Spectrometric solutions from components to systems

JETI TECHNISCHE INSTRUMENTE GMBH

Technical Note 34

Optical Hazard Measurements with JETI specbos 25x1-UV

Contents

1 Introduction

Modern non coherent light sources became brighter and brighter during previous years, therefore the danger of injuries of human skin and eye increases. Typical examples are LED spot lights. But also classical sources as metal halide lamps produce high intensities and can damage human organs. So the legislation created regulations to protect the population against such injuries, especially the employees of companies, theatres and workshops. These regulations contain hazard categories and related exposure limits. If the risk cannot be calculated using available data it is necessary to proceed special optical measurements to obtain the individual exposure values. The final result of a hazard evaluation will be the classification of the source into a risk group.
The following application note contains the main measurement related aspects of the regulations as well as special hints for the usage of **specbos 25x1-UV** and its accessories for this measuring task.

2 Regulations

The main legal regulations for optical hazard check-up are:

Standards IEC 62471 and **ANSI/IESNA RP-27** as well as the **directive 2006/25/EC**

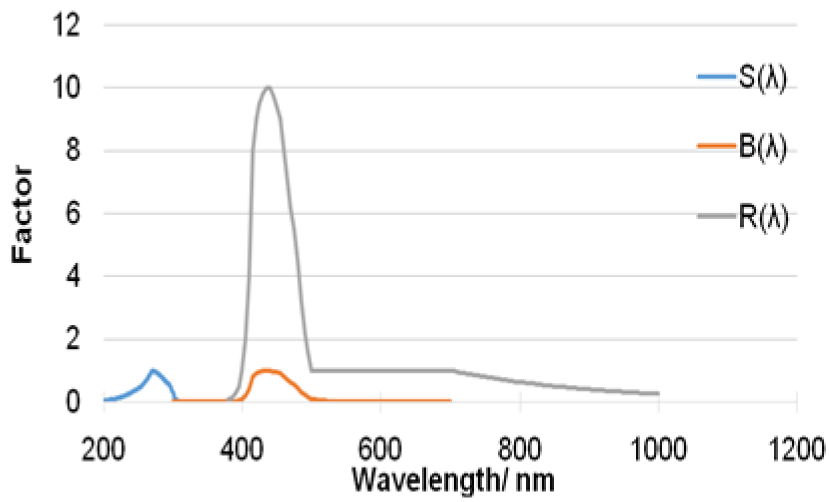
Additionally there exist many instructions and explanations about the topic, especially made by the National Employer´s Liability Insurance Associations. A good help for beginners is the **Practical Guide for 2006/25/EC**, although containing many typing errors. A special standard with the topic Blue Light Hazard is **IEC/TR 62778**. There exist also light source specific standards as **IEC 62471-5** for image projectors and **IEC 62035** for discharge lamps.
All these regulations define several hazard effects (categories), their exposure limits, how to measure or calculate the radiation and contain specific comments. The measurements can be distinguished between radiance based and irradiance based types. After getting acquainted with these regulations, it becomes clear that especially the radiance based measurements are different from standard radiometric measurements because the sources can be inhomogeneous or point like. This is not the case in general light measurement applications, where only homogeneous sources as TV screens are characterized by their radiance/ luminance.
It is recommended to proceed the measurements using a double monochromator due to its superiour stray light properties, but such device is expensive, heavy and difficult to transport. Therefore it is possible to use filter instruments or spectro radiometers, but only, if the user has convinced himself by measuring uncertainty considerations that the measuring results will be within the accepted tolerances.

3 Categories of Optical Hazard

The mentioned documents define several hazard quantities concerning human eye and human skin. The measurements related to skin and cornea of the eye are irradiance-based measurements, whereas the measurements related to the retina of the eye are radiance based measurements. Some values are obtained directly as integral values of a defined spectral range, whereas others are obtained by applying spectral weighting functions (actinic spectra) and a following integration of the modified spectrum.
The following table shows all hazard categories and the diagram below shows the weighting functions:

Measuring quantity	Hazard	Abbreviation	Eye/ skin	Weighting function	Wavelength range/ nm
Irradiance	Eye UV-A	E_{UVA}	Eye	-	315 ... 400
	Actinic UV	E_s	Eye & Skin	S(λ)	200 ... 400
	Blue Light (Small Source)	E_B	Eye	B(λ)	300 ... 700
	IR	E_{IR}	Eye	-	780 ... 3000
	Thermal	E_H	Skin	-	380 ... 3000
Radiance	Blue light	L_B	Eye	B(λ)	300 ... 700
	Retina, Thermal	L_R	Eye	R(λ)	380 ... 1400
	Retina, Thermal, (Low Visual Stimulus)	L_{IR}	Eye	R(λ)	780 ... 1400

Table 1. Optical hazards for human eye and skin



S(λ) – UV hazard for skin and eye
B(λ) – Blue light hazard for human eye
R(λ) – Burn hazard

Fig. 1 Actinic (weighting) spectra

Five categories are based on Irradiance measurements and three categories on Radiance measurements. The ANSI/IESNA regulation includes an additional category for the lenseless eye (Aphakic eye).
All categories can be measured using **specbos 25x1-UV** and its special hazard measuring accessories and the hazard calculation preset of JETI LIVal. It is necessary to keep in mind that the device measures from 200 to 1100 nm. Therefore the last 300 nm of thermal hazard of the retina and the range between 1 and 3 µm of E_{IR} and E_H cannot be measured. It must be ensured that the source under test does not emit in these missing wavelength ranges. The type and technology of the source is often known and so it is clear if an emission below 200 nm and above 1 100 nm can be expected or not.

4 Available Accessories for JETI specbos 25x1-UV

The following table shows the accessories of **specbos 25x1-UV** for the different hazard measurements:

Hazard category	Name of the accessory	Part number
Blue light, > 10 000 s	Beam shaping optics for 100 mrad Radiance measurement with internal OD2 filter and external filters OD1 + OD2	included in ACC 080
	Beam shaping optics for 100 mrad Radiance measurement with internal OD2 filter and external filters OD1 + OD2	ACC 080/100
	Mechanical elements for turning / tilting to find the maximum emission with ACC 024	ACC 025
Blue light, 10 s to 100 s	Beam shaping optics for 11 mrad Radiance measurement and external filters OD1 + OD2	included in ACC 080
	Beam shaping optics for 11 mrad Radiance measurement and external filters OD1 + OD2	ACC 080/11
Blue light, small source	Diffusor for Irradiance measurement, measuring area ø 8mm	ACC 081
Eye UV-A, Actinic UV, Eye IR, Skin thermal	Diffusor for Irradiance measurement - Actinic UV and UV-A hazard, measuring area ø 8mm	ACC 081
	80° aperture for Diffusor ACC 026	ACC 027
Retina, thermal (and weak stimulus)	Beam shaping optics for 11 mrad Radiance measurement with filters OD1 + OD2	ACC 080/11
	Aperture tube for 1.7 mrad measurements only in combination with ACC 081 (fixed measuring distance 200 mm)	ACC 054

Table 2. Accessories for hazard measurement

The original measuring angle of **specbos 25x1-UV** is 2.1° = 32 mrad. Therefore for the Blue light Hazard measurements beam shaping optics for 100 mrad (fig. 2) and 11 mrad (fig. 3) are available. Both optics include internal OD 2 filters. The optics will be screwed on the measuring head of the device and the appropriate calibration file will be loaded automatically.

The measuring diameter with the standard diffusor, delivered with **specbos 25x1-UV** is around 4 mm. Therefore the Irradiance based hazard measurements have to be done with a special diffusor to be compliant to IEC 62471 (measuring diameter ≥ 7 mm). If the angular subtense of source is larger than 80°, then it is necessary to use a limiting aperture for the diffusor in case of UV-A and actinic UV measurements (see fig. 4 and table 3).

