Annex F
(informative)

Flowcharts showing the assessment of optical radiation safety of LEDs in electric toys

Figures F.1 to F.5 present a series of flowcharts to assist in the assessment of optical radiation safety of **LEDs** in **electric toys**.

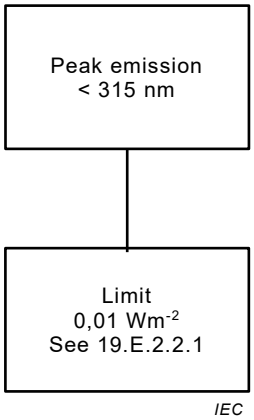

Figure F.1 – Flow chart addressing UVB and UVC emissions

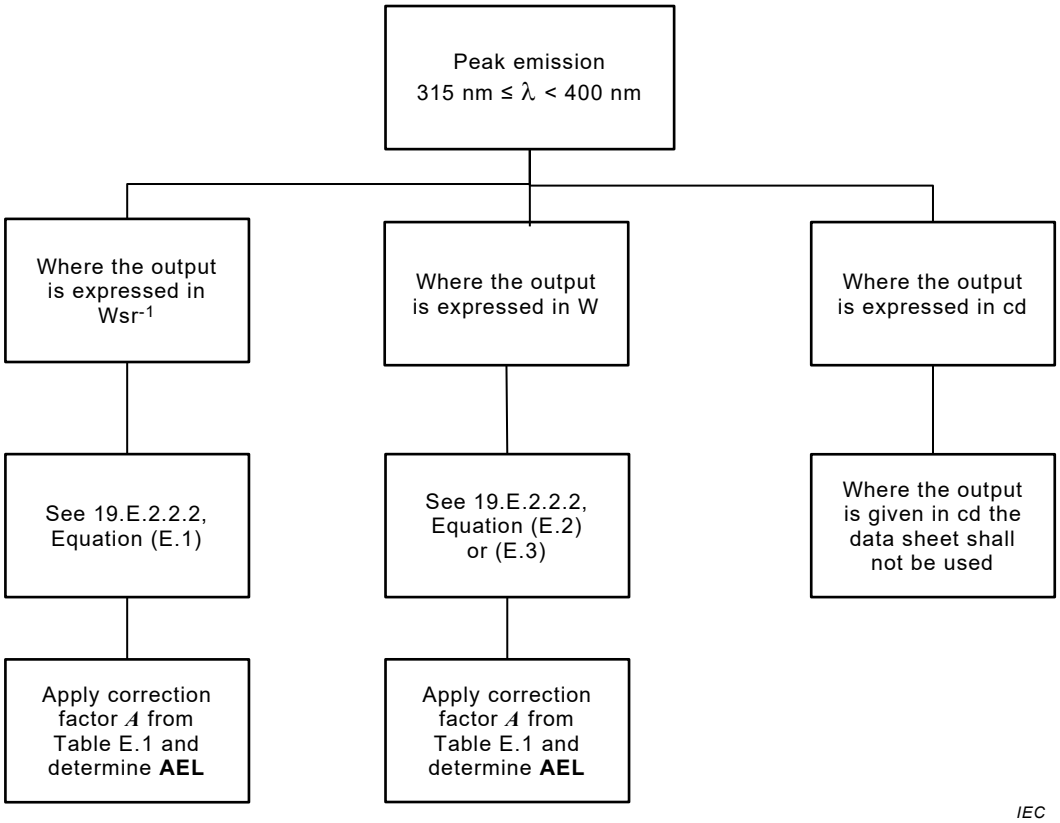

Figure F.2 – Flow chart addressing UVA emissions

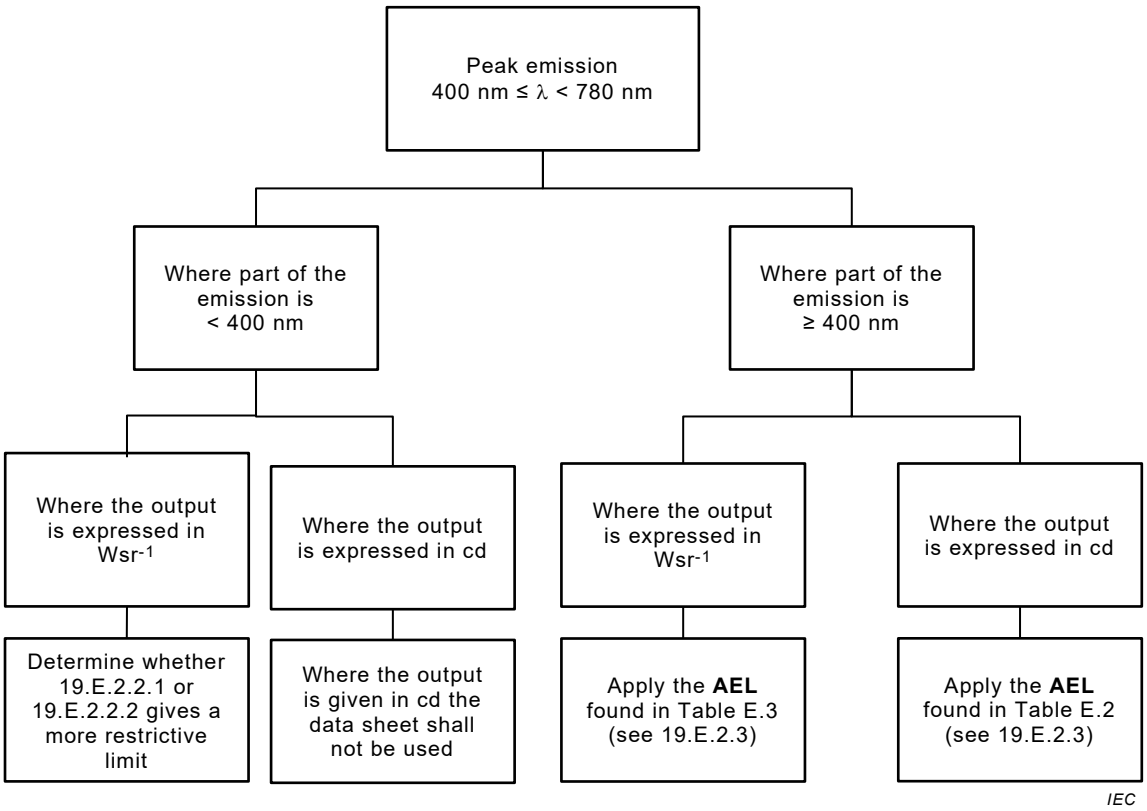

Figure F.3 – Flow chart addressing visible emissions

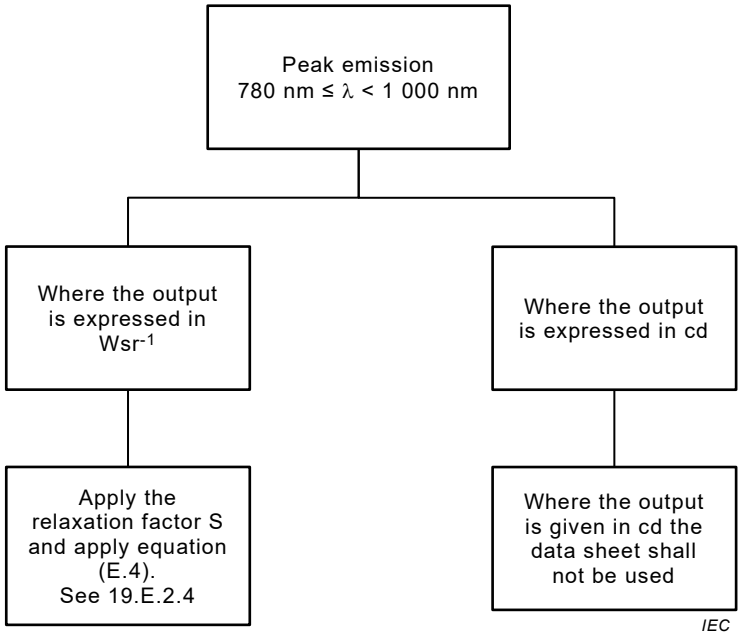

Figure F.4 – Flow chart addressing IR emissions < 1 000 nm

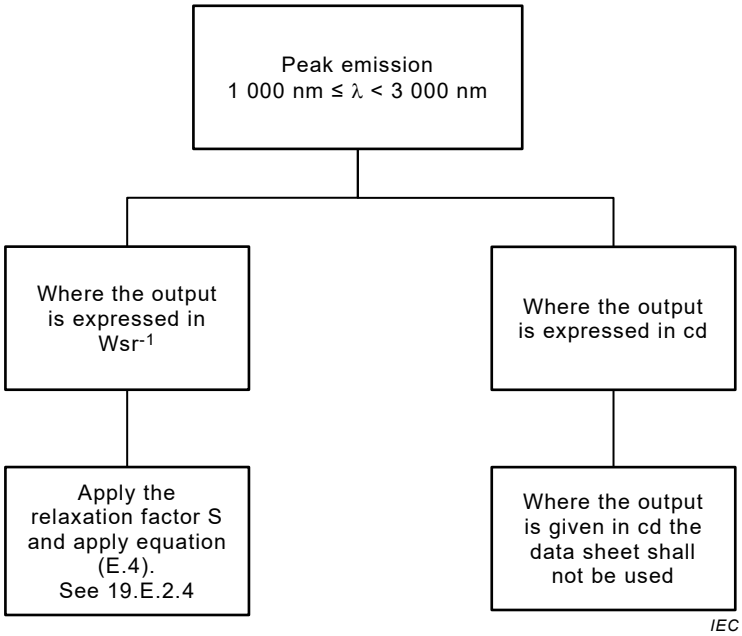

Figure F.5 – Flow chart addressing IR emissions ≥ 1 000 nm

Annex G
(informative)

Examples of calculations on LEDs

G.1 Green LED

An example of calculation for a green **LED** is provided in this Clause G.1.

Data sheet information:

Luminous intensity: 3,2 cd
Peak emission wavelength: 520 nm
