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sense and simplicity

A closer look at photobiological safety measurements

Egbert Lenderink
Philips Lighting
May 4-6, 2011

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Outline

- Photobiological safety standards and risk groups
- A closer look at the required measurement conditions
- Quantitative implications of measurement condition choice
- Transferring risk group information from light source to fixture
- Summary and conclusions

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Photobiological safety: IEC 62471

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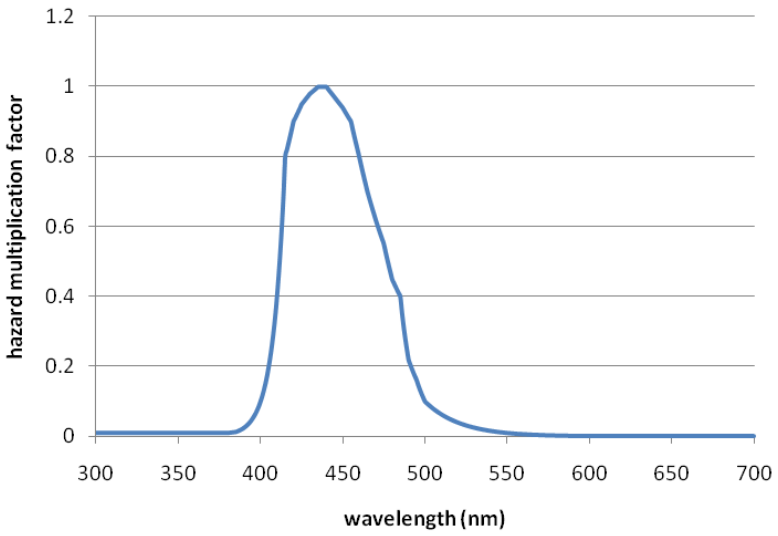
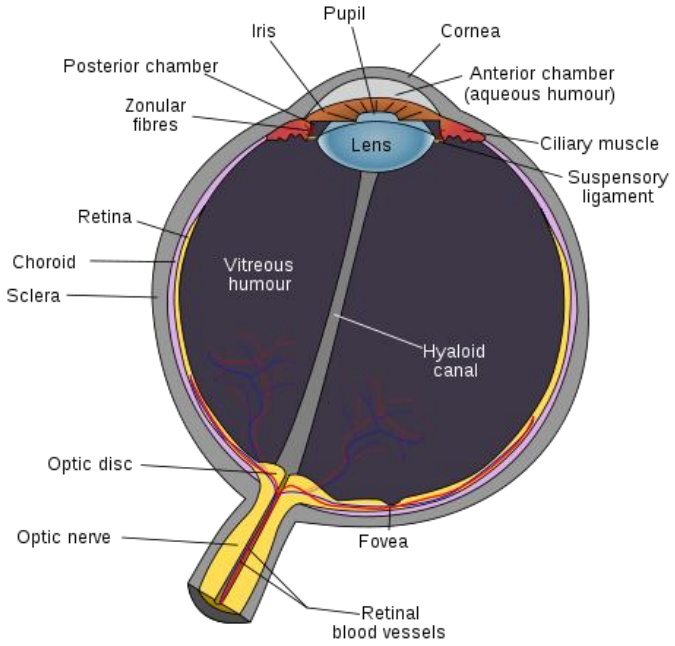
Blue light hazard

- Leading cause of eye damage after looking into sun, welding arcs, etc.
- Photochemical damage of retina
- Action spectrum described, peaks around 450 nm
- Radiation density on retina depends partly on *luminance* of the source





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Exposure limits: large source

- Source is imaged over a certain area of the retina
- **Luminance of the source** determines the local illuminance at the retina, and is therefore used to set the exposure limit
- Quantity L_B: blue-light weighted radiance, unit W/m²sr
- Large source if subtended angle > specified viewing angle

For a weighted source radiance, L_B, exceeding 100 $W \cdot m^{-2} \cdot sr^{-1}$, the maximum permissible exposure duration, t_{max}, shall be computed:

$$t_{max} = \frac{10^6}{L_B} \quad \text{s} \quad (\text{for } t \leq 10^4 \text{ s}) \quad (4.6)$$

where:

t_{max} is the maximum permissible exposure duration in seconds,
L_B is the blue-light hazard weighted radiance.

Note 1: The spectral radiance L_λ shall be averaged over a right circular cone field-of-view of α_{eff}, as described in clause 4.2.2.

