Ocular Safety During the Observation of the Sun and of Planckian Radiators

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1 Introduction

A total solar eclipse will be visible in Central Europe, the Middle East, Persia and India as well as in some other parts of Asia on August 11, 1999. A partial solar eclipse will be visible in a much larger part of the world, including all of Europe, North Africa, most of Asia and the North-east of North America. On the occasion of former such events, there were always reports on eye injuries because the sun was observed without the eyes being sufficiently protected. It is therefore important to examine this risk during sun observation. In the Internet, many pages make reference to the oncoming solar eclipse, some of them discussing means to protect the eye [e. g. 1, 2]. These recommendations usually lack a thorough analysis of the risk by comparison of the spectral radiance or irradiance, respectively, produced by the sun with established maximum permissible exposure values.

In many cases welding filters with scale numbers between 14 and 16 are recommen-ded for the observation of the sun during solar eclipses. This recommen-dation seems to be mainly attributable to glare considerations. In [2] the recom-menda-tion of a luminous transmittance of less than 0,0003 % (corresponding to a scale number 14[1] for the visible spectral range which extends from 380 nm to 780 nm) is linked to the requirement of a transmittance of not more than 0,5 % in the near infrared spectral range between 780 nm and 1400 nm. This requirement does not hold here. It appears to have been derived from the American standard for welding filters [3] which specifies a maximum infrared transmittance, averaged between 780 nm and 2000 nm, of 0,3 %. On the other hand, between 780 nm and 1400 nm the European standard for welding filters [4] requires a maximum mean spectral transmittance of 0,007 % for welding filters of scale number 14 and of 0,003 % for those of scale numbers 15 and 16.

However, the solar spectrum is quite different from a welding spectrum: while the solar spectrum is a more or less continuous one similar to the spectrum of that of thermal radiators such as Planckian radiators, the welding spectrum is dominated by many strong emission lines at different wavelengths depending on the composition of the material welded and the electrode used for welding. In Europe a standard specifically developed for such thermal radiators is available, namely EN 171 [5]. This standard was drawn up to provide protection against thermal radiation as emitted for example by ovens or by large glowing steel parts. It extends to a scale number of 10 (i. e. 4–10) only, i. e. the range of the luminous transmittance goes down to 0,0085 %. These filters are not dark enough to avoid glare during the observation of the sun. They are intended for use with radiators up to a temperature of about 2500 K, whereas the temperature of the sun is about 6000 K. At this luminous transmittance value, the maximum mean spectral transmit-tance in the near infrared stated for the near infrared is 0,05 %. Extrapolating the requirements in the infrared to the temperature of the sun would mean an infrared transmittance of less than 0,001 %. This leads to the questions as what infrared transmittance is needed for the protection of the eyes against the sun and whether the requirements of EN 171 are really warranted?

2 Damage mechanisms

The sun emits in the ultraviolet (UV), visible and infrared spectral ranges, Planckian radiators with temperatures up to 2500 K emit mainly in the visible and infrared spectral ranges. From the ultraviolet radiation of the sun only wavelengths longer than about 280 nm penetrate through the atmosphere and reach the ground. When the sun is directly looked at,

[1]Between the scale number N and the luminous transmittance τ_v the following relation holds: $N = 1 - 7/3 \cdot \lg \tau_v$

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the UV irradiance is not substantially higher than during usual exposure to sunlight.

In the UV, the cornea and the lens are the parts of the eye which are mainly at risk. UV radiation produces photochemical injuries. The main effects are photokeratitis, photoretinitis and ultraviolet cataract.

In the visible and infrared spectral ranges, due to focussing of the radiation by the anterior parts of the eye on the retina, it is the retina which is most susceptible to injuries. In the short wavelength region of the visible up to about 500 nm, it is the blue light hazard (see figure 2), a photochemical damage to the retina, which causes injuries. In the longer wavelength ranges, the thermal damage mechanisms prevail.

Infrared radiation can also cause cataract. This is valid not only for the near infrared radiation (IR-A, 780 nm – 1400 nm) partly absorbed by lens and iris, but also for the longer wavelength radiation of IR-B (1400 nm – 3000 nm) absorbed in lens and iris, and to a lesser extent it is valid for the IR-C (3000 nm – 1 mm) radiation absorbed mainly by the cornea and the aqueous which can be effective through thermal conduction.