Spectral emission bandwidth: 20 nm
Half-power beam angle (**HWHM** angle): ±30 degrees

There is no emission below 400 nm: the UVA **AEL** is not applicable and only the visible light **AEL** should be considered.

The visible light **AEL** from Figure G.1 for 520 nm peak emission and 20 nm **spectral emission bandwidth** is 38,4 cd.

Therefore, the visible light **AEL** for this **LED** is 38,4 cd, which is >> 3,2 cd and the **LED** is safe to use as a single component.

G.2 Narrow angle blue LED

An example of calculation for a narrow angle blue **LED** is provided in this Clause G.2.

Data sheet information:

Luminous intensity: 3,0 cd
Peak emission wavelength: 460 nm
Spectral emission bandwidth: 30 nm
Half-power beam angle (**HWHM** angle): ±10 degrees

There is no emission below 400 nm: the UVA **AEL** is not applicable and only the visible light **AEL** should be considered.

The visible light **AEL** from Figure G.1 for 460 nm peak emission and 30 nm **spectral emission bandwidth** is 2,2 cd.

Therefore, the visible light **AEL** for this **LED** is 2,2 cd. The luminous intensity of the **LED** is 3,0 cd; it exceeds the **AEL** and the **LED** may not be safe to use in an **electric toy**, even as a single component.

G.3 UVA LED

In Clause G.3, an example of calculation for a UVA **LED** where the output is given in candela. The example shows the inaccuracy of using candela as an expression of UVA output.

Data sheet information:

Luminous intensity: 1,5 cd
Peak emission wavelength: 405 nm
Spectral emission bandwidth: 20 nm
Half-power beam angle (**HWHM** angle): ±25 degrees

Luminous intensity (I_{DS}) of this **LED** is expressed in cd. To convert luminous intensity to radiant intensity (I_e) in Wsr^{-1}, the **LED** spatial distribution and luminous efficiency $V(\lambda)$ values for the peak emission wavelength and **spectral emission bandwidth** of the **LED** shall be taken into account.