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Exposure limits: small source

- Source is essentially not imaged sharply and/or constantly moving over retina due to eye and head movements
- **Illuminance on the eye pupil** determines the exposure limit
- Quantity E_B: blue-light weighted irradiance, unit W/m²
- Small source if subtended angle < specified viewing angle

For a source where the blue light weighted irradiance, E_B, exceeds 0,01 $W \cdot m^{-2}$, the maximum permissible exposure duration shall be computed:

$$t_{max} = \frac{100}{E_B} \quad \text{s} \quad (\text{for } t \leq 100 \text{ s}) \quad (4.8)$$

where:

t_{max} is the maximum permissible exposure duration in seconds,
E_B is the blue light hazard weighted irradiance.

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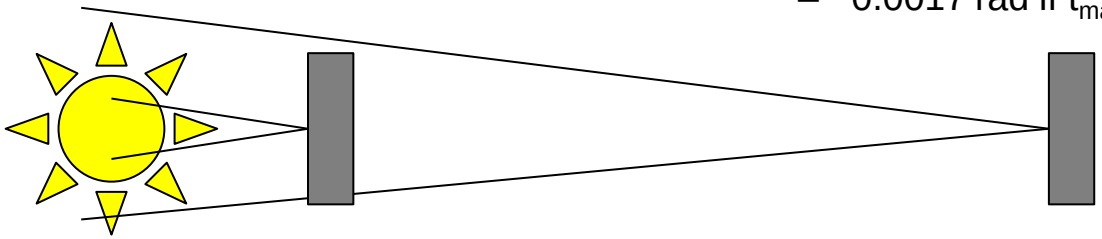
Risk classifications and labeling requirements

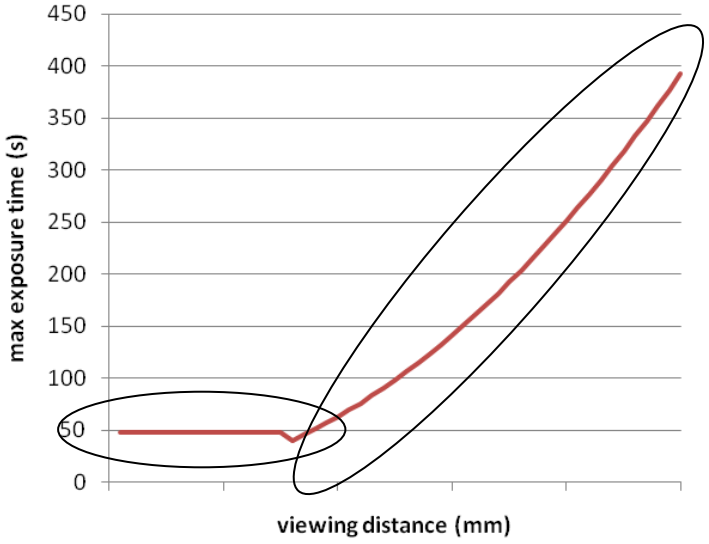
risk group	t_{max} for blue light hazard	max L_B (large source) or E_B (small source)	labeling requirement
0: Exempt	>10,000 s	100 W/m²sr or 1 W/m²	none
1: Low risk	100-10,000 s	10,000 W/m²sr or 1 W/m²	none
2: Moderate risk	0.25-100 s	4,000,000 W/m²sr or 400 W/m²	**CAUTION** Possibly hazardous optical radiation emitted from this product. Do not stare at operating lamp. May be harmful to the eyes.
3: High risk	<0.25 s		**WARNING** Possibly hazardous optical radiation emitted from this product. Do not look at operating lamp. Eye injury may result.

Conditions affecting outcome of measurement

- Distance
- Viewing angle

- IEC 62471 prescription:
  - general lighting services: distance where illuminance = 500 lux
  - all other or unknown applications: 200 mm
  - 0.011 rad if t_{max} > 10 s
  - 0.0017 rad if t_{max} < 0.25 s





