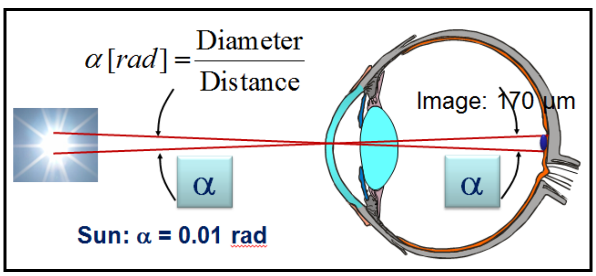

Figure 2. The angular subtense of the sun is equal to the angular subtense of the retinal image.

Dividing the effective irradiance of 520 W/m^2 by this solid angle gives an effective radiance value of the sun of 7.2 MW m^{-2} sr^{-1}.

Constancy of Radiance

Since radiance does not depend on distance and is not changed by lenses, it is also valid for "inside" of the eye as long as the pairing of the area and solid angle element is properly considered. The radiance (in this case of the sun) can then be used, for instance, to determine the retinal irradiance level in the imaging plane of a system such as the eye: the retinal irradiance (area element located at the retina) is simply obtained by multiplication of the radiance by the solid angle that is subtended by the pupil of the eye and reduction by transmission losses. Again, here the location of the vertex of the solid angle cone at the areal element (retina) is important. Due to the multiplication with the solid angle of the pupil, it is accounted for that the retinal irradiance obviously scales with the area of the pupil.

This is a good example of the pairing of areal element and solid angle remaining constant (see also Fig. 3, where the aperture on top of the lens is equivalent to the pupil in the eye, and the image is formed on the retina):

area of aperture × solid angle of image =
area of image × solid angle of aperture;

if the pupil becomes smaller, this has the same effect on the area of the pupil (left hand side) as on the solid angle of the pupil (right hand side).

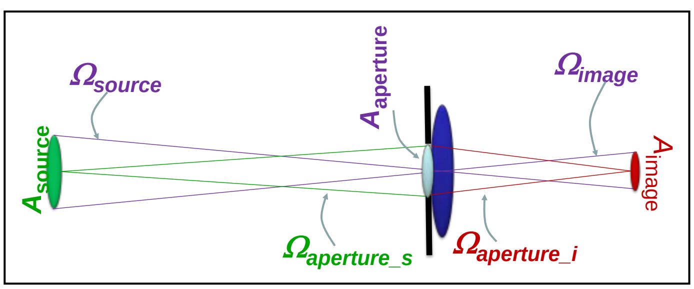

Figure 3. System of pairs of area and solid angle elements for a homogenous source such as a diffusor.

For a system of: source – lens – image plane, there are several of those area-solid angle pairs, as shown in Fig. 3: one at the source (such as a diffusor), one at the imaging lens with a certain aperture stop (with the solid angle of the source and the image to either side, but equal), and one at the image plane. Again it is mentioned that we assume here that the source (and therefore also the image irradiance profile) is homogeneous, so that there is no averaging.

$$A_{source} \times \Omega_{aperture\_s} = A_{aperture} \times \Omega_{source} = A_{aperture} \times \Omega_{image} = A_{image} \times \Omega_{aperture\_i}$$

We can also easily see why the radiance of the sun remains constant with distance, such as for different planets: the irradiance at the surface of the planet decreases with the square of the distance to the sun (1/r^2 rule), while the diameter of the sun as seen from the planet deceases with the distance, so that the solid angle also decreases exactly in the same way as the irradiance level. In other words, the sun has the same brightness from all planets when one looks into the sun, but the size of the sun changes. However, the "lighting level" (irradiance) of the surface of the planet changes with distance.

Also, an optical instrument such as a telescope does not change the radiance of the sun: while the larger optics will result in a higher irradiance level on the cornea, the retinal image area is increased by the same factor (see Fig. 4).