The luminous intensity in candela is converted to radiant intensity in units of Watts per steradian as follows.

$$I_e(\theta) = I_0 \cos^m(\theta)$$

By definition $\frac{I_e(\theta_{HWHM})}{I_0} = 0{,}5$

Hence $m = \frac{\log 0{,}5}{\log(\cos\theta_{HWHM})}$

$$m = \frac{\log 0{,}5}{\log(\cos 25)} = 7{,}05$$

For photopic vision (well-lit conditions)

$$I_e = \frac{2I_{DS}}{(m+1)\,683\,V(\lambda)}$$

$$\frac{2I_{DS}}{m+1} = \frac{2\times 1{,}5}{7{,}05+1} = 0{,}37\,\text{cd}$$

$$I_e = \frac{\text{cd}}{V(\lambda)\times 683} = \frac{0{,}37}{0{,}00064\times 683} = 0{,}84\ \text{Wsr}^{-1}$$

where $V(\lambda)$ is the CIE photopic spectral luminous efficiency function and for λ = 405 nm; $V(\lambda)$ = 0,000 64.

NOTE Values of $V(\lambda)$ are given in Table 1 of ISO 23539:2005.

Based on equation (E.3), the radiant intensity I_e can be converted to Watts to compare with the maximum power consumption obtained from the **LED** datasheet.

$$I_e = \frac{0{,}84\times\pi\times\alpha^2}{4} = 0{,}5\ \text{W}$$

where $\alpha = \frac{2\pi\theta_{HWHM}}{180} = 0{,}87$ rads

Taking into account that the maximum power consumption of the **LED** in the example is 0,07 W (20 mA at 3,5 V), which is lower than the calculated output by a factor of almost 10, then the conclusion of this example is: output of UV **LEDs** expressed in candela may be highly inaccurate and should not be used for safety assessment.

G.4 UVA LED

Data sheet information:

Output: 0,01 Wsr^{-1}
Peak emission wavelength: 405 nm
Spectral emission bandwidth: 20 nm
Half-power beam angle (**HWHM** angle): ±25 degrees

The UVA **AEL** without relaxation is 0,01 Wsr^{-1}.

Relaxation factor A from Table E.1 for 405 nm peak and 20 nm **spectral emission bandwidth** is 0,4; therefore, the UVA **AEL** for this **LED** is $\frac{0{,}01}{0{,}4} = 0{,}025\ Wsr^{-1}$ without the child correction factor C.

Visible light **AEL** from Table E.3 for 405 nm peak and 20 nm **spectral emission bandwidth** is 0,1 Wsr^{-1} without the child correction factor C which is less restrictive than UVA **AEL** so the UVA **AEL** should be used as **accessible emission limit** for this **LED**.

LED output of 0,01 Wsr^{-1} is below UVA **AEL** of 0,025 Wsr^{-1}so this **LED** is safe to use as a single component in **electric toys** for children 3 year and older (C = 1).

If the **electric toy** was intended for children under 3 year of age, (C = 0,1) and the

AEL = 0,025 × 0,1 Wsr^{-1}= 0,002 5 Wsr^{-1}

Therefore, the **AEL** would be exceeded and the **LED** may not be safe to use in **electric toys** for children under 3 year of age, even as a single component.

G.5 IR LED

An example of calculation for an IR **LED** is provided in Clause G.5.

Data sheet information:

Radiant intensity: 0,06 Wsr^{-1}
Peak emission wavelength: 940 nm
Spectral emission bandwidth: 50 nm
Half-power beam angle (**HWHM** angle): ±15 degrees

There is no emission below 780 nm: the UVA and visible light **AELs** are not applicable and only the IR **AEL** should be considered.

The IR **AEL** is $\frac{0{,}32\ Wsr^{-1}}{S}$ where S = 0,5 for 940 nm.