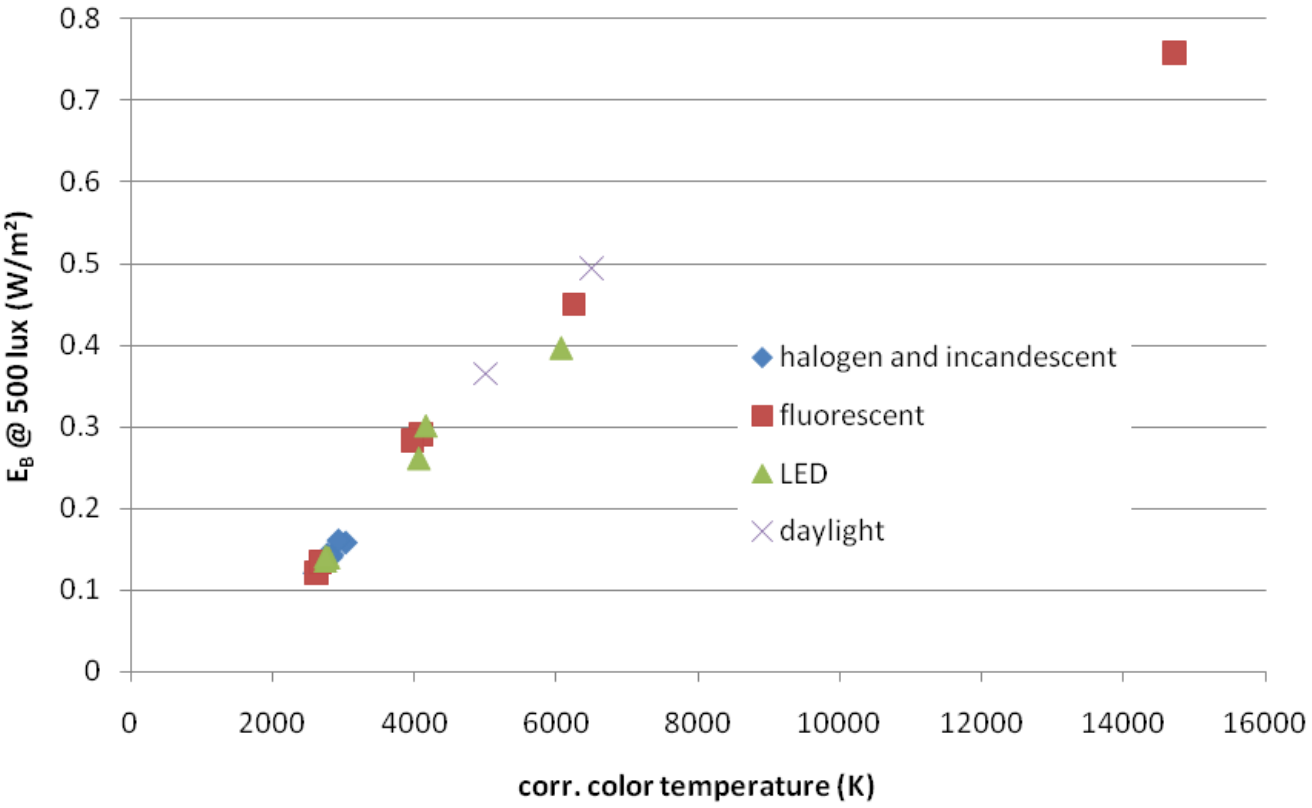
short distance:
large source regime
t_{max} determined by L_B

longer distance:
small source regime
t_{max} determined by E_B

A closer look at 500 lux

- Two possibilities at the distance corresponding to 500 lux:
  - Light source is *small* : determine E_B
    - Total emission spectrum, scaled to 500 lux, weighted with the blue hazard action spectrum
  - Light source is *large*: determine L_B
    - Spectral radiance measurement from the brightest part of the source, averaged over the area corresponding to the specified viewing angle, weighted with the blue hazard action spectrum
- Measurements and calculations to gain understanding
  - focusing on sources of **white light**
  - lamps of various technologies