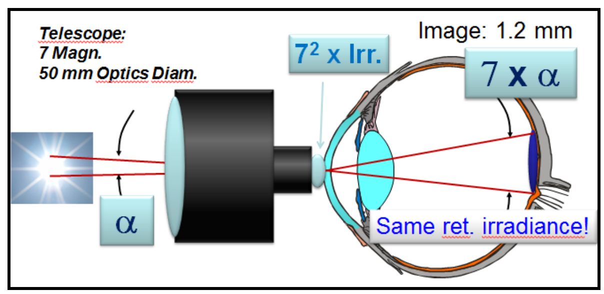

Figure 4. A telecope results in a higher irradiance at the imaging element, but the irradiance in the imaging plane is the same as for the naked eye.

What makes looking into the sun with a telescope so hazardous - causing immediate injury - is that the image of the retina is enlarged and a larger image suffers from reduced radial cooling – the 1/α dependence in the retinal thermal exposure limits when presented as radiance or radiance dose.

Equivalence to laser beam parameter product

In that sense, radiance is a quantity of the source as well as a field quantity, as it also does not matter where in the light field radiance is determined. For laser engineers, the constancy of radiance is known as the **beam parameter product**, which is also associated to a beam in the sense of a field quantity and which is also not changed by optical instruments (as long as the beam is not cut by an aperture). For laser beams, the product of beam divergence θ and beam waist diameter d_0 (Fig. 5.) is constant. This is nothing else than the pair of areal and solid angle unit as discussed above, as divergence squared is proportional to solid angle and beam waist diameter squared is proportional to area.

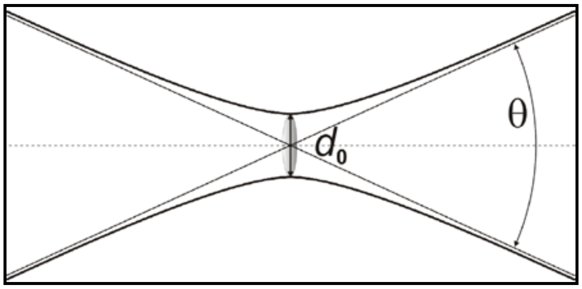

Figure 5. The constancy of the beam parameter product θ d_0 is another form of the constancy of radiance, where the product of area and solid angle is constant.

Measurement of Non-Homogeneous sources

The sun, the moon, or a frosted light-bulb are all examples of sources where the radiance can be taken as constant over the source, so that we can determine the solid angle from which the radiation is incident on the optical imaging system by the geometric form of the source, i.e. by the solid angle subtended by the source. For the sun and the moon this has the advantage that one does not actually need to know how far the emitter is away and how large it really is; it is sufficient to measure the angular subtense as it appears on the earth. By dividing the irradiance on the earth surface by the solid angle of the source, we, however, have performed an averaging over that solid angle, because we cannot resolve any inhomogeneity in the source, such as protuberances for the sun, or areas on the moon with lower reflectance.

If there are hot-spots in the source and if the radiance determination has to resolve those, it is necessary to restrict the field of view of the radiance measurement to the required resolution. This is done with a “field stop”, an aperture that defines the field of view. For the above example of measurement of the irradiance at the earth’s surface, the field of view of the system was assumed to be “open”, i.e. larger than the source. For the sun, one would actually make a small error doing that, because the detector would also receive radiation from the blue sky around the sun; the measurement values that we used for the reference sun, were, however, those from the sun only, i.e. with a proper measurement field of view that would exclude the blue sky and only image the sun. Another, equivalent name for the field of view of a measurement system is also angle of acceptance. The measurement in such cases, when the source is not accessible, needs to be done with an imaging set-up as shown in Fig. 6.