The IR **AEL** for this **LED** is 0,64 Wsr^{-1}, which is >> 0,06 Wsr^{-1} and **LED** is safe to use as a single component.

G.6 3x3 cluster of red LEDs

An example of calculation for a cluster of red **LEDs** is provided in Clause G.6.

Data sheet information of individual **LED**:

Luminous intensity: 2,45 cd
Peak emission wavelength: 630 nm
Spectral emission bandwidth: 20 nm
Half-power beam angle (**HWHM** angle): ±60 degrees

There is no emission below 400 nm: UVA **AEL** is not applicable and only the visible light **AEL** should be considered.

The visible light **AEL** from Figure G.1 for 630 nm peak emission and 20 nm **spectral emission bandwidth** is 38,4 cd.

Therefore, visible light **AEL** for a single **LED** is 38,4 cd, which is >> 2,45 cd and the **LED** is safe to use as a single component. Total luminous intensity of 3x3 **LED** cluster is 2,45 × 9 = 22,05 cd – which is below the visible light **AEL**: these **LEDs** are safe to use in a 3x3 cluster.

G.7 LED array 1

An example of calculation for an **array of LEDs** is provided in Clause G.7.

LEDs 1, 2 and 3 are used in the same **electric toy**. **LEDs** 1, 2 and 3 are positioned at the corners of a triangle with side dimension of 50 mm and form a “running” light so that only one colour **LED** is ON at any time.

Data sheet information of individual **LEDs**:

Luminous intensity: 1,0 cd
Peak emission wavelength of **LED** 1: 460 nm
Peak emission wavelength of **LED** 2: 520 nm
Peak emission wavelength of **LED** 3: 630 nm
Spectral emission bandwidth: 30 nm
Half-power beam angle (**HWHM** angle): ±10 degrees

There is no emission below 400 nm: UVA **AEL** is not applicable and only the visible light **AEL** should be considered.

LEDs 1, 2 and 3 are separated by more than 40 mm and should be considered as independent sources.

The visible light **AELs** (from Figure G.1) are:

– for 460 nm peak emission and 30 nm **spectral emission bandwidth** is 2,2 cd;
– for 520 nm peak emission and 30 nm **spectral emission bandwidth** is 38,4 cd;
– for 630 nm peak emission and 30 nm **spectral emission bandwidth** is 38,4 cd.

Visible light **AELs** applicable to **LEDs** 1, 2 and 3 are above the stated 1 cd output, and these **LEDs** are safe to use in **electric toys** in the designed configuration.

G.8 LED array 2

An additional example of calculation for an **array of LEDs** is provided in Clause G.8.

LEDs 1, 2 and 3 are used in the same **electric toy**. **LEDs** 1, 2 and 3 are positioned next to each other and operate simultaneously.

Data sheet information of individual **LEDs**:

Luminous intensity: 1,0 cd
Peak emission wavelength of **LED** 1: 460 nm
Peak emission wavelength of **LED** 2: 520 nm
Peak emission wavelength of **LED** 3: 630 nm
Spectral emission bandwidth: 30 nm
Half-power beam angle (**HWHM** angle): ±10 degrees

There is no emission below 400 nm: the UVA **AEL** is not applicable and only the visible light **AEL** should be considered.

LEDs 1, 2 and 3 are separated by less than 40 mm, operate simultaneously and should be considered as additive:

Stated output of **LED** 1 accounts for 45,5 % of the **AEL** (1 cd/2,2 cd x 100 = 45,5 %);

Stated output of **LED** 2 accounts for 2,6 % of the **AEL** (1 cd/38,4 cd x 100 = 2,6 %);

Stated output of **LED** 3 accounts for 2,6 % of the **AEL** (1 cd/38,4 cd x 100 = 2,6 %).

Total percentage is <51 % of the visible light **AEL** (45,5 %+2,6 %+2,6 % = 50,7 %): these **LEDs** are safe to use in **electric toys** in the designed configuration.

