Optical Radiation Action Spectra for Safety Regulations and Their Realization Using Integral Detector Measurement Devices

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Abstract. Over the years many action spectra have been created dealing with potential human health risk due to exposure to optical radiation. The main photobiological action spectra are for the eye, blue light (retina) and thermal effects within the retina and skin. Most of these spectra fall within the wavelength range from 180 to 3000 nanometers. There are many manufacturers of photobiologically weighted detectors designed to mimic these action spectra. Currently no international regulations exist on how to specify the accuracy of these measurement devices. For more reliable measurements a method to compare these devices will be proposed.
A method to reduce measurement uncertainty caused by the detector spectral mismatch will also be discussed.

BGI5006 dated October 2004 lists the following photobiological action spectra:

Wavelength (nm)	Action Spectra	Units (or J instead of W)	Health Risk
180 - 400	ICNIRP	W/m^2.eff	Skin
315 - 400	Radiometric	W/m^2	Eye
380 – 600	Blue Light	W/m^2sr.eff	Eye
380 – 600	Blue Light	W/m^2.eff	Eye
380 – 1400	Retinal Thermal	W/m^2sr.eff	Eye
780 - 3000	Radiometric	W/m^2	Eye & Skin
380 - 1000000	Radiometric	W/m^2	Skin

Table 1 List of photobiological action spectra

1. Spectral Mismatch Factor

Since calibration methods, standards and instrumentation vary from device manufacturer to manufacturer and one uniform method of calibration would not be accepted universally, another tool to provide reliable measured values is required.
One tool is the calibration correction factor using the a(Z) formula outlined below.

$$a(Z) = \frac{\int_0^\infty S_{\lambda,c} \cdot s(\lambda)_{act,rel} \cdot d\lambda}{\int_0^\infty S_{\lambda,c} \cdot s(\lambda)_{rel} \cdot d\lambda} \cdot \frac{\int_0^\infty S_{\lambda,Z} \cdot s(\lambda)_{rel} \cdot d\lambda}{\int_0^\infty S_{\lambda,Z} \cdot s(\lambda)_{act,rel} \cdot d\lambda}$$

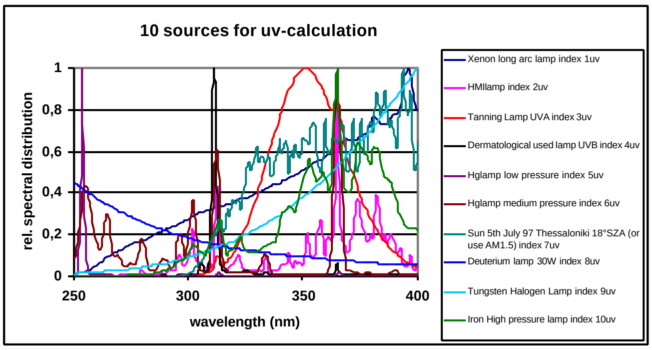
Formula 1 Spectral Mismatch Factor
where

$S\lambda$,c spectral distribution of the source used for calibration
$S\lambda$,Z spectral distribution of the source in a particular application
$s(\lambda)$act,rel relative spectral actinic weighting function
$s(\lambda)$rel relative spectral responsivity of the radiometer head

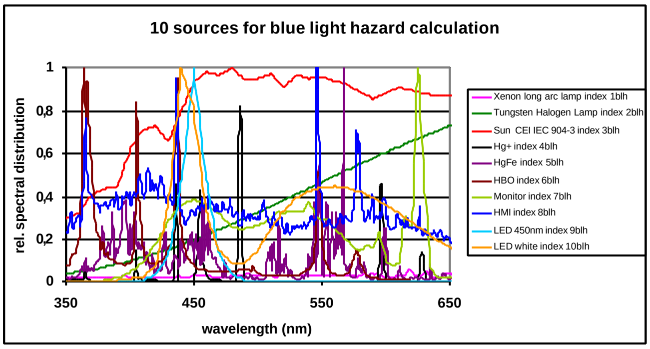
From this formula it can be shown that an
a(Z) >1 yields a lower real value (detector reads too high) and
a(Z) <1 a higher real value (detector reads too low)

2. Spectral distribution of 10 sources for different wavelength regions

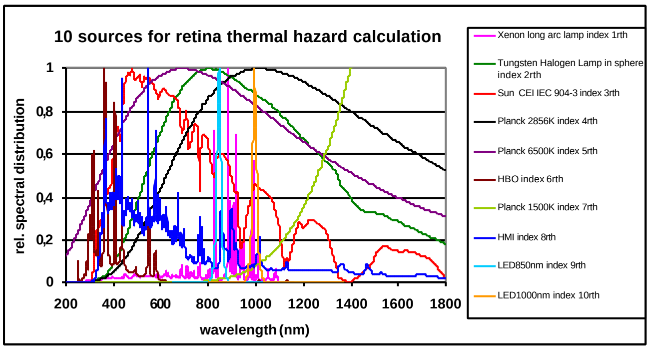
It will be essential to have for every wavelength region a set of different sources to calculate the correction factor. The more different the sources the better is the confidence in the sensor, if all calibration correction values a(Z) are as close as possible to 1 for each source.