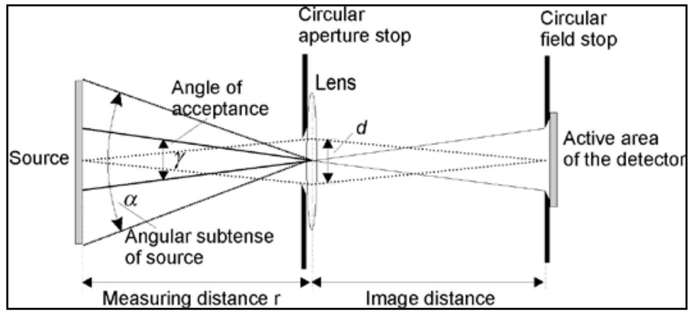

Figure 6. Imaging set-up for measurement of radiance; the resolution of the radiance measurement is given by the field stop, over which the image irradiance (and therefore radiance) is averaged.

The field stop (or the size of the detector in the imaging plane) determines the resolution of the radiance measurement and what part of the source is “seen” by the power detector in the image plane. Within the field stop, the irradiance in the image plane is averaged, so that the radiance is averaged over the solid angle that is subtended by the field stop, which is equal to the field of view in direction towards the source (compare Fig. 3).

When the source is accessible, one can also place the field stop on the source, as shown in Fig. 7.

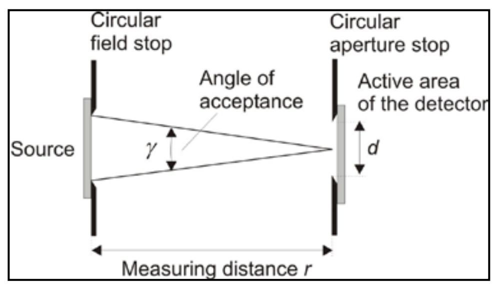

Figure 7. When the source is accessible, the field stop can be placed on the source to obtain a certain field of view.

Usually, the field of view is not allowed to be larger than the source, to prevent undue averaging. However, for measurement of the effective radiance to be determined with the photochemical retinal broadband limit, this is permitted, or rather, specified to be done, to account for the assumed extent of eye-movements. For the case that the source is smaller than the averaging field of view, the measured radiance is correspondingly smaller than the actual radiance of the source, and the analysis is less restrictive (reflecting that eye movements for the photochemical hazard decrease the retinal radiant exposure or average irradiance). A detailed discussion can be found in [8,9].

Limitations for a Point Source

To lead to the issue of a 1 mW laser pointer, the limitation of radiance for the case of a sun other than our own is to be discussed: stars are so far away, that they are point sources, which means that their angular subtense does not reflect the actual size and distance of the source, but is given by the resolution of the imaging system. This is the background of the value of α_{min}: it is assumed that a point source such as a star produces a retinal image of 25 µm, or 1.5 mrad angular subtense. The actual angular subtense, even of the closest star, Alpha Centauri (we neglect Proxima Centauri here since it is a red dwarf), is roughly 0.0001 mrad. The result of the situation that the image size is no longer determined by the actual angular subtense of the source but by the limitation of the imaging system is that radiance (brightness) is no longer independent of distance, because the irradiance that is incident on the eye increases for closer stars, but the "image" size remains the same (for instance 1.5 mrad), so that the closer stars are obviously brighter than the more distant stars (for same radiant exitance). Also, contrary to an extended source, a telescope correspondingly increases the radiance of the star (the brightness) with the area of telescope input optics. This means also that even with a telescope, a star is still a point source, i.e. is not magnified in size, but the telescope catches more light which then is imaged into the minimal spot on the retina. If we would use a pixel array in a telescope where one pixel extends a smaller angular subtense (as seen from the principle plain of the optics) than 1.5 mrad, it would have a better resolution and the light of a star would still be concentrated only on this one pixel, leading to a higher irradiance of that one pixel, or a higher brightness. Consequently, for point sources, radiance depends on the imaging qualities of the imaging system and is no longer a quantity that characterizes the source, and loses the constancy of radiance of an extended source, i.e. of the "real" radiance.