3 Maximum permissible exposure

There are mainly two international standards which define **M**aximum **P**ermissible **E**xposure (MPE) values, IEC 60825-1 [6] and IEC 60825-9 [7]. The first one applies to laser radiation, the second one to incoherent radiation. Since the damage mechanisms are not influenced by the coherence of the radiation, both sets of values should be equal. However, for historical reasons there are some differences between these standards, therefore the following safety analysis will be performed according to both standards. The laser standard is at present under revision. The main change of significance here is the treatment of extended sources. The future rules will be used for the discussion.

3.1 Ultraviolet spectral range

For the spectral region between 180 nm and 302,5 nm IEC 60825-1 specifies a total maximum dose of 30 J/m² and for the spectral between 315 nm and 400 nm for exposure durations between 10 s and 1000 s, a total maximum dose of 10^4 J/m². Between 302,5 nm and 315 nm there is a continuous transition between these values.

For the spectral range between 180 nm and 400 nm IEC 60825-9 requires weighting of the spectral radiant exposure $H_\lambda(\lambda)$ with a relative spectral effectiveness function $S(\lambda)$ (see figure 1), and an effective

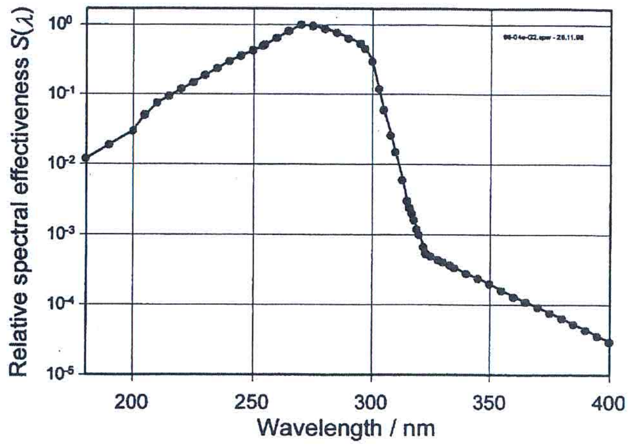

Figure 1. Wavelength dependence of the relative spectral effectiveness $S(\lambda)$ of UV radiation

radiant exposure H_{eff} of a source has to be calculated using the following formula:

$$H_{eff} = \sum_{180\,nm}^{400\,nm} H_\lambda(\lambda) \cdot S(\lambda) \cdot \Delta\lambda \qquad (1)$$

where $\Delta\lambda$ is the spectral bandwidth. The maximum permissible effective radiant exposure H_{eff} is

$$H_{eff} = 30\,\frac{J}{m^2} \qquad (2)$$

In addition, a maximum permissible total radiant exposure within an eight-hour period in the spectral range from 315 nm to 400 nm is given:

$$H_{UV} = 10^4\,\frac{J}{m^2} \qquad (3)$$

3.2 Visible spectral range

In the visible spectral range, for the observation of the sun or of thermal radiators the luminance must be reduced to a level which is comfortable for the eye. In the European standards for eye protection this level is assumed to be 730 cd/m². At this level no eye damage would be expected from such continuously emitting sources as are the sun and thermal radiators. Therefore the limit values for the visible spectral range will not be specifically discussed.

3.3 Infrared spectral range

In the infrared spectral range, a distinction must be made between the IR-A spectral range where the retina may be damaged due to the focussing of the radiation by the anterior parts of the eye and the total infrared range whose radiation may cause a cataract.

3.3.1 Retinal damage zone

3.3.1.1 IEC 60825-1

In this standard for the wavelength range from 780 nm to 1400 nm, the MPE value not only is time-dependent but also varies with the source size, i. e. the angle a under which the source appears for the eye. The reason for this size dependence is that with small images on the retina most of the heat will flow to the side. In the standard the MPE values for small sources apply to angles $\alpha < \alpha_{min} = 1{,}5$ mrad. The heat flow will be reduced if a larger area is irradiated. For an image size subtending an angle a larger than $\alpha_{max} = 100$ mrad, this lateral heat flow can be neglected. For intermediate sizes, the angle dependence of the MPEs is expressed using a correction factor C_6 with

$$C_6 = 1 \text{ for } \alpha \leq \alpha_{min} = 1{,}5 \text{ mrad} \quad (4)$$

$$C_6 = \alpha/\alpha_{min} \text{ for } \alpha_{min} < \alpha \leq \alpha_{max} \quad (5)$$

$$C_6 = \alpha_{max}/\alpha_{min} \text{ for a} > \alpha_{max} = 100 \text{ mrad} \quad (6)$$