E_B at 500 lux measurement if in small source regime

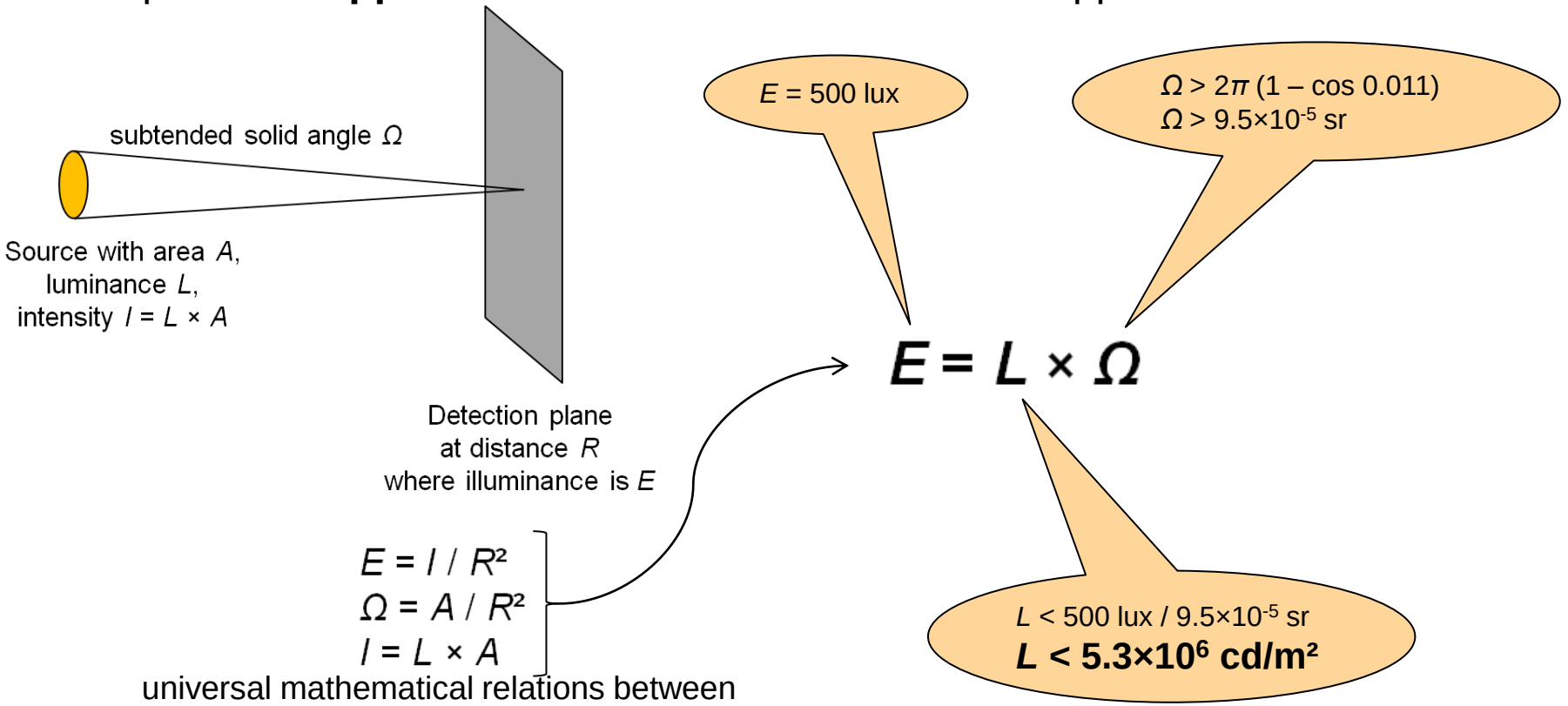


Correlates mainly with CCT, only very slightly with spectral details related to lamp technology
Throughout this CCT range: always below the 1 W/m² limit where t_{max} = 100 s

500 lux in the large source regime

- Combination of the two conditions
  - *E = 500 lux*
  - *subtended angle > 0.011 rad (large source condition)*

  poses an **upper limit** to the source luminance of approx **5 Mcd/m²**



universal mathematical relations between photometrical and geometrical quantities

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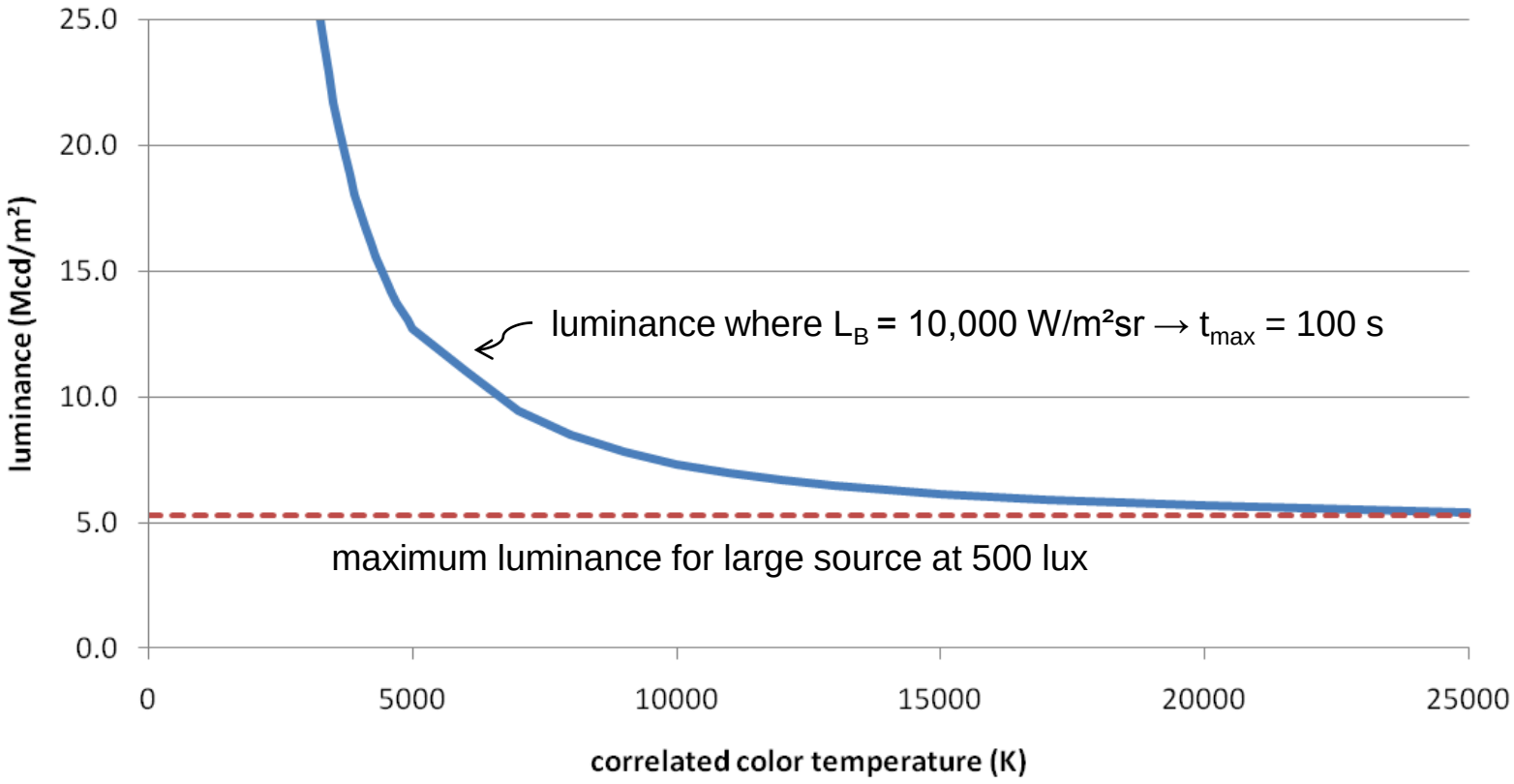
Luminance value where t_{max} = 100 s