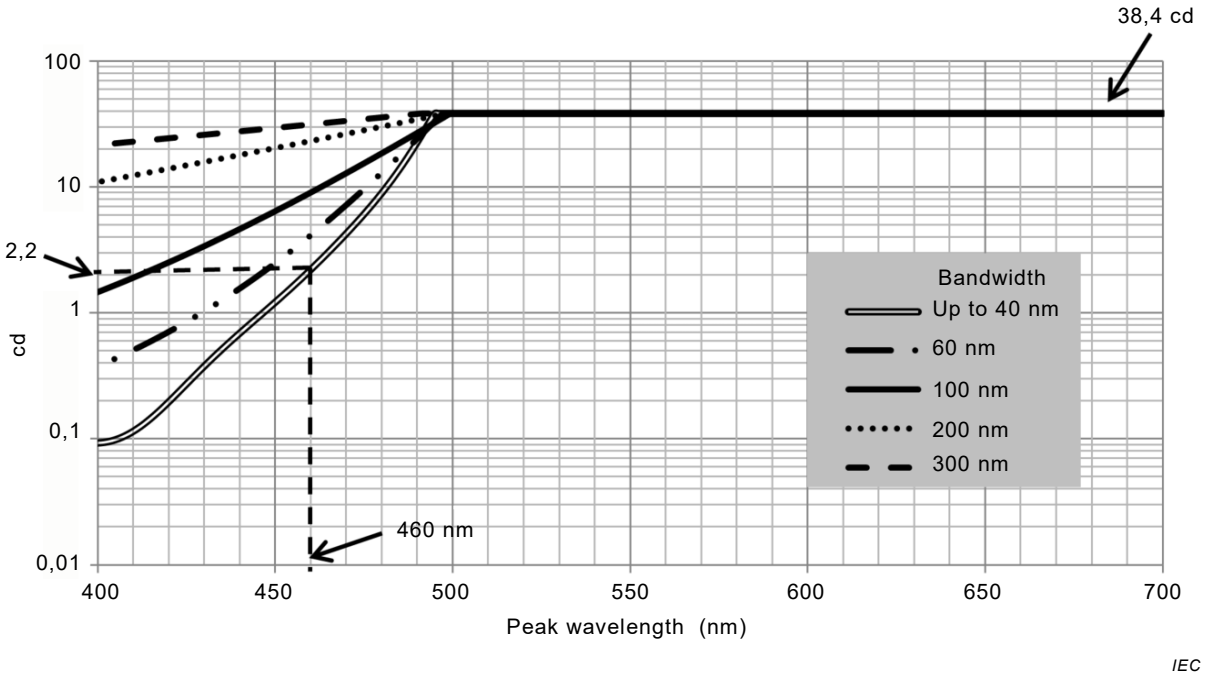

Figure G.1 – Visible light AEL in cd

Annex H
(informative)

Explanation of the principles used for the requirements of Annex E

H.1 Background

The **accessible emission limits AEL** of Annex E ensure that optical radiation from **electric toys** (during normal use and under foreseeable misuse) do not exceed exposure limits recommended by the International Commission on Non-Ionizing radiation Protection (ICNIRP). These limits are maximum levels of exposure that are not expected to result in adverse health effects.

The **accessible emission limits** for **LEDs** have been set to ensure that any focussing of the emission will not increase the risk of injury significantly.

IEC 62471 on the safety of lamp systems contains a classification scheme for **LED** products. However, the limits and the exposure scenarios of the classification scheme are not considered appropriate for **electric toys** as factors such as viewing time and distances, are often too onerous. Therefore, the values and the assessment methodology in Annex E have been developed based on the ICNIRP Exposure Limit Values (ELVs).

Incandescent lamps used in **electric toys** do not to pose a hazard with regard to optical radiation exposure during normal use, foreseeable use or fault conditions as the nominal supply voltage of **electric toys** is limited to 24 V. Therefore, Annex E only covers UV-emitting lamps, **LEDs** and **lasers**.

Where data sheet information is not available, or not valid for the application of the LED, measurement according to 19.E.2.1 should be used. When data sheets are used it is the **electric toy** manufacturer's responsibility to ensure the accuracy of the data sheets.