The limit value for the irradiance E at the cornea is

$$E = 18 \cdot C_4 \cdot C_6 \cdot C_7 \cdot T_2^{-0{,}25} \quad (7)$$

Where

$$C_4 = 10^{0{,}002(\lambda - 700)} \text{ from 700 nm to 1050 nm} \quad (8)$$

$$C_4 = 5 \text{ from 1050 nm to 1400 nm} \quad (9)$$

$$C_7 = 1 \text{ from 700 nm to 1150 nm} \quad (10)$$

$$C_7 = 10^{0{,}018(\lambda - 1150)} \text{ from 1150 nm to 1200 nm} \quad (11)$$

$$C_7 = 8 \text{ from 1200 nm to 1400 nm} \quad (12)$$

$$T_2 = 10 \cdot 10^{(\alpha - 1{,}5 \text{ mrad})/98{,}5 \text{ mrad}} \quad (13)$$

3.3.1.2 IEC 60825-9

For the wavelength range from 780 nm to 1400 nm in IEC 60825-9 a distinction is made between the normal MPE values and the MPE values for infrared sources with a weak visual stimulus inadequate for activating an aversion response. Moreover, as in the ultraviolet spectral range, a weighting function $R(\lambda)$ is defined

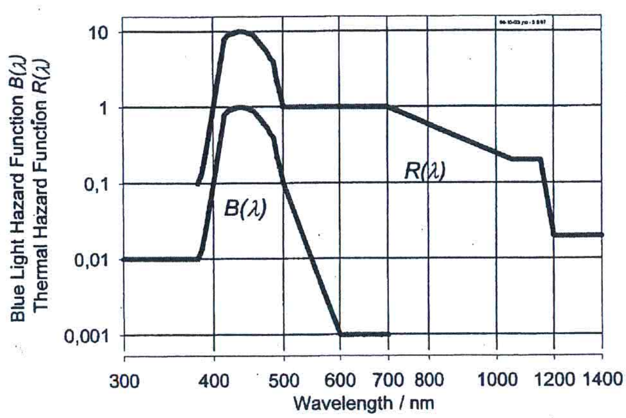

Figure 2. Retinal thermal hazard function $R(\lambda)$ and retinal blue light hazard function $B(\lambda)$

(see figure 2). Where an adequate visual stimulus exists, an effective radiance L_{RTH} of a source has to be calculated using the following formula:

$$L_{RTH} = \sum_{380 \text{ nm}}^{1400 \text{ nm}} L_\lambda(\lambda) \cdot R(\lambda) \cdot \Delta\lambda \quad (14)$$

where $L_\lambda(\lambda)$ is the spectral radiance of the source and $\Delta\lambda$ the spectral bandwidth. The MPE value for exposure times longer than 10 s is

$$L_{RTH} = \frac{2{,}8 \cdot 10^4}{C_\alpha} \frac{\text{W}}{\text{m}^2 \cdot \text{sr}} \quad (15)$$

where $C_\alpha = \alpha$ is a correction factor similar to C_6 above. C_α varies between α_{min} and α_{max} only.

For infrared sources with a weak visual stimulus inadequate for activating the aversion response, an effective infrared radiance L_{IR} has to be determined using the following formula (a weak visual stimulus is defined as one whose maximum luminance averaged over a circular field of view subtending 0,011 rad is smaller than 10 cd/m²):

$$L_{IR} = \sum_{780 \text{ nm}}^{1400 \text{ nm}} L_\lambda(\lambda) \cdot R(\lambda) \cdot \Delta\lambda \quad (16)$$

where $R(\lambda)$ is the retinal thermal hazard weighting function (see figure 2) and $L_\lambda(\lambda)$ the spectral radiance of the source. The MPE value for exposure durations > 10 s is given by

$$L_{IR} = \frac{6000}{C_\alpha} \frac{\text{W}}{\text{m}^2 \cdot \text{sr}} \quad (17)$$

where $C_\alpha = \alpha$ is the same correction factor as above.