Conclusion on 500 lux measurement

- No **white** light source can be measured to be higher than RG 1 at 500 lux!
  - If it is a *large* source at the 500 lux distance, the resulting L_B is always below 10,000 W/m²sr
    - RG 2 luminance and large source size by necessity >500 lux
  - If it is a *small* source at the 500 lux distance, the resulting E_B is always below 1 W/m²
    - This is a property of white light spectra, hardly influenced by other properties of the light source

Note: The 500 lux measurement does not discriminate if the source would fall into higher RG at shorter distances!

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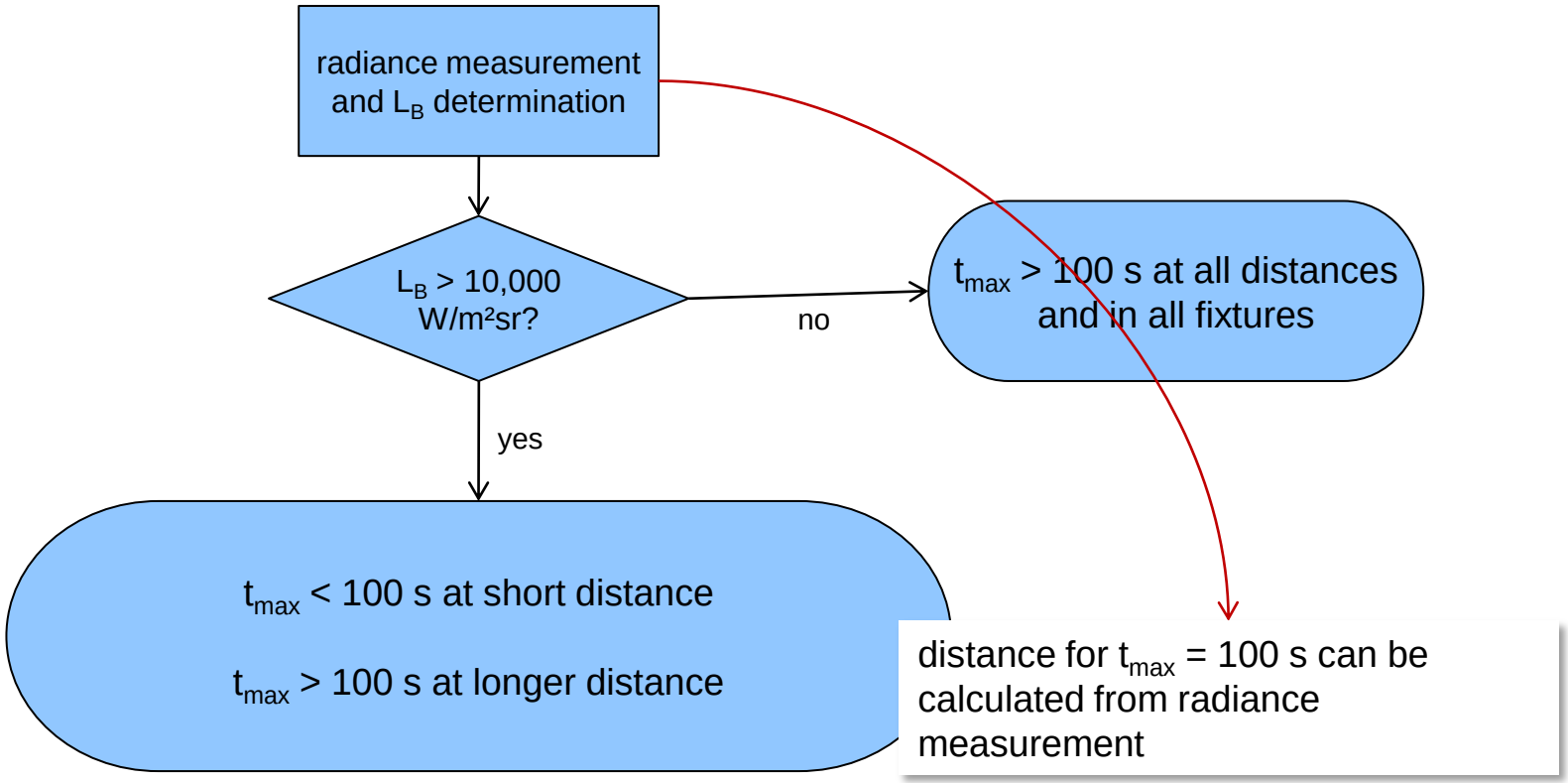
Outcome of the 200 mm measurement