Fig. 2 Beam shaping optics for 100 mrad (ACC 080/100) and 11 mrad (ACC 080/11)

Fig.3 UV Diffusor ACC 081, diameter = 8 mm

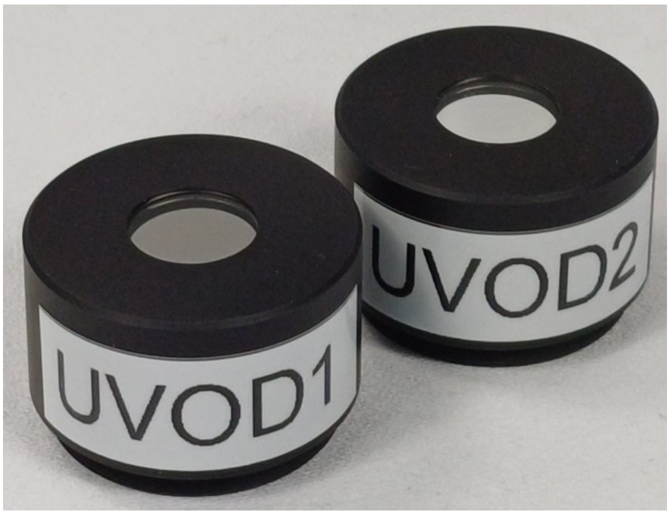


Fig. 4 External UV Filter OD1.0 and OD 2.0

Fig. 5 specbos 2501-UV mounted on mechanical elements for turning/ tilting (ACC 025)

The Radiance of sources to be tested is sometimes as high, that additional attenuation filters are necessary. 10 fold attenuation (OD 1) and 100 fold attenuation (OD 2) are available for **specbos 25x1-UV** (see fig. 5). If one of these filters is used, the related calibration file (optics + filter) must be selected manually in JETI LiVal to get correct readings, because it cannot be recognized by the instrument (see 7.7.).

The software JETI LiVal includes a special hazard measuring window in the custom preset menu:

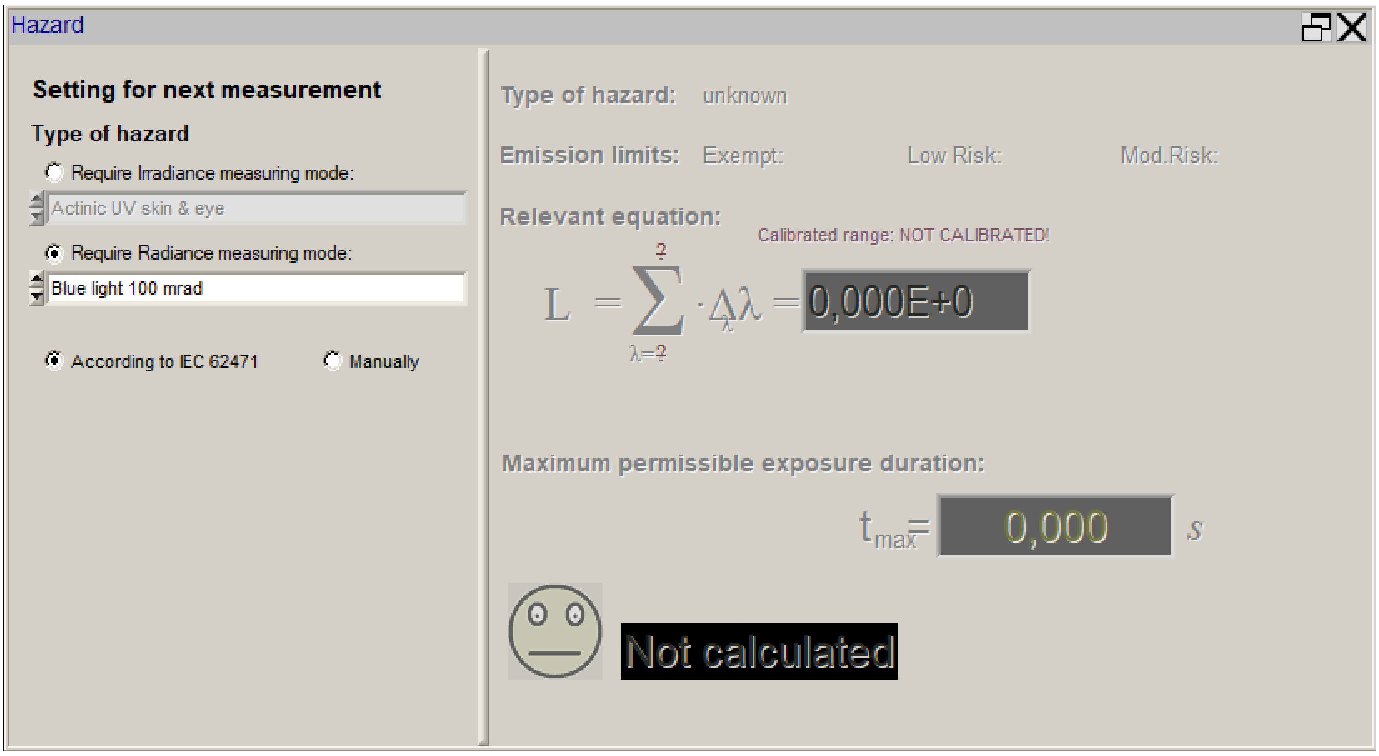


Fig. 6 Hazard window set to the Blue light hazard measurement

It includes the emission limits for each category, the measuring result of the hazard quantity, the maximum permissable exposure time and the related risk group for the category.
All data of the following table are already included in the software and will be used for the hazard measurement and classification:

Hazard Name	Accessory	Exposure Duration t_{max} (s)	Limiting Aperture rad (deg)	Relevant Equation	Exposure Limit W/m²
Eye UV-A (E_{UVA})	8 mm Diffusor (+UV filter)	≤ 1000 > 1000	1.4 (80)	$E_{UVA} = \sum_{315}^{400} E_\lambda \cdot \Delta\lambda$	10000/t 10
Actinic UV (E_s)	8 mm Diffusor (+UV filter)	< 30000	1.4 (80)	$E_S = \sum_{200}^{400} E_\lambda \cdot S(\lambda) \cdot \Delta\lambda$	30/t
Blue Light (Small Source) (E_B)	8 mm Diffusor	≤ 100 100	< 0.011	$E_B = \sum_{300}^{700} E_\lambda \cdot .B(\lambda) \cdot \Delta\lambda$	100/t 1.0
Eye IR	8 mm Diffusor	≤ 1000 > 1000	1.4 (80)	$E_{IR} = \sum_{780}^{3000} E_\lambda \cdot \Delta\lambda$	18000/$t^{0.75}$ 100
Skin thermal	8 mm Diffusor	< 10	1.4 (80)	$E_H = \sum_{380}^{3000} E_\lambda \cdot \Delta\lambda$	20000/$t^{0.75}$
Blue Light (L_B)	- 11 mrad optics 100 mrad optics	0.25 to 10 10 to 100 100 to 10000 ≥ 10000	0.011√(t/10) 0.011 0.0011√t 0.1	$L_B = \sum_{300}^{700} L_\lambda \cdot .B(\lambda) \cdot \Delta\lambda$	10^6/t 10^6/t 10^6/t 100
Retina thermal (L_R)	- 11 mrad optics	< 0.25 0.25 … 10	0.0017 0.011√(t/10)	$L_R = \sum_{380}^{1400} L_\lambda \cdot .R(\lambda) \cdot .\Delta\lambda$	$\frac{5000}{\alpha * t^{0.25}}$ $\frac{5000}{\alpha * t^{0.25}}$
Retina thermal, weak visual stimulus (L_{IR})	11 mrad optics	> 10	0.011	$L_{IR} = \sum_{780}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$	6000/α

Table 3. Summary of exposure limits for human eye and skin with related accessories of specbos 25x1-UV for Irradiance (above) and Radiance measurements (below)

5 Schemes and Peculiarities of the Measurements

The following two figures show schemes for radiance and irradiance based measurements from the regulation documents:

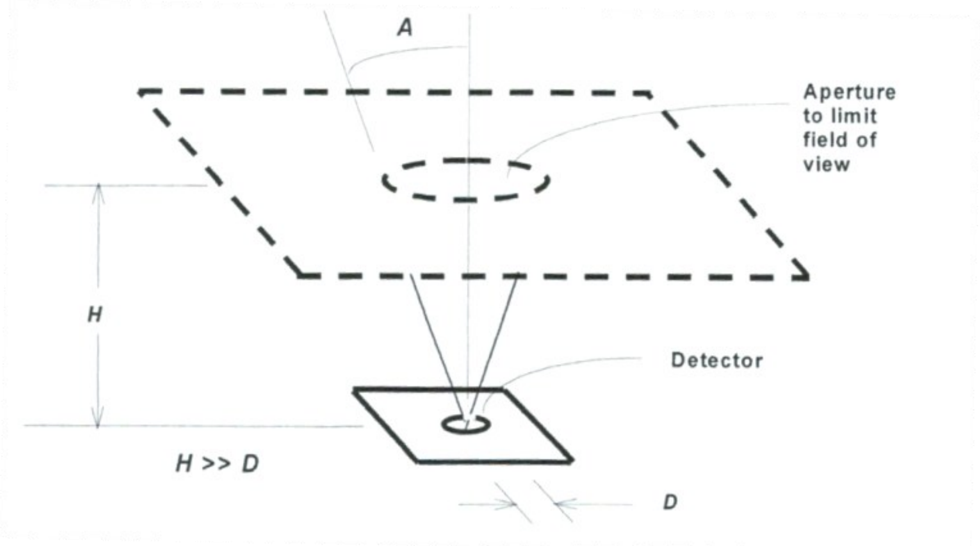


Fig. 7 Scheme of irradiance based measurements (picture: specbos 2511-UV with diffusor)

The peculiarity of Irradiance based UV hazard measurements is, that they must have a 80° angular limitation. This limitation can already be caused by the source itself or it must be created by the appropriate aperture (ACC 027).

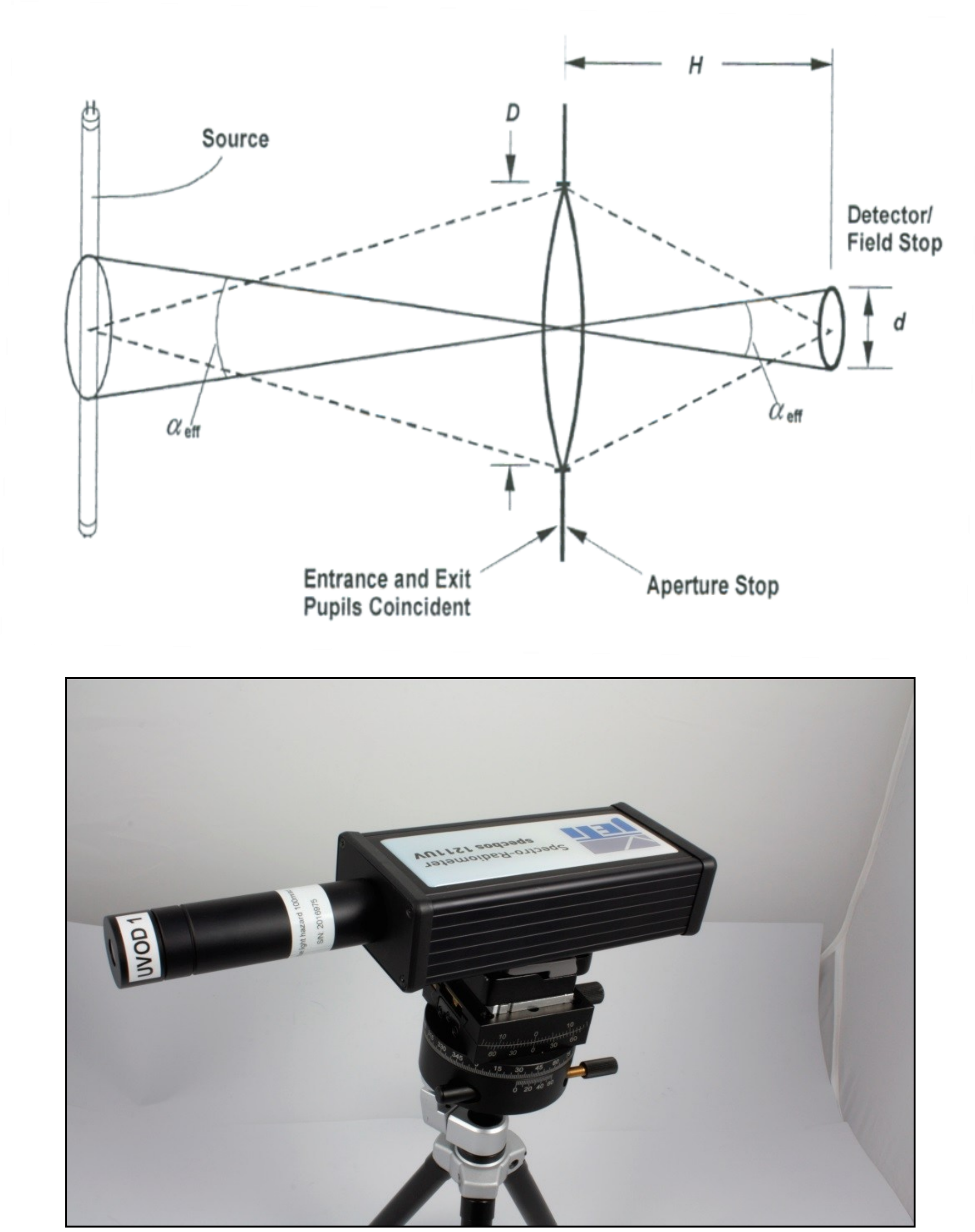


Fig. 8 Scheme of radiance based measurements (picture: specbos 2501-UV with 100 mrad optics and additional OD1 filter)

A peculiarity of the Radiance measuring based types is, that they must be done under specified angular conditions with related exposure times. Therefore the 100 mrad and 11 mrad beam shaping optics are available for **specbos 25x1-UV**. A 1.7 mrad FOV external optics for short exposure time of less than 10 s is not yet available, because such measurements are always related to the extreme risk group 3. But it can be

used the alternative method (see ACC 054 aperture tube for 1.7 mrad in combination with diffusor in tab. 2) in such cases.
Another feature of these measurements is, that the field of view don´t needs to be fully filled by a homogeneous source as it is usual in normal light measuring applications (see fig. 9 left), but the source can fill the FOV only partly (see fig. 9 right). The reason is, that the measuring angle represents the eye movement: the longer the exposure time, the larger is the angle.

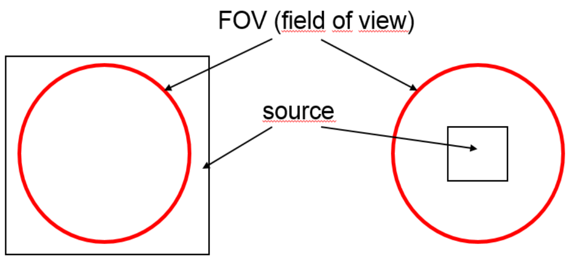


Fig. 9 Relation between the size of the source and the field of view in Radiance based measurements

The final specific feature is that the sources under test are often very bright and can produce extremely high luminance values up to around 75 000 000 cd/m^2. In such cases it will be necessary to apply the already mentioned attenuation filters to avoid overexposure of the meter.

Measuring distance:
The standard IES 62471 states that the measuring distance for lamps intended for general lighting services (GLS) shall be the position, where 500 lx are reached. The minimum distance shall be 200 mm, as it shall be the case for all other lamps. This definition is not reasonable for some special lamps like street lamps or spot lights. In such cases the measuring distance should be the minimum operation distance.
The measuring distance counts from the front face of each accessory.

6 General Procedure of Hazard Measurements

The following list gives an overview of the steps for a hazard measurement:

1. Define which categories of hazard are valid for the source under test (depending from its wavelength range).
2. Define the measuring distance (500 lx distance or 200 mm or the nearest operation distance, e.g. for spotlights or street lights).
3. Determine the angular subtense of the source (for Blue light, UV-A and Actinic UV hazards).
4. Determine the needed accessories.
5. Position the meter in the correct distance to the source (a laser distance meter may be helpful in some cases).
6. Adjust the meter to get the maximum readings in case of Radiance based categories (for tilting use mechanical elements ACC 025).
7. Proceed the measurement.
8. Calculate the hazard value, the maximum permissible exposure time and the risk group.