3.3.2 Cataract risk zone

Long-term irradiation of the eye with high levels of infrared radiation is known to cause cataract (glass-blower's cataract). The temperature rise in the eye is responsible for the cataract produced by infrared radiation. Energy absorbed by the cornea, the iris and the lens may contribute to the temperature rise. It should be limited to less than 1 K. According to IEC 60825-9, this is achieved by the following MPE value applying to the total irradiance E_{IR} in the spectral range between 780 nm and 3000 nm:

$$E_{IR} = 100 \frac{\text{W}}{\text{m}^2} \quad (18)$$

4 The radiators

Two kinds of radiators will be considered here, the sun the radiation of which outside the atmosphere roughly follows Planck´s law and thermal radiators which very closely follow Planck´s law.

4.1 Planck´s law

The emission of so-called black bodies can be described by Planck´s radiation law. Black bodies are best approached by cavities with a small opening through which the radiation is emitted. However, many other sources lsuch as for example incandescent lamps, very closely follow this law. It gives the spectral radiance $L_{e\lambda}(\lambda, T)$ in dependence on the radiator temperature T and the wavelength λ (see figure 3).

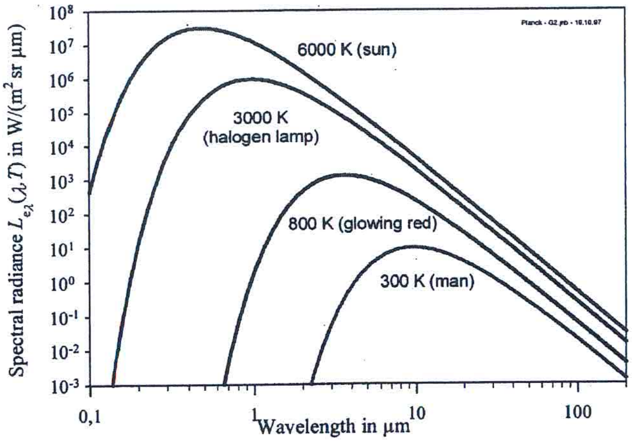

Figure 3. Spectral radiance of black bodies for different radiator temperatures

$$L_{e\lambda}(\lambda, T) = \varepsilon(\lambda, T) \cdot \frac{c_1}{\pi\, n^2\, \lambda^5\, (e^{c_2/\lambda \cdot T} - 1)} \quad (19)$$

where

$c_1 = 2\,\pi\,h\,c_0^2 = 3{,}742 \cdot 10^{-16}$ W · m²

$c_2 = h\,c_0/k = 1{,}4388 \cdot 10^{-2}$ K · m

$h = 6{,}6260755 \cdot 10^{-34}$ J · s

$k = 1{,}380658 \cdot 10^{-23}$ J/K

n refractive index of the surroundings

$c_0 = 299\,792\,458$ m/s

$\varepsilon(\lambda, T)$ emissivity

Radiators exactly following this law with an emissivity $\varepsilon(\lambda, T) = 1$ are called black bodies. For most radiators $\varepsilon < 1$. The emissivity usually depends on wavelength and temperature.

4.2 The sun and solar radiation

The sun is a star with a surface temperature of 5800 K. In sunspots this temperature is 3800 K only, whereas temperatures in the sun's corona are over 1 000 000 K. The sun has a diameter of 1 390 000 km and the earth is at a mean distance of 149 600 000 km from the sun.

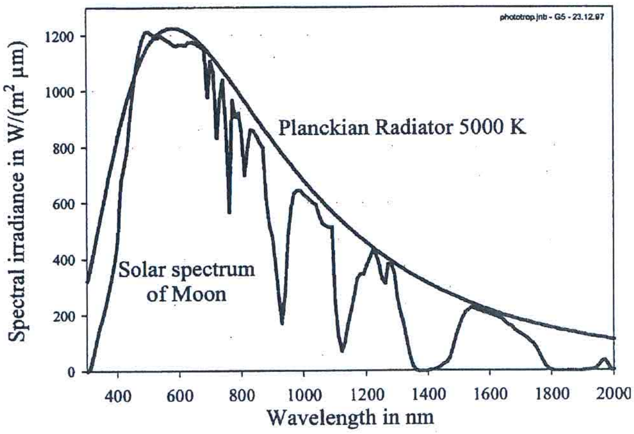

Figure 4. Spectral irradiance produced by the sun at ground level for AM 2 (i. e. the sun shines at an angle of 30°) [8]

This means that the angle a under which the sun appears from the earth is 0,0093 rad.