- Nearly all sources are large → L_B is determined



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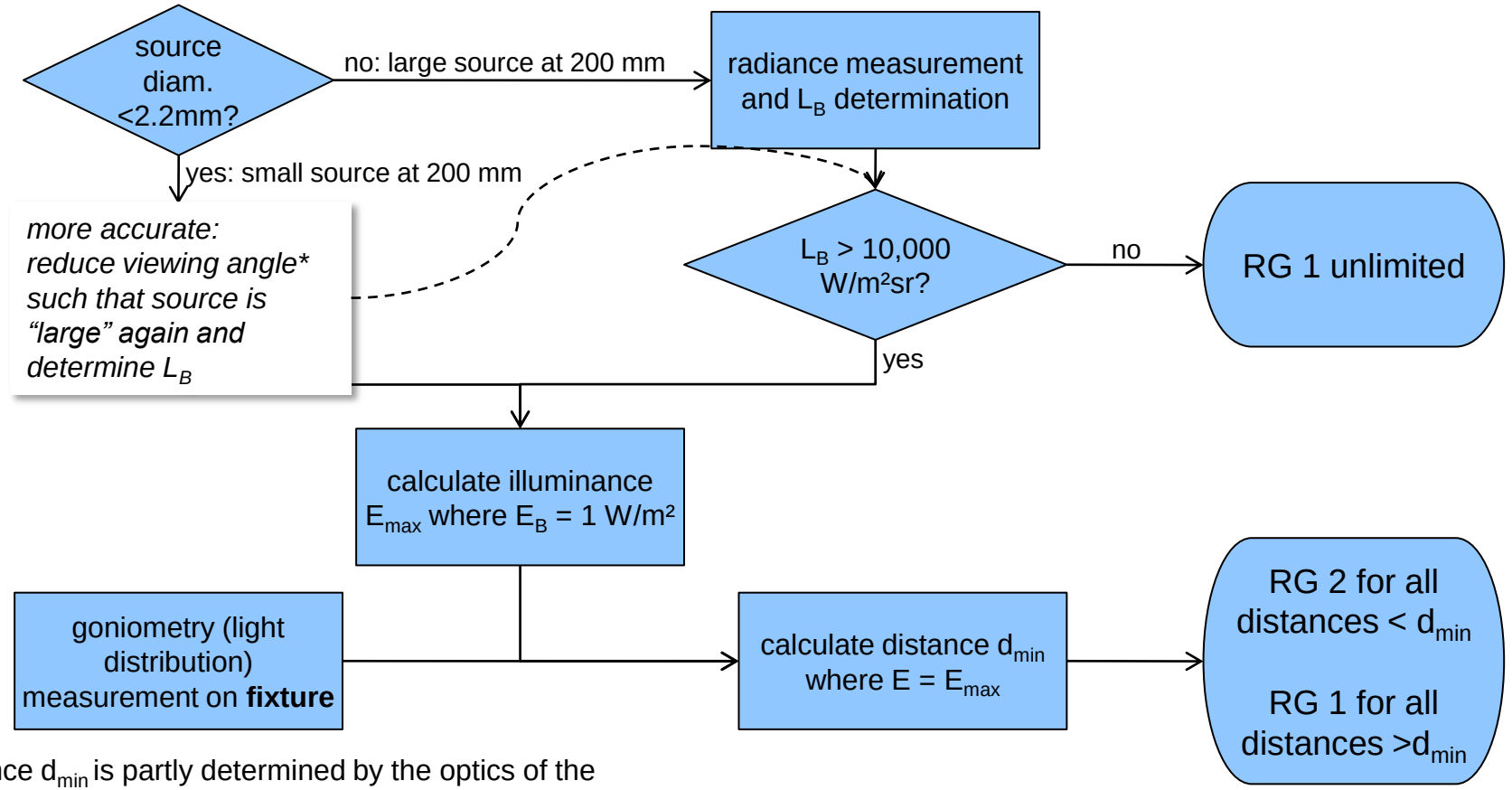
Transfer data from light source to fixture