The radiance in such a system is averaged over the resolution of the imaging system, in the same way as we know it from the rules for averaging of the radiance to be compared to the photochemical retinal limit [9]. There, the measurement field of view (such as 110 mrad) is defined to account for assumed eye movements, which increase the retinal area that is exposed by the source to an area larger than the actual image. This is the same principle as the minimal resolution of a detector discussed above, i.e. the radiance is averaged over the measurement field of view and the effective radiance is no longer a measure of the source but is determined by the averaging field of view (and no longer independent of distance or optical elements). This is also why the transformation of the photochemical retinal *radiance* exposure limits into an *irradiance* limit lends itself for so called "small sources" [9] (i.e. sources that are smaller than the specified averaging field of view).

Example for a Phosphor on a Fiber

One of the new light sources which prompted the amendment of IEC 60825-1 to permit to characterize the emitted light beam under IEC 62471 is a blue laser incident on a phosphor diffuser to create a source of white light (the phosphor adds the other wavelength components to the blue laser light, in the same as for blue LEDs). The advantage is that the light source is small in diameter and can therefore be shaped well with optical elements. For a corresponding power incident on the phosphor, the radiance can be correspondingly high.

The laws of radiometry and the principle of radiance allow a relatively simple calculation of the radiance of such as source, as well as a simple calculation of the permitted power for the case that it is to be classified under IEC 60825-1 (i.e. under the current Edition 2.0).

Let us assume that a power level P is emitted from the phosphor, with a certain beam diameter (or fibre diameter). The power emitted per source area, the exitance M on the surface of the phosphor is therefore the power divided by the emitting area A_{source}:

$$M = \frac{P}{A_{source}}$$

A diffuse source can be assumed to be a lambertian emitter, with radiation emitted into the half sphere but decreasing from the central direction with a cosθ dependence, so that when one looks at it from the side (when the projected area is smaller), the brightness (radiance) is the same as looking at it from the front (which is also why the sphere of the moon has a constant brightness as if it would be a disk). The radiance of a lambertian emitter can thus be calculated by dividing the exitance M with π sr:

$$L = \frac{M}{\pi}$$

This is an example where radiance is determined as seen from the source, i.e. power emitted per source area into a certain solid angle.

The irradiance E at a given distance r can be calculated from radiance in a simple way, again considering the pairing of area and solid angle and assuming large enough distances so that cosθ can be neglected (and the $1/r^2$ rule applies):

$$E_{aperture} = L \cdot \Omega_{source} \quad \text{and} \quad \Omega_{source} = \frac{A_{source}}{r^2}$$

Inserting $L=M/\pi$ results in the irradiance at distance r being independent of source area (for small areas relative to distance r):

$$E_{aperture}(r) = \frac{P}{r^2 \pi}$$

This equation can be used to calculate the permitted power of such a source by setting E equal to the limit given in irradiance, such as the laser exposure limit for 0.25 s (which is equivalent to the Class 2 limit when aperture area is considered). For instance, if the permitted power through aperture area $A_{aperture}$ equals 0.001 C_6 Watt, and α is taken to be d_{source}/r then

$$C_6 = \frac{d_{source}}{r} \frac{1000}{1.5}$$ when r and d_{source} are in meters.

The permitted power P_{max} in Watt of the source not to exceed the exposure limit for 0.25 s then becomes

$$P_{max} = \frac{d_{source} \cdot r \cdot \pi}{1.5 \cdot A_{aperture}}$$

and for a 7 mm aperture and the classification distance r = 0.1 m:

$$P_{max\_Class2} = 5442 \cdot d_{source}$$

For instance for a fibre/irradiated phosphor diameter of 0.7 mm (d_{source} = 0.0007 m), the permitted emitted power for Class 2 equals **3.8 Watt**. For Class 3R, the permitted power would is 19 Watt.