Outside the atmosphere, the radiation of the sun approximately follows Planck´s law for a temperature of about 6000 K. The atmosphere absorbs a considerable part of this radiation in the ultraviolet and in the infrared spectral ranges. This absorption becomes very obvious in the water bands in the infrared. Due to this absorption the envelope of the radiation spectrum follows Planck´s law more closely for 5000 K than for 6000 K (see figure 4).

4.3 Thermal radiators

In figure 3 black body radiation is shown for several temperatures. In an industrial environment such radiation is encountered when glass blowers take glass with their glass pipe from an oven or where molten iron flows from a blast furnace or on other occasions where high-temperature work pieces are observed. The emission of all these emitters is lower than that of a Planckian radiator of equal temperature since the emissivity of all real bodies is lesser than 1, usually between about 0,5 for typical metals and nearly 1 for ovens. Therefore the emission of a real emitter against which protection is to be afforded by infrared protection filters can be simulated quite well by the emission of a Planckian radiator.

5 Transmittance requirements for eye protection filters

The transmittance requirements for eye protection filters in the different spectral ranges must be derived from the emission of the radiators as described in section 4 and the MPE values according to section 3.

5.1 Ultraviolet spectral range

5.1.1 Filters for solar eclipse

Looking directly at the sun without optical instruments as it is done for a few minutes during a solar eclipse produces no considerably higher irradiance than during usual outdoor stay. That means that UV protection exceeding that of ordinary sunglasses is not needed. But the UV irradiance produced by the sun is, especially towards noon, much higher than the limit values given in section 3.1. This can be directly experienced when the untanned skin is exposed to high levels of solar radiation. This causes an erythema, a photochemical response of the skin. Skin pigmentation and „conditioning“ (thickening of the stratum corneum and tanning) may result in a reduction of the sensitivity of the skin by at least one order of magnitude. For the protection of the eye, the European sunglass standard EN 1836 [9] allows in the case of the darkest filters (luminous transmittance 3 %) a maximum value of the spectral transmittance between 280 nm and 315 nm of 0,3 %, and of 1,5 % between 315 nm and 350 nm. When weighted with the solar spectrum and the weighting function $S(\lambda)$ from section 3.1, between 315 nm and 380 nm, the maximum transmittance value given in the standard is 1,5 %. These values could well be also applied to filters used for the observation of a solar eclipse without optical instruments.

When optical instruments such as telescopes are used, much higher power is collected and the irradiance at the cornea increases by a factor corresponding to the magnification of the instrument squared if the objective diameter is at least equal to the ocular diameter multiplied by the magnification. This consideration is valid only in the spectral range in which typical optical glasses are transparent, i. e. mainly for wavelengths greater than 315 nm. Assuming a magnification of 10, the value of 1,5 % specified above should be reduced to 0,015 % when telescopes are used.

5.1.2 Infrared protection filters

In the case of thermal radiators up to a temperature of 2500 K for which the infrared protection filters are designed, it is not necessary to give special attention to UV protection since at such low temperatures the UV emission of the radiators is well below the MPE values.

5.2 Visible spectral range

Since it is the purpose of the filters to provide protection when looking into a furnace or at the sun, it is necessary to reduce the luminance of the sources to a level at which it is possible to see the necessary details without glare. At this level an injury of the retina is excluded for continuous emitters. As mentioned above, the European eye protection standards are based on a luminance of 730 cd/m² for comfortable viewing of a source.

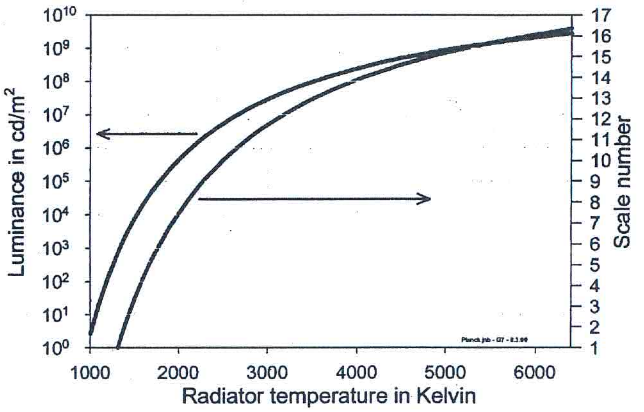

Figure 5. Luminance of Planckian radiators of different temperatures (with $\varepsilon = 1$) and scale number needed to reduce it to 730 cd/m²

The luminance L_v of a source may be calculated from its spectral radiance $L_{e\lambda}$ using the following formula,

$$L_v = 683 \frac{\text{lm}}{\text{W}} \cdot \int_{380\,\text{nm}}^{780\,\text{nm}} V(\lambda) \cdot L_{e\lambda}(\lambda, T) \cdot d\lambda \qquad (20)$$

where $V(\lambda)$ is the relative spectral luminous efficiency of the eye and 683 lm/W the luminous efficacy of radiation.