- Optical law: luminance/radiance cannot be **increased** by any optical system
  - remains the same in clear optics
  - is reduced in diffusive optics
- Outcome of L_B measurement can be transferred from light source to lighting fixture!

Information flow (clear optics)



The distance d_{min} is partly determined by the optics of the **fixture**. It is not a value that can be transferred from the source to the fixture without an additional measurement on the light distribution of the fixture.

*Agreement needed on relevant viewing angle.

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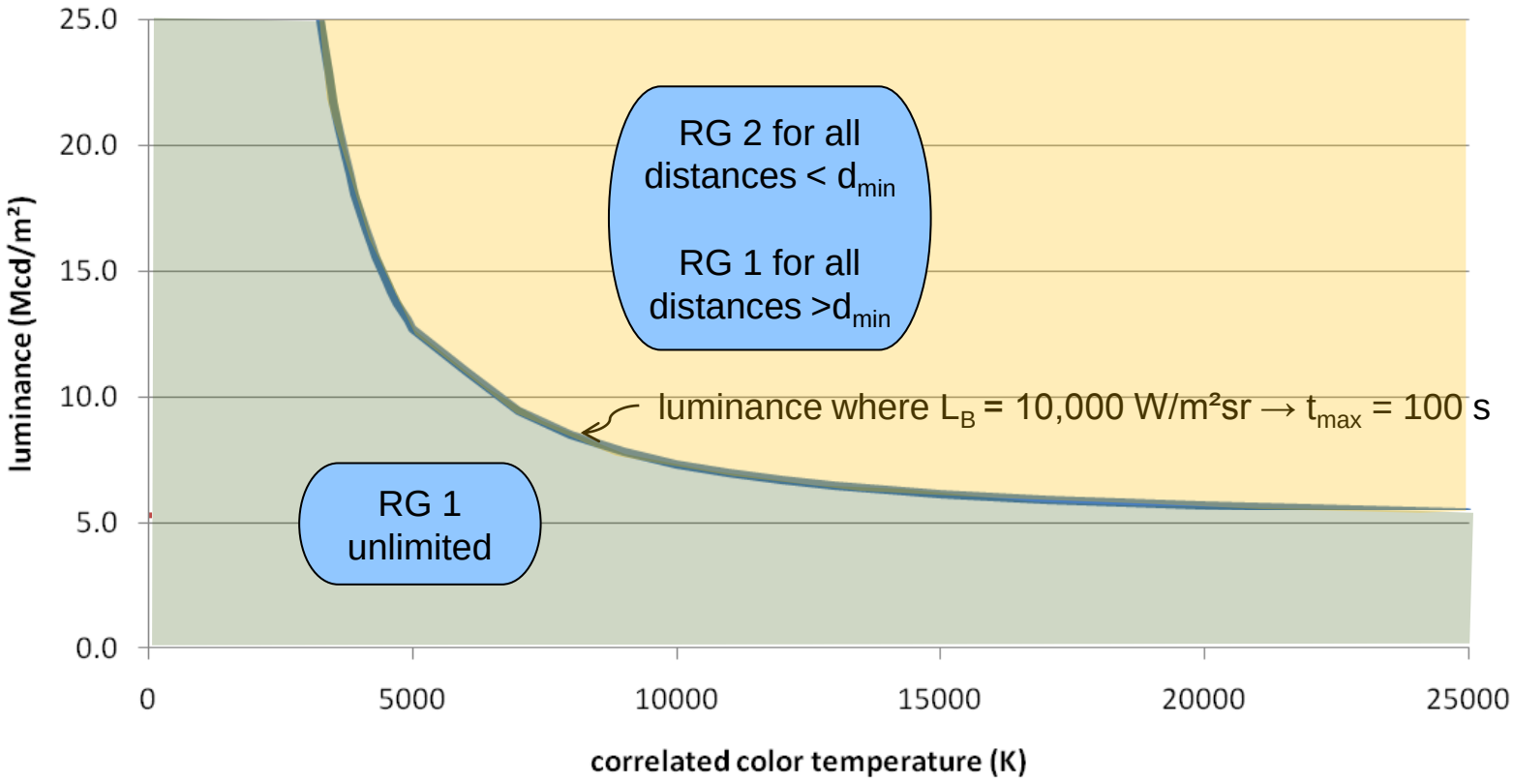
Relation with CCT and source luminance