Exposure Limits

The updated "new" retinal thermal exposure limit EL given as radiance dose [4, 11] is:

$$EL = \frac{20\,000\, t^{-0.75}}{\alpha} \frac{J}{m^2 sr}$$

where α is in rad and t in seconds; the time dependence is defined such that the above formula applies up to exposure durations of 0.25 s, from which onwards it remains a constant radiance value. For 10 mrad source size and 0.25 s exposure duration, the exposure limit equals 2.8 MW m^{-2} sr^{-1}. The sun exceeds the exposure limit for 0.25 s exposure duration by a factor of 2.5. This was some reason for criticism of the new limits (as it is known from experience that a short exposure to the sun with the naked eye does not cause retinal injury), however, this criticism neglects that also the current ("old") ICNIRP limits [12] as well as the "new" ACGIH limits [13] are exceeded by the sun. The background of the restrictive limit in this case is that it is based on the 7 mm pupil diameter that is prudent for pulsed sources to use, but is over-restrictive for the sun, as the pupil will be smaller than 7 mm when exposure occurs. Also, as mentioned, the reduction factor for 0.25 s is somewhat larger than necessary; however, this is needed to have sufficient reduction factor for 1 ms pulses. When a pupil diameter of 4.5 mm is assumed for the determination of the effective ocular exposure, the exposure limit is not exceeded for the new ICNIRP exposure limits. For the comparison of the exposure limits it also needs to be considered that the weighting function $R(\lambda)$ is also amended, so that the new $R(\lambda)$ has a maximum of 1 in the blue wavelength range, where the old one had a maximum value of 10, overweighting the blue component. The extent of the effect of the new weighting function to reduce the effective radiance that is compared with the limits depends on the blue component. For a pure blue source, the difference is a factor of 10. For a "white" spectrum, it depends on the spectral distribution: for a cool white (high color temperature), the impact is bigger than for a warm white source (low color temperature). For 110 lamps (see these proceedings Paper for Poster P104), the ratio of the "new" and "old/current" effective radiance is plotted in Fig. 8. The horizontal line of a factor of 2.5 in Fig. 8 is relevant because this is the factor by which the exposure limit for 0.25 s is reduced for the new limit compared to the current limit. Therefore, for those sources where the plotted ratio is above the red line, the overall effect of the changes to the retinal thermal limit will be less restrictive than currently, i.e. higher permitted emission/exposure. For the sun reference spectrum used above, the net effect is that the new limits are a factor of 1.14 more restrictive than the current one, i.e. a rather small factor, which does not justify to serve as argument that the new limits are so much more restrictive than the current ones.

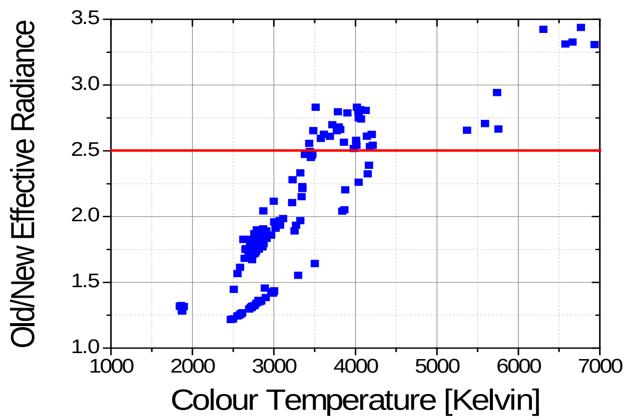

Figure 8. For 110 lamps used for lighting, the ratio of the effective radiance determined with the current and new $R(\lambda)$ is plotted as function of color temperature.

Radiance of a 1 mW Laser Pointer

The above discussion on stars as an example of point sources also applies to the collimated beam of a laser pointer, which is also a point source [8,14]. Here we assume that the divergence of the beam is smaller than 1.5 mrad, so the apparent source is at infinity and the angular subtense of the retinal spot is assumed to be α_{min} = 1.5 mrad (for a discussion of the apparent source see for instance [14]). Regarding the radiance no longer being a characteristic of the source, but of the imaging properties of the imaging system, we have the same situation as for a star. For the laser pointer (a collimated beam with a diameter of the order of 1 mm), we have the additional peculiarity - which we almost never have for a broadband incoherent source - that the beam is smaller than the pupil. For a source such as the sun (and all other conventional light sources for normal viewing distances), the irradiance distribution at the position of the eye is homogenous and the irradiance field is significantly larger than the pupil of the eye. Therefore, there is no averaging effect regarding the irradiance that is incident on the eye when irradiance is measured with a detector of finite area, irrespective of the size of the detector. However, for a 1 mm laser beam, care needs to be taken when characterizing the radiance because of the small beam diameter.