7 Hazard Measurement Steps using specbos 25x1-UV and the JETI LiVal Software

This paragraph describes the steps of the measurement more in detail:

1. **specbos 25x1-UV** must be mounted on the two-axis goniometric and tripod setup as shown in fig. 10.
2. Switch 'ON' the light source to be tested with its appropriate power supply. Wait for the necessary heat up time. Connect the spectroradiometer to PC and place it in front of the light source. Start the software JETI LiVal.

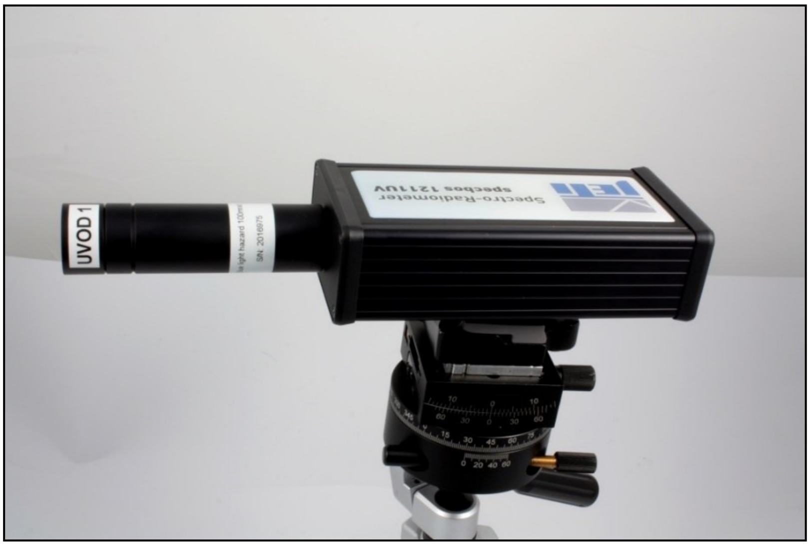


Fig. 10 Goniometer and tripod setup

3. Set the tripod in the measuring distance to the light source. Use either the distance where 500 lx are reached (measure it with diffusor on the device), 200 mm or the minimum operation distance). Adjust the target circle into the centre of the light source (instrument without accessory).

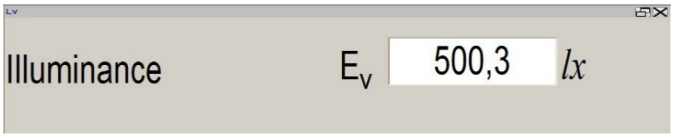


Fig. 11 “Lux meter” window of LiVal

Fig. 12 Adjusting the target circle into the centre of the light source

4. a) **Steps for radiance-based measurements:**
   Attach one of the beam shaping optics (100 mrad or 11 mrad) and adjust the instrument for maximum signal. Use the goniometer screws and the Maximal Signal targeting help in the Extra menu of JETI LiVal.

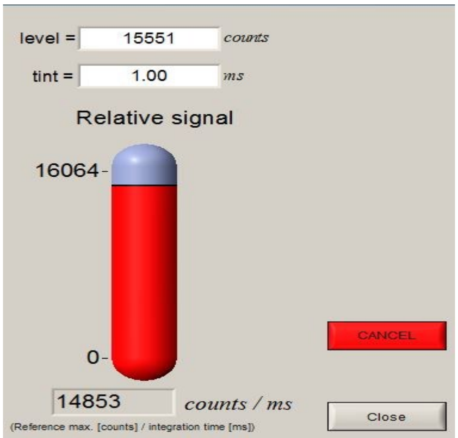


Fig. 13 Maximal signal targeting help in LiVal showing counts / ms

- For Blue Light Hazard
  To be used, if the angular subtense of the source is more than 11 mrad. Use the 100 mrad optics → Proceed blue light hazard measurements (see 5.) → Hazard results for Blue light LB are calculated by integrating the measured spectrum with the B(λ) actinic curve → If the result is not exempt group: measure with the 11 mrad optics.
- For Retina Thermal Hazard/ Retina Thermal Hazard low visual stimulus
  The measuring angle should be 11 mrad for an exposure time of 10 s. Follow the above blue light hazard measurement steps using 11 mrad external optics in the spectroradiometer → Proceed retinal thermal hazard measurements (see 5.) → Hazard results for Retinal thermal LR and LIR are calculated by integrating the measured spectrum with the R(λ) actinic curve.

b) **Steps for irradiance-based measurements:**
The following steps need to be followed for each hazard category.

- For Eye UV-A hazard

Mount the 8 mm cosine diffusor on the spectroradiometer head → Proceed Eye UV-A hazard measurements (see 5.) → Hazard results for Eye UV-A E_{UVA} will be calculated.

- For Actinic UV hazard
  Mount the 8 mm cosine diffusor on the spectroradiometer head → Proceed actinic UV hazard measurements (see 5.) → Hazard results for actinic UV E_S are calculated by integrating the measured spectrum with S(λ) actinic curve.
- Blue-light small source hazard
  To be used if the angular subtense of the source is less than 11 mrad. Mount the 8 mm cosine diffusor on the spectroradiometer head → Proceed Blue light small source hazard measurements (see 5.) → Hazard results for Blue light small source E_B are calculated by integrating the measured spectrum with B(λ) actinic curve.
- For Eye IR and Skin thermal hazard

  Mount the 8 mm cosine diffusor on the spectroradiometer head → Proceed Eye IR/ Skin thermal hazard measurements (see 5.) → Hazard results for E_H/ E_{IR} will be calculated.

5. Select the correct calibration file for the measuring head after disabling the accessories sensor in Sensor mode.

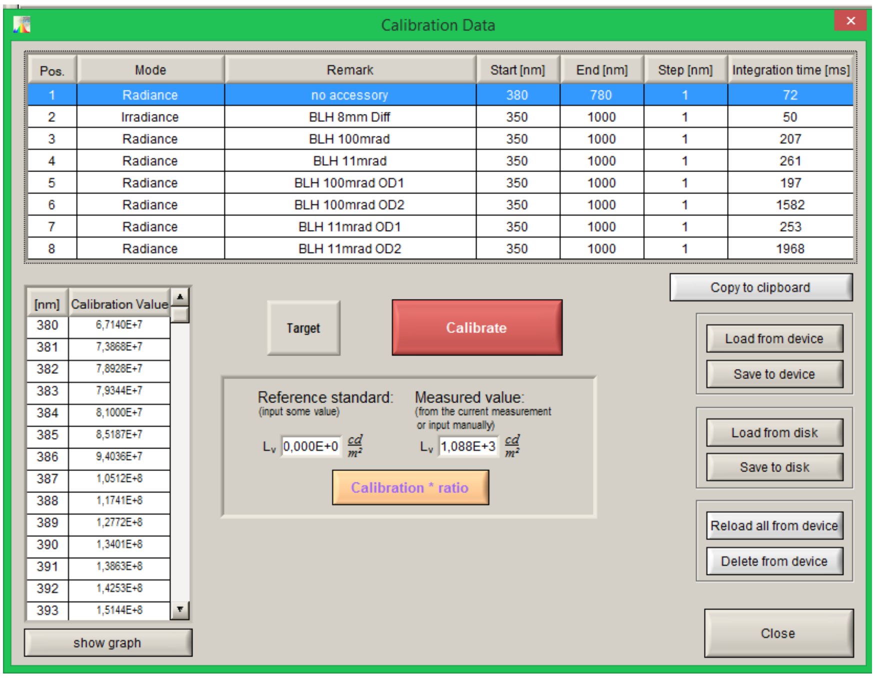


Fig. 14 Selection of calibration file and mode

6. Proceed the measurement. The hazard window of JETI LiVal software (see fig. 6) shows the limits of the different risk groups, the measured hazard quantity including the related equation, the maximum possible exposure duration and the classified risk group.
7. In case of the error message overexposure:
   An additional OD filter has to be added for brighter lighting measurements (e.g. spot lights). Start with OD1 and if still overexposure occurs, then apply OD2.
   Don´t forget to select the appropriate calibration file manually (optics + filter, e.g. pos. 5 in fig. 14).