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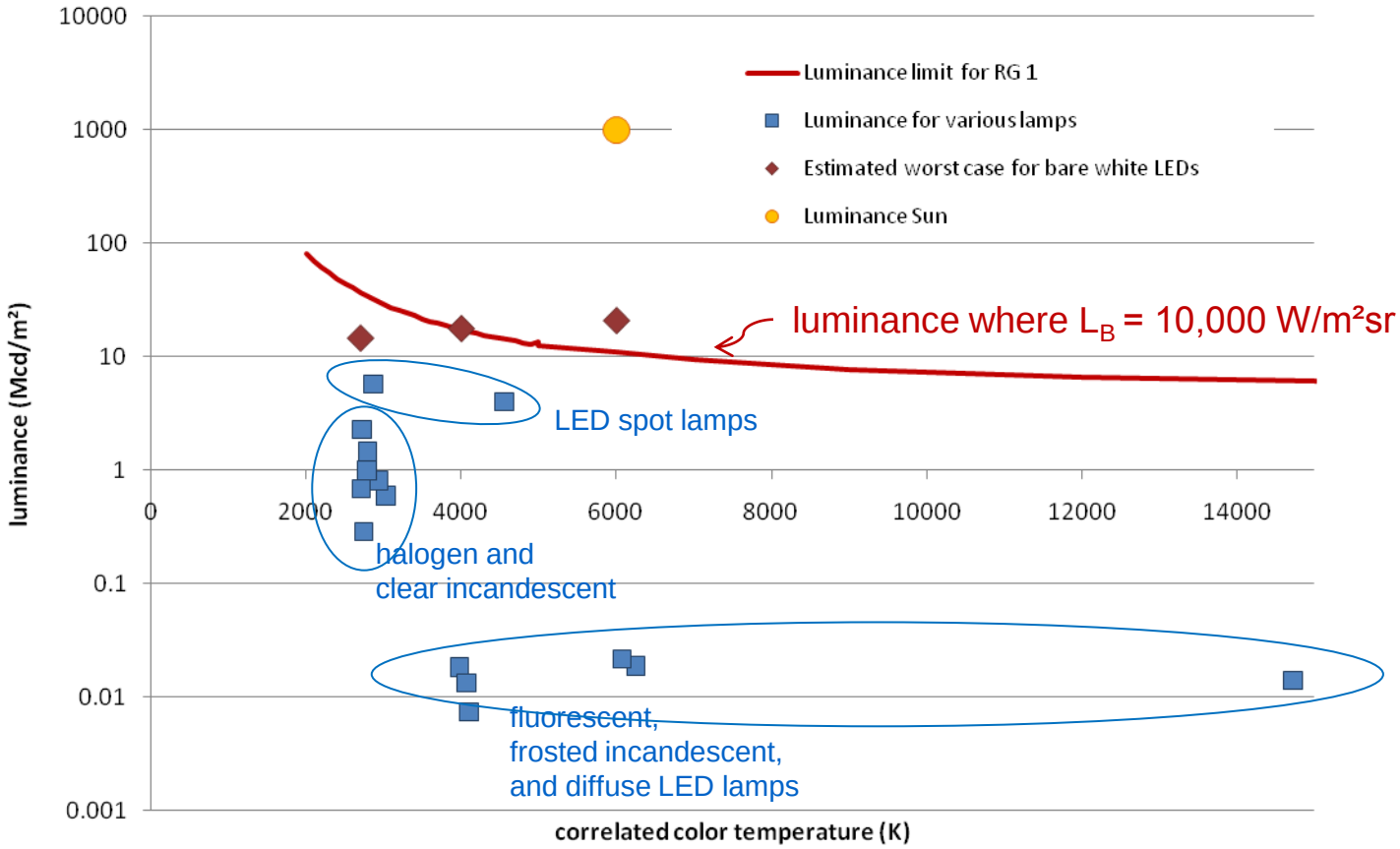
Concrete examples of light sources



Conclusions

- The blue-hazard risk correlates mainly with color temperature and source luminance, hardly with spectral details related to lamp technology
- The 200 mm measurement gives more complete information than the 500 lux measurement
  - Can be converted to quantities that give adequate information on maximum exposure time at all distances
  - Gives information that can be transferred from light source to lighting fixture
  - Agreement needed on relevant viewing angle for sources < 2.2 mm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