5.2.1 Infrared protection filters

In the case of infrared protection filters, the spectral radiance $L_{e\lambda}$ according to relation (19) may be used for the calculation. Applying formula (20) leads to the luminance values shown in figure 5.

In order to reduce the luminance L_v to a comfortable level, a filter with a spectral transmittance τ_v given by

$$\tau_v = (730\,\text{cd}/\text{m}^2)/L_v \qquad (21)$$

must be used. Determined with the relation for the scale number $N = 1 - 7/3 \cdot \lg \tau_v$ as defined in EN 166, the necessary values for N are also plotted in figure 5. As can be seen from this figure, a filter to reduce glare is not needed for radiators with temperatures below about 1300 K and a scale number 16 is needed for radiator temperatures around 6000 K.

5.2.2 Filters for viewing a solar eclipse

As mentioned above, the temperature corresponding to the emission spectrum of the sun is about 6000 K outside the earth atmosphere and, as can be seen from figure 4, smaller than about 5000 K on the ground if the sun shines under an angle of 30°. To reduce the luminance to 730 cd/m², a filter with a scale number of about 15 is then needed according to figure 5. To have a more exact value for the sun's luminance, one can use spectral irradiance produced by the sun at ground level according to [8] for air mass two (AM 2), i. e. the sun shines at an angle of 30° (typical for central Europe) and the formula relating the radiance L to the irradiance E:

$$L = E \cdot A / a^2 \qquad (22)$$

where A is the area of the radiator (e. g. the sun) and a the distance of the radiator from the irradiated surface (e. g. the distance earth – sun). Together with formula (20), which is equally valid for radiance/luminance and for irradiance/illuminance, one gets for the values according to figure 4 a luminance of $1{,}27 \cdot 10^9$ cd/m², a value leading to a scale number $N = 15{,}5$. This value is well comparable with the preceding estimates.

5.3 Infrared spectral range

In the infrared spectral range, two criteria have to be considered, a possible hazard to the retina according to section 3.3.1 and the risk of getting a cataract according to section 3.3.2. As in the UV spectral range, during the observation of a solar eclipse, the risk of contracting a cataract if no optical instruments are used is not greater than during a normal stay outdoor, especially since the formation of a cataract is a long-term process over tens of years. Even with a telescope, the cataract risk would not be heavily increased since the observation of an eclipse is a matter of minutes only. However, the situation will be quite different in the case of infrared protection filters if very high irradiance values occur and the occupational situation implies long-term exposure.

5.3.1 Retinal hazard

In the retinal hazard zone, the infrared radiance L_{IR} has to be weighted according to equation (16) between 780 nm and 1 400 nm and then compared with the limit value according to equation (17) valid for a weak visual stimulus. This latter value has to be used even if the radiance is higher than the value 10 cd/m² defined as the limit for a weak stimulus because the idea behind these dual limits is that one would look for a longer time into a source with a weak stimulus than into a source where glare might be produced. However, in our situation, intentional viewing for a longer time would occur in the case of the observation of a solar eclipse as well as when looking into an oven.

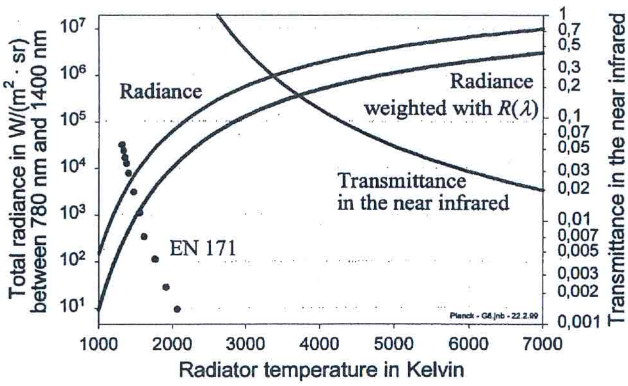

Figure 6. Total radiance of Planckian radiators of different temperatures and mean transmittance between 780 nm and 1400 nm needed to reduce the radiance to the limit value according to equation (17) and requirements according to EN 171 (•)