Graph 1 Relative spectral distribution of ten uv sources



Graph 2 Relative spectral distribution of ten blue light hazard sources

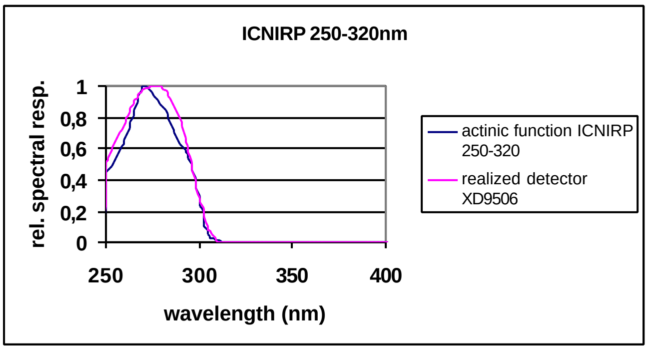


Graph 3 Relative spectral distribution of ten retina thermal hazard sources

3. Action spectra with realized detector

3.1 ICNIRP action spectra 180-400nm

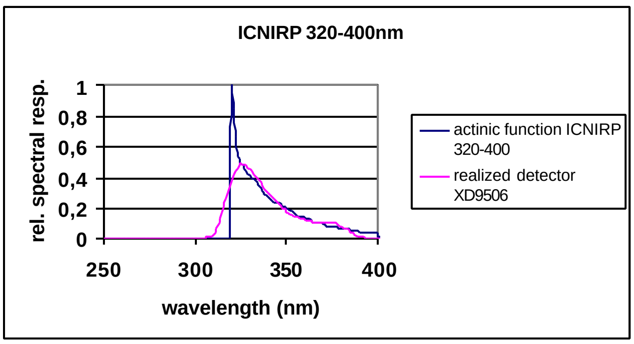
To match these action spectra it is easier if the function is split into two separate ones where two different detectors can be used. Otherwise a double monochromator based spectral radiometer must be used to evaluate the entire function wavelength by wavelength.



Graph 4 ICNIRP action spectra 250-320nm

Xenon long arc lamp index 1uv	a(Z)=	1,01
HMI lamp index 2uv	a(Z)=	1,00
Tanning lamp UVA index 3uv	a(Z)=	0,94
Dermatological used lamp UVB index 4uv	a(Z)=	0,88
Hg lamp low pressure index 5uv	a(Z)=	1,08
Hg lamp medium pressure index 6uv	a(Z)=	1,01
Sun 5th July 97 Thessaloniki 18°SZA (or use AM1.5) index 7uv	a(Z)=	1,10
Deuterium lamp 30W index 8uv	a(Z)=	1,00
Tungsten halogen lamp index 9uv	a(Z)=	1,01
Iron high pressure lamp index 10uv	a(Z)=	1,02

Table 2 Uncertainty of values for ICNIRP detector for wavelength range 250 to 320nm.



Graph 5 ICNIRP action spectra 320-400nm normalized at 320nm with a factor of 1000

Xenon long arc lamp index 1uv	a(Z)=	0,98
HMI lamp index 2uv	a(Z)=	1,00
Tanning lamp UVA index 3uv	a(Z)=	1,00
Dermatological used lamp UVB index 4uv	a(Z)=	1,85
Hg lamp low pressure index 5uv	a(Z)=	1,58
Hg lamp medium pressure index 6uv	a(Z)=	1,31
Sun 5th July 97 Thessaloniki 18°SZA (or use AM1.5) index 7uv	a(Z)=	0,98
Deuterium lamp 30W index 8uv	a(Z)=	1,04
Tungsten halogen lamp index 9uv	a(Z)=	0,95
Iron high pressure lamp index 10uv	a(Z)=	0,99

Table 3 Uncertainty of values for ICNIRP detector for wavelength range 320 to 400nm.

In table 3 we can see e.g. for Dermatological used lamp UVB index 4uv the poor a(Z) with 1.85 did not effect in case of very less weighted irradiation in this wavelength range from 320 to 400nm occur.

Any classification for UV meters should depend on the uncertainty of its spectral response, since it influences the measurement the most. To classify a meter the $f_1(Z)$ criteria can be applied again using the spectral distribution data of the light sources shown in graph 1-3.