8 Hazard Classification

8.1 Irradiance Based Hazard Measurements:

a. Eye UV-A hazard

Eye UV-A (near UV) hazard will be measured in the spectral region between 315 nm and 400 nm.

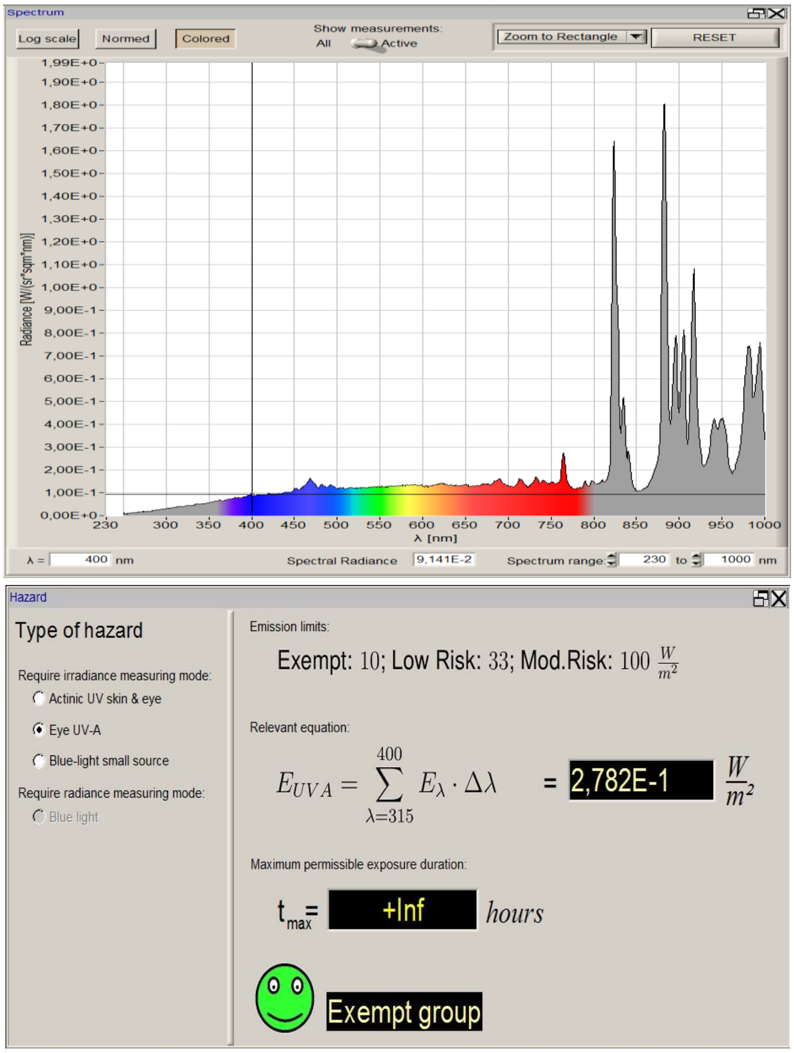


Fig. 15 Measuring result for Eye UV-A hazard measurement of a Xenon lamp

The permissible time for exposure to ultraviolet radiation upon the unprotected eye for time less than 1000 s is computed by the following formula:

$$t_{\max} \leq \frac{10000}{E_{UVA}}(s) \qquad \text{(for t < 1000 s)}$$

$$E_{UVA} \leq 10 \;\; Wm^{-2} \qquad \text{(for t} \geq \text{1000 s)}$$

b. Actinic UV hazard for Skin & Eye

Actinic UV for skin and eye hazard falls under the spectral region between 200 nm and 400 nm range. Spectral weighting function for assessing ultraviolet hazards for skin and eye is the S(λ) actinic curve.

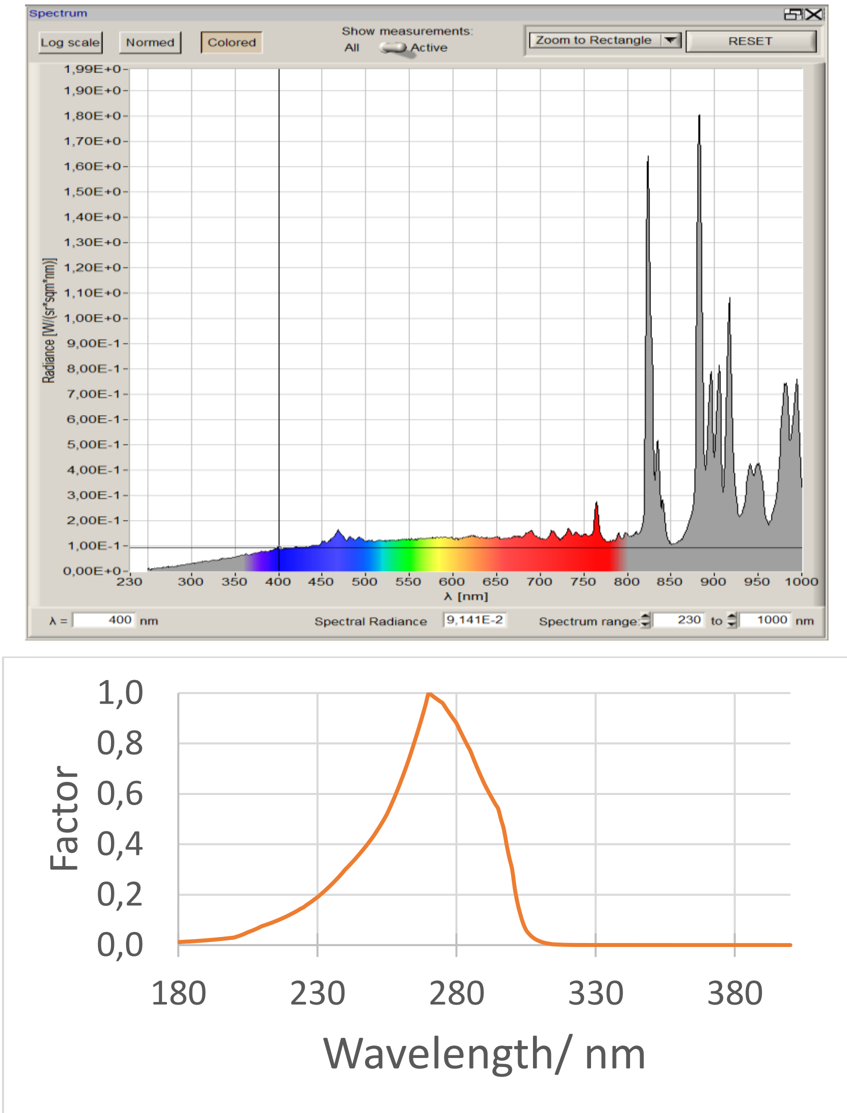


Fig. 16 Spectrum of a Xenon lamp (above) and weighting function S(λ) (below)