Just as the irradiance that is incident on the eye needs to be averaged [15] over a 7 mm aperture to be compared to the 25 W m^{-2} laser exposure limit for 0.25 s exposure duration and collimated beams (C_6=1), so has radiance also to be averaged in that way when it is to be compared to the radiance exposure limit defined for broadband sources. If this averaging is considered, it can be shown that the laser exposure limit is a factor of 1.3 lower (more restrictive) than the new ICNIRP broadband exposure limit.

The radiance of a collimated 1 mW laser beam, properly averaged to be compared with the broadband exposure limit, is thus calculated by dividing 0.001 watt by the area of a 7 mm aperture and the solid angle that is subtended by α_{min} = 1.5 mrad, which equals **14.7 MW m^{-2} sr^{-1}**.

If the actual beam diameter is used to determine radiance, the radiance would be correspondingly higher, such as a factor of 49 for a 1 mm beam diameter. This would be in the same way incorrect as if the actual irradiance (and not the irradiance averaged over 7 mm) is compared with the 25 W m^{-2} laser exposure limit.

The new broadband exposure limit for 1.5 mrad (the smallest α to be input into the new exposure limit is also set to 1.5 mrad, as for the laser exposure limits) equals 19 MW m^{-2} sr^{-1}. Thus, a 1 mW collimated laser beam does not exceed the broadband retinal thermal exposure limit for 0.25 s exposure duration, but is a factor of 1.3 below it (which is to be expected, as the laser exposure limit is generally a factor of 1.3 below the broadband retinal thermal limit, and 1 mW is just the laser exposure limit).

When we assume that the retinal image for the 1 mW laser beam subtends 1.5 mrad, its radiance is about twice that of the sun. The answer to the question why the sun with half the radiance of a 1 mW laser pointer (which does not exceed the limit) exceeds the broadband exposure limits, is that the sun is 6,6 times larger than α_{min}.

Summary and Conclusions

The concept of radiance is discussed for some representative extended sources such as the sun and a laser illuminated phosphor. It is shown why radiance is constant with distance and not affected by optical instruments. The limitations of radiance when the resolution of the radiance measurement or the imaging device is larger than the angular subtense of the source is pointed out. In this case, radiance is determined by the resolution of the imaging device and is not the "real" radiance. In some cases, this is intended, such as when the field of view represents the angular extent of eye movements for the photochemical retinal limit.

When the radiance of a 1 mW collimated laser beam with small beam diameter is determined for comparison with the broadband retinal exposure limit, averaging over the 7 mm pupil needs to be considered. If the actual beam cross-section were used, the radiance would be grossly overestimated.

References

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Meet the Author

Karl Schulmeister, PhD, is a consultant on laser and broadband radiation safety at the Seibersdorf Laboratories, where also a specialized accredited test house is operated. Karl is a member of ICNIRP SCIV as well as of ANSI ASC Z136 TSC-1 (Bioeffects). He also serves as the secretary of IEC TC 76 WG1, the working group responsible for IEC 60825-1. He is associated division director of CIE Div. 6 Photobiology which is responsible for CIE S009/IEC 62471. The research in his group over the last six years concentrated on thermally induced injury that also provided the basis for amending the spot size dependence of the retinal thermal limits.

Presentations on the new ICNIRP exposure limits were given at the ICNIRP Workshop in Edinburgh in 2012. The videos of the Workshop presentations are available at www.icnirp.org

http://www.icnirp.org/NIR2012/NIR2012video.html