H.2 Hazards

Three optical radiation hazards have been considered in Annex E:

UV hazard to the eyes,

– Blue light photochemical hazard (potential for a photochemically induced retinal injury resulting from optical radiation exposure in the wavelength range 300 nm to 700 nm) to the eye retina; and
– Infrared hazard to the cornea and the eye lens;
– UV radiation with wavelengths below 315 nm, UVB and UVC, should not be used in **electric toys**. Therefore **electric toys** with emissions of wavelengths below 315 nm are restricted to very low levels.

H.3 Exposure scenarios

To determine the **accessible emission limits** (**AELs**) for **LEDs**, two different exposure scenarios were considered:

– The first exposure scenario represents a child staring directly into a light source at close range. As a conservative choice of this foreseeable misuse condition a viewing distance of 10 mm over a time of 100 s was selected.
– The second exposure scenario represents longer term direct viewing. As a worst case condition of use a viewing distance of 200 mm, as an approximation of the length of a

child arm, over a time of 30 000 s for UV exposure and 10 000 s for blue light source exposure was selected.

The **AELs** in Annex E were chosen by comparing the two exposure scenarios and using the more restrictive of the two values.

H.4 Accessible emission limits (AEL)

H.4.1 UVA AEL

Concerning UVA and the ICNIRP ELV of 10 000 Jm^{-2}, the UVA **AEL** for each exposure scenario was calculated as follows:

At 200 mm $$AEL_{315-400\ nm} = \frac{10000\ Jm^{-2}}{30000\ s} = 0{,}333\ Wm^{-2}$$

At 10 mm $$AEL_{315-400\ nm} = \frac{10000\ Jm^{-2}}{100\ s} = 100\ Wm^{-2}$$

Considering how the **LED** is viewed and taking into account the solid angle of the **LED** emission, the UVA **AEL** at 10 mm for 100 s is more restrictive than the UVA **AEL** at 200 mm for 8 h:

At 200 mm
AEL (W) = **AEL** (Wm^{-2}) × Area (m^2)
= 0,333 Wm^{-2} × (solid angle Ω × $distance^2$)
= 0,333 Wm^{-2} × (Ω × 0,04 m^2) = (0,0133 × Ω) W.

At 10 mm
AEL (W) = **AEL** (W m^{-2}) × Area (m^2)
= 100 Wm^{-2} × (solid angle Ω × $distance^2$)
=100 Wm^{-2} × (Ω × 0,0001 m^2) = (0,01 × Ω) W.

Therefore, the most restrictive value of (0,01 × Ω) W or 0,01 Wsr^{-1} is introduced as the **AEL** in 19.E.2.2, where Ω is the solid angle of **LED** emission.

The requirements of 19.E.2.2 detail how to assess this limit when technical data sheets express output in watts and the solid angle is presented as a function of the **half width half maximum** (**HWHM**) angle.

The UVA **AEL** only applies to the spectral range of 315 nm to 400 nm. Therefore, **LEDs** having emissions with wavelengths above and below 400 nm, only the portion of the emission with wavelengths below 400 nm are included as contributing to the UVA **AEL**. To allow for this, a relaxation factor A has been introduced in the formula for calculating the limit in 19.E.2.2. The relaxation factor accounts for the percentage of emission below 400 nm with respect to total emission depending on the peak emission wavelength λ and **spectral emission bandwidth** and is given in Table E.1.

Please note that with UV **LEDs**, the human aversion response may be compromised, even though the **LED** may have a high output power. A child's curiosity triggered by fluorescence of the eye lens may even increase the possibility of harmful exposure. This exposure has been considered when setting the exposure scenarios.

It is also a fact that the transmittance of UV through the crystalline lens is much higher for children under the age of 2 years than for older children. To account for this a correction factor, C, has been included in the formula for calculating the limit in 19.E.2.2. This correction factor reduces the UVA **AEL** by a factor of 10 for **electric toys** intended for children under 3 years of age.