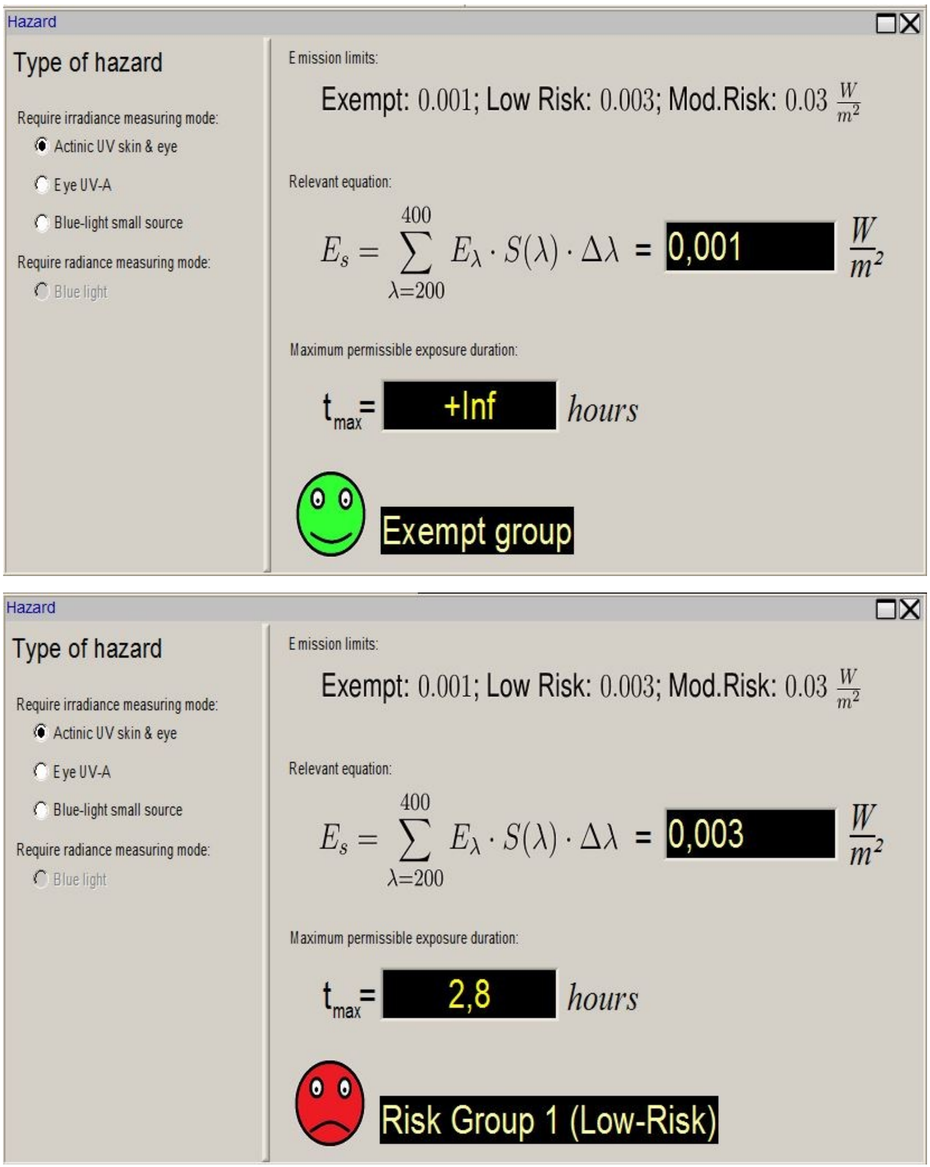


Fig. 17 Windows of Actinic UV Skin and Eye hazard measurement results

Above hazard windows showing different **'Risk Group'** for Actinic UV Skin and Eye hazard category measured from a HMI UV lamp source. The permissible time for exposure to ultraviolet radiation incident upon the unprotected skin or eye is computed by the following formula:

$$t_{\max} = \frac{30}{E_S}(s)$$

Note:

1. Maximum permissible exposure time in hazard window is calculated using the emission limits and not by the measured irradiance/radiance value.
2. When t_{max} results in +Infinity, it is the condition that the measured lamp source has no hazard and can be exposed to any number of hours (exempt group).

c. Retinal blue light (Small Source) hazard

For a light source subtending an angle less than 0.011 radian (α), it is said to be a small source. The blue light hazard under such conditions is measured based on spectral irradiance method.

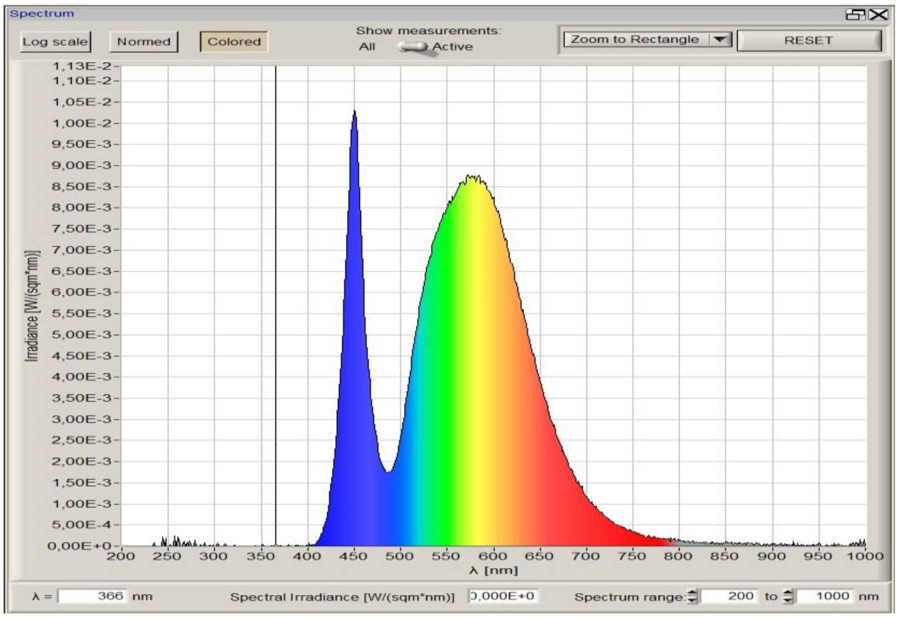


Fig. 18 Spectrum of a white power LED

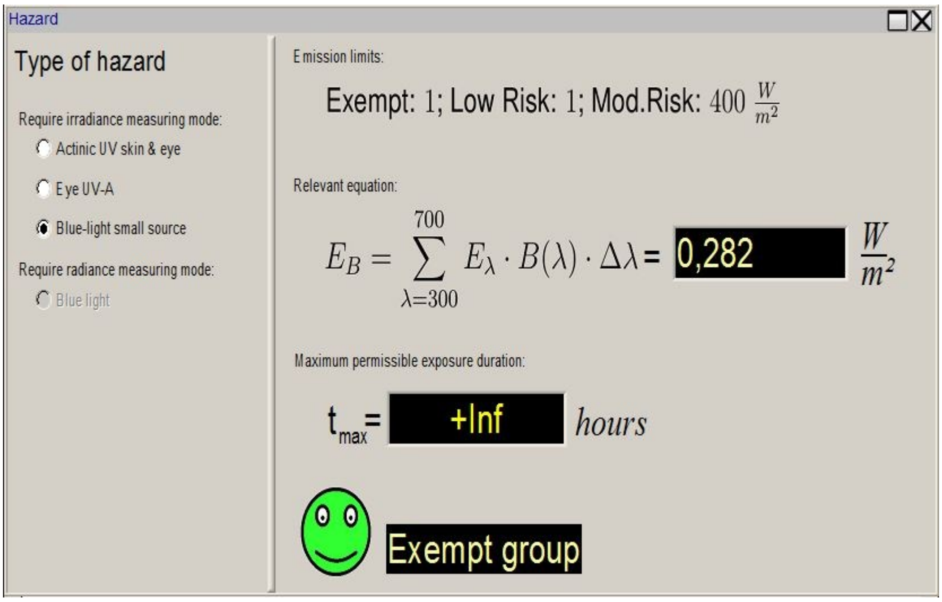


Fig. 19 Window of Blue light small source measurement of a white LED

The maximum permissible exposure duration is computed by the following formula:

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

$$E_B = \sum_{300}^{700} E_\lambda \cdot B(\lambda) \cdot \Delta\lambda \leq 1 \; Wm^{-2} \quad \text{(for t > 100 s)}$$

8.2 Radiance Based Hazard Measurements:

a. Retinal blue light hazard (BLH)

Blue light is said to be the high energy light, which is in the visible region (300 nm - 700 nm) of the electromagnetic spectrum. To protect against retinal photochemical injury from chronic blue-light exposure, the integrated spectral radiance of the light source weighted against the blue-light hazard function, B(λ) i.e, the blue light weighted radiance shall not exceed the level defined by:

$$L_B = \sum_{300}^{700} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda \leq 100 \;\; Wm^{-2} sr^{-1} \qquad \text{(for t > } 10^4 \text{ s)}$$

where:

$L_\lambda \; (\lambda, t)$ is the spectral radiance in W m^{-2} sr^{-1} nm^{-1},

$B(\lambda)$ is the blue-light hazard weighting function,

$\Delta\lambda$ is the bandwidth in nm and t is the exposure duration in seconds.