5.3.1.1 Infrared protection filters

The total radiance of Planckian radiators in dependence on the temperature is shown by the upper curve of figure 6. When weighted with the retinal thermal hazard function, the curve is lowered by a factor of about 10. These weighted radiance values must be compared to the limit value according to equation (17). In this equation the correction factor C_α is needed. In cases in which infrared protection filters are used, such as for the observation of ovens, the source is rather large, in any case greater than 100 mrad. Therefore the correction factor is equal to 0,1.

With this correction factor and by dividing the results according to equation (16) by the limit value according to equation (17), the permissible transmittance in the near infrared between 780 nm and 1400 nm is obtained. This is shown by the right-hand curve. As can be seen from the figure, for radiator temperatures lower than about 2500 K, no protection is needed in this wavelength range.

Figure 6 also shows the requirements according to EN 171 (dots). This standard requires a transmittance value lower than the one determined here by more than a factor of 1000. The requirements of EN 171 were derived in [10] on the basis of a limit value of 20 W/(m² · sr) for the radiance as specified time in the 1973 edition of the ANSI standard Z 136.1 [11]. The conclusion from this compari-son of the radiance with the actual limit values would be that no protection in the near infrared was necessary in the temperature range covered by EN 171.

The calculations used the limit values applicable to incoherent sources. Using the limit values for laser sources, the permissible transmittance values would even be higher by nearly 10 %.

5.3.1.2 Filters for viewing a solar eclipse

In the case of filters for viewing a solar eclipse, the same calculations must be carried out using the distribution temperature of the sun which is between 5000 K and 6000 K. However, in the case of the sun, the correction factor C_α would be different: C_α = 0,0093 (see sections 3.3.1.2 and 4.2) instead of 0,1. This means that the limit values are about ten times higher in this case. For 6000 K, the exact evaluation gives a transmittance in the infrared of 33 %.

Telescopes are very often used for the observation of a solar eclipse. In this case the image of the sun on the retina is magnified, and if the magnification is greater than eleven times, the source would become a large source (see 3.3.1.1) and the lower limit values calculated in 5.3.1.1 would apply. It is implicitly assumed here that the diameter of the telescope objective is large enough so that the retinal irradiance is the same as without telescope. In this case according to equation (5) the transmittance in the near infrared should not be higher than 3 % if a telescope is used for the observation of the sun.

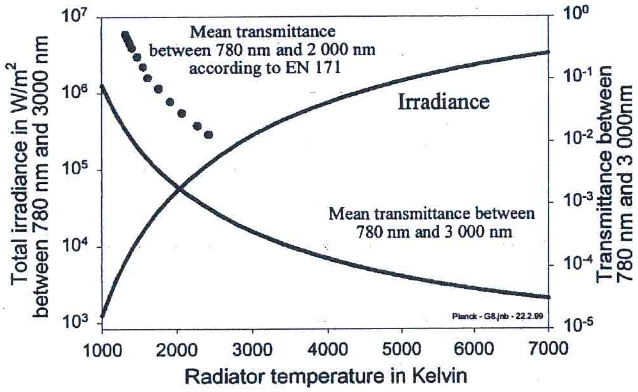

Figure 7. Total irradiance of Planckian radiators of different temperatures and mean transmittance between 780 nm and 3000 nm needed to reduce the radiance to the limit value according to equation (18) and requirements according to EN 171 (•) for the spectral range between 780 nm and 2000 nm

5.3.2 Infrared protection filters – cataract risk

Considering the risk of cataract from thermal radiators, according to IEC 60825-9, the total irradiance E_{IR} between 780 nm and 000 nm has to be calculated and the limit value of equation (18) has to be applied. In [10] it was assumed that a reasonable condition would be that an oven has an opening of 25 cm × 25 cm and a glass blower would stand at a distance of 50 cm from this opening. With an emissivity ε = 1, using equations (19) and (22) equation (23) is obtained:

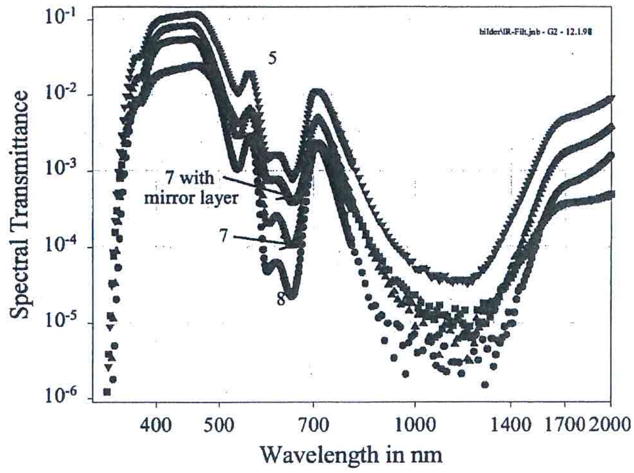

Figure 8. Spectral transmittance of IR-filters with scale numbers 5, 7 und 8, one of them covered with a reflecting layer

$$E_{IR} = \sum_{\lambda = 780\,\text{nm}}^{3000\,\text{nm}} \frac{c_1}{\pi \cdot n^2 \cdot \lambda^5 \cdot (e^{c_1/\lambda \cdot T} - 1)} \cdot \left(\frac{0{,}25\ \text{m}}{0{,}5\ \text{m}}\right)^2 \qquad (23)$$

The total irradiance is shown in figure 7. This figure equally shows the mean transmittance between 780 nm and 3000 nm permissible when the irradiance values are compared with the limit value 100 W/m². The dots in this figure also show the mean transmittance values required by EN 171 in the spectral range between 780 nm and 2000 nm. It is obvious that these values are greater than those calculated here by more than a factor of ten. Since the spectral range is smaller, these filters would allow even more energy to reach the eye. Consi-dering spectral transmittance curves of infrared protection filters as they are shown in figure 8 going up at the long wavelength end, this would mean that the transmittance averaged over the total spectral range would be even higher. The values in EN 171 were derived using the wavelength dependence of the absorption in the eye and based on the absorption of solar radiation calculated in the same way. Since the sun produced an irradiance well above 100 W/m², it is not surprising that the values in EN 171 were higher. However, since very low transmittance values were required in the near infrared spectral range, the necessary overall protection was still ensured.

6 Conclusion

The present evaluations show that for the *observation of a solar eclipse* protection is needed in the ultraviolet, visible and infrared spectral ranges. Between 280 nm and 315 nm the spectral transmittance should not be greater than 0,3 % and between 315 nm and 350 nm not greater than 0,015 %. When weighted with the solar spectrum and the weighting function

Scale number	Maximum mean transmittance between 780 nm and 3 000 nm	Typical radiator temperature
	%	~~K~~ °C
4-1.2	1,5	<1050
4-1.4	1,4	1070
4-1.7	1,3	1090
4-2	1,2	1110
4-2.5	1,1	1140
4-3	0,82	1210
4-4	0,62	1290
4-5	0,51	1350
4-6	0,33	1500
4-7	0,23	1650
4-8	0,16	1800
4-9	0,11	2000
4-10	0,083	2150

$S(\lambda)$ the transmittance between 315 nm and 380 nm should be not greater than 0,015 %.

In the visible spectral range the luminous transmittance should correspond to a scale number of 15 or 16, however, since the reference luminance of 730 cd/m^2 is not very high, scale numbers down to 13 would also be tolerable.

In the near infrared spectral range between 780 nm and 1400 nm, the mean transmittance should not be higher than 3 % if a telescope is used for the observation of the sun.

The present evaluations show that for infrared filters intended for use for the *observation of ovens and hot metal parts*, protection is needed in the visible and infrared spectral ranges only. In the visible spectral range, attenuation of the luminance to 730 cd/m^2 is provided by the recommendations given in EN 171 (see table).

For the near infrared spectral range between 780 nm and 1400 nm, EN 171 requires fairly low transmittance values which were derived from a former edition of ANSI Z 136.1. Using the new limit values of the IEC 60825 series, it can be shown that no retinal risk exists in this wavelength range for the radiator temperatures covered by EN 171.

However, a high risk of cataract exists when looking into an oven or at large hot parts. Whereas the standard EN 171 extends the wavelength range in which protection is required from 780 nm to 2000 nm only, it should go to at least 3000 nm since in this wavelength range radiation is absorbed in the anterior parts of the eye and can contribute to the development of a cataract. The values calculated in this study are much smaller than those required by EN 171. They may be taken from the following table.

7 Literature

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