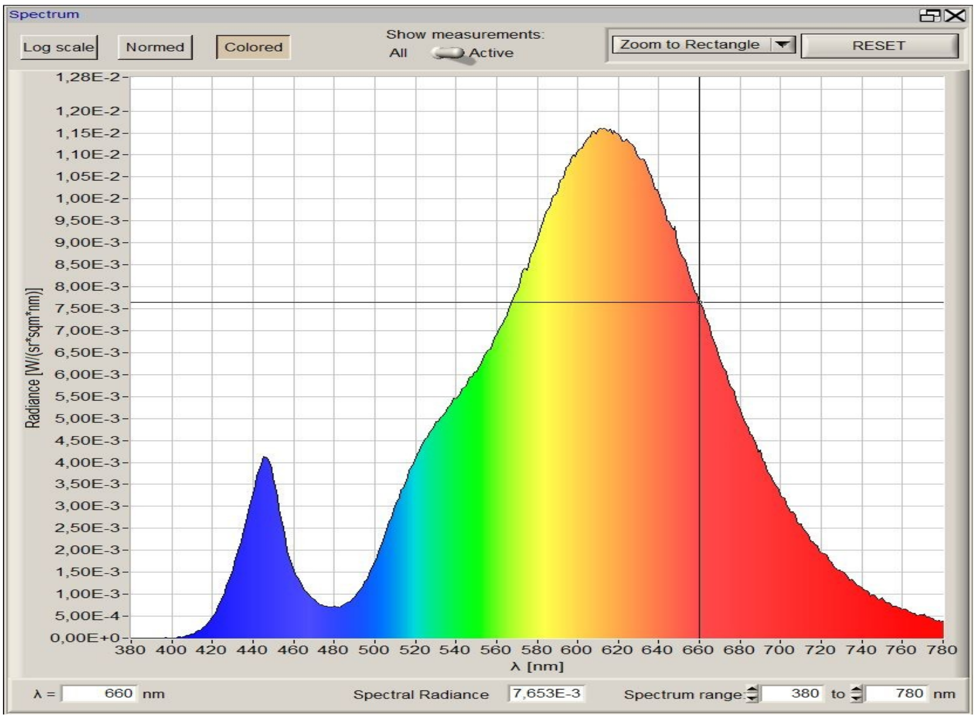


Fig. 20 Spectrum of a white light measured with the 100 mrad Radiance optics

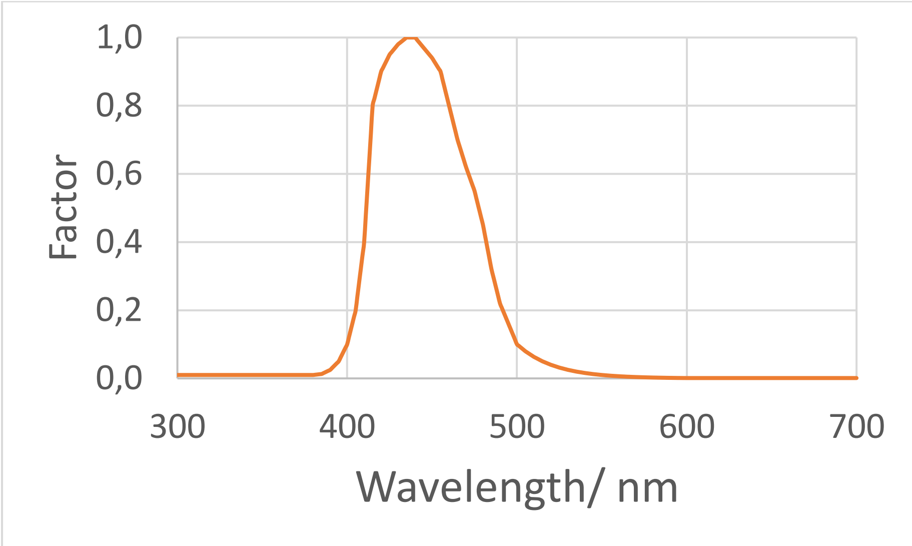


Fig. 21 Blue-light spectral weighting function B(λ)

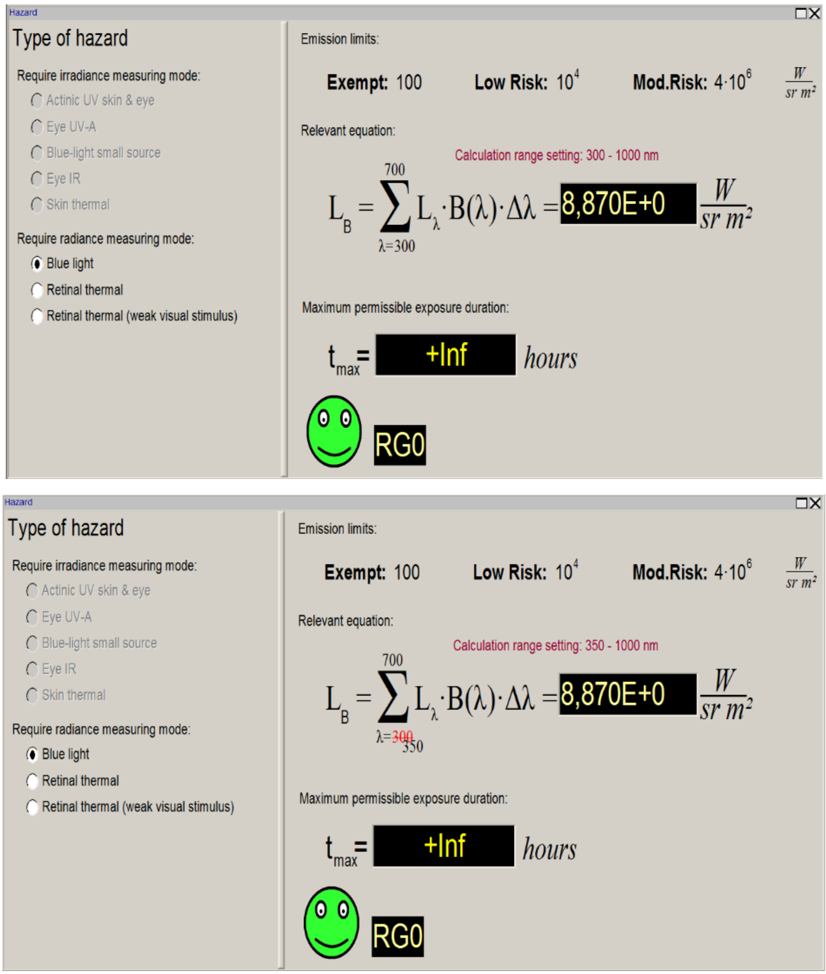


Fig. 22 Window of Blue light hazard measurement of a white LED

The maximum permissible exposure duration for blue light hazard is computed by

$$t_{\max} = \frac{10^6}{L_B}(s) \qquad \text{(for } t \le 10^4 \text{ s)}$$

If the wavelength range of the meter does not cover the range necessary for the calculation, this will be shown as in fig. 22 below. The calculation range can be changed in the menu Options/ Calculation range.

b. Retinal thermal hazard

Retinal thermal hazard is measured using the radiance based set up. This hazard category is valid in the spectral region between 380 nm and 1400 nm.

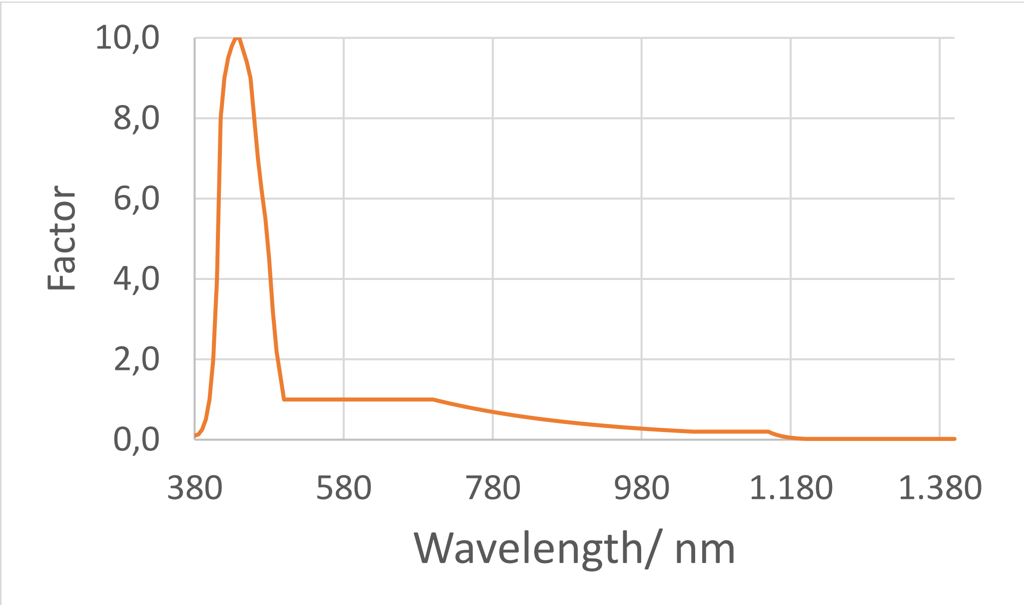


Fig. 23 Retinal thermal spectral weighting function R(λ)

The weighted radiance value against retinal thermal injury L_R should not exceed the level defined by:

$$L_R = \sum_{380}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \le \frac{50000}{\alpha . t^{0.25}} \; Wm^{-2} sr^{-1} \qquad (10\mu s \le t \le 10s)$$

α – angular subtense of the source in radians

c. Retinal thermal hazard (weak visual stimulus)

If the spectrum has only contributions in the NIR region and not in the VIS part, then the pupil diameter will be larger and more NIR hits the retina. Therefore exists another hazard category – Retinal thermal hazard with weak visual stimulus (less than 10 cd/m^2). It will be measured with the 11 mrad field of view and the weighted Radiance L_{IR} shall be limited to

$$L_{IR} = \sum_{780}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \;\; \le 6000/\alpha \quad \text{(for t > 10 s)}$$

The following table shows the summary of emission limits for the risk groups of continuous wave lamps (from IEC 62471):

Risk	Action Spectrum	Symbol	Emission Limits			Units
			Exempt	Low Risk	Mod Risk	
Near UV	-	E_{UVA}	10	33	100	W m^{-2}
Actinic UV	S(λ)	E_s	0.001	0.003	0.03	W m^{-2}
Blue light (Small Source)	B(λ)	E_B	1.0*	1.0	400	W m^{-2}
Blue light	B(λ)	L_B	100	10000	4000000	W m^{-2} sr^{-1}
Retinal thermal	R(λ)	L_R	28000/α	28000/α	71000/α	W m^{-2} sr^{-1}
* Small source defined as one with α < 0.0011 rad. Averaging field of view at 10000 s is 0.1 rad.						

Table 4. Emission limits for risk group classification

9 Summary

The present application note describes, how to measure the different optical hazard quantities and how to use **specbos 25x1-UV** for these measurements.
This document does not replaces the reading of the mentioned publications before starting the measurements.
Special care has to be taken to the measuring uncertainty calculation. There are many influences on the results as

- Influences of the meter like its wavelength precision, optical resolution, stray light, linearity
- Influences of the calibration like the calibration uncertainty
- Influences of the source under test like its stability and burn in behavior
- Environmental effects as temperature

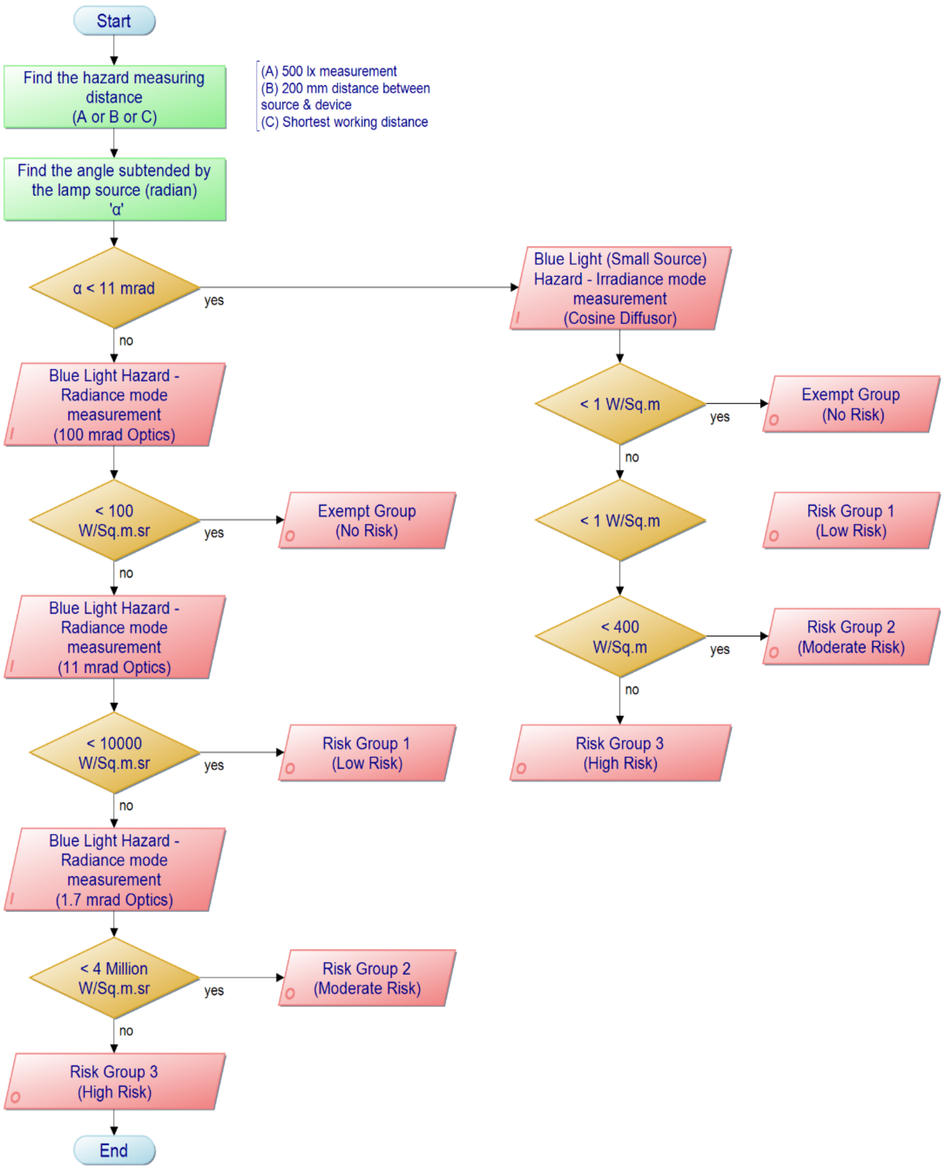
The uncertainty consideration has to be done according to the Guide to the expression of Uncertainty in Measurement (GUM).

10 Safety Measures

- Always wear protective glasses for high energy lamp sources like UV or attenuating glasses.
- Do not stare into the light source directly when it is turned 'ON'.
- Be cautious while using the spectroradiometers, because it has an inbuilt laser target. Do not look into the front window of the spectroradiometer.
- When continuous measurements are to be taken in the dark laboratory for a long time, please allow your eye to relax by looking into far outdoor brighter objects for at least 5 minutes.

Appendix

Steps for Blue Light Hazard Measurements



Last modified: May 2026