The remaining deviation $f_1(Z)$ is given according to formula 2

$$f_1(Z) = a(Z) - 1 = \frac{s_Z}{s_c} - 1$$

Formula 2 Deviation including spectral mismatch factor

where

s_Z radiometric responsivity of the radiometer head using source Z

s_C radiometric responsivity of the radiometer head using the calibration source c

a(Z) relative responsivity correction factor according to formula 1

The groups are classified as:

$f_1(Z)max \leq 20\%$ as best class (green); a(Z) between 0.8 and 1.25

$f_1(Z)max \leq 40\%$ as normal class (orange); a(Z) between 0.6 and 1.66

$f_1(Z)max \leq 70\%$ as worst class (red); a(Z) between 0.3 and 3.33

Radiometers with an $f_1(Z)max \geq 70\%$ are not useable in general (black).

a(Z) below 0.3 an above 3.33.

But for a specific light source a generally unusable UV-radiometer could be changed into the best class within 20%.

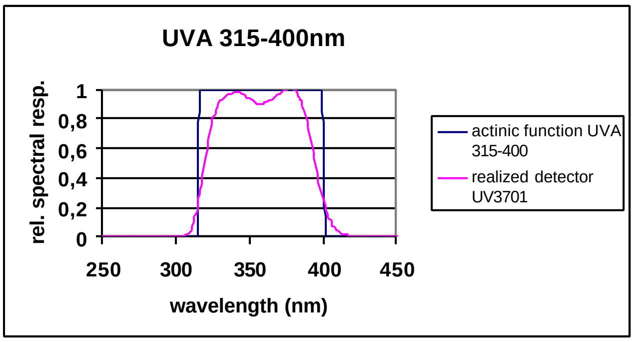
Notice that the a(Z) value for any given lamp is typically within less than 20% of the real value.

Only those sources rich in irradiance below approximately 260nm are about 25% outside of the real value with the deuterium lamp 40% out.

A newly developed double broadband detector head device for the ICNIRP function is shown below.

Picture 1 Double Broadband Detector with Display Unit

3.2 Radiometric spectra 315-400nm (UVA)



Graph 6 UVA action spectra 315-400nm

The out-of-band signal blocking capability of the measurement equipment has to be as good as possible below 315nm and above 400nm.

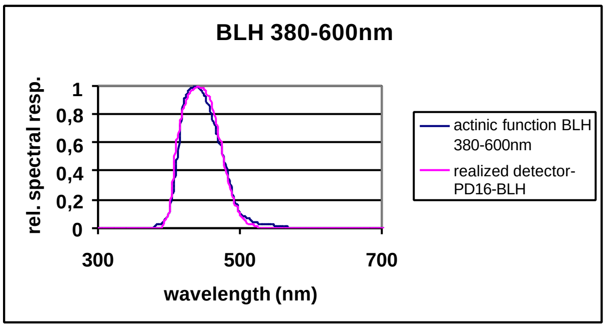
Xenon long arc lamp index 1uv	a(Z)=	0,93
HMIlamp index 2uv	a(Z)=	1,00
Tanning Lamp UVA index 3uv	a(Z)=	1,01
Dermatological used lamp UVB index 4uv	a(Z)=	1,27
Hglamp low pressure index 5uv	a(Z)=	1,15
Hglamp medium pressure index 6uv	a(Z)=	1,08
Sun 5th July 97 Thessaloniki 18°SZA (or use AM1.5) index 7u	a(Z)=	0,95
Deuterium lamp 30W index 8uv	a(Z)=	0,92
Tungsten Halogen Lamp index 9uv	a(Z)=	0,94
Iron High pressure lamp index 10uv	a(Z)=	0,98

Table 4 Uncertainty of values for UVA detector for wavelength range 315 to 400nm.

The groups for uva-detectors and all following detectors are classified as:

$f_1(Z)max \leq 5\%$ as best class (green); a(Z) between 0.95 and 1.05
$f_1(Z)max \leq 10\%$ as normal class (orange); a(Z) between 0.9 and 1.11
$f_1(Z)max \leq 20\%$ as worst class (red); a(Z) between 0.8 and 1.25

3.3 Blue Light hazard spectra 380-600nm

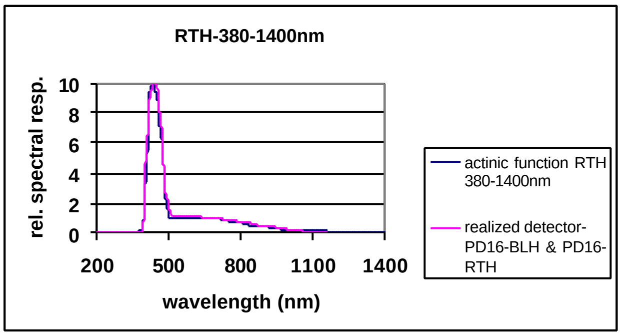


Graph 7 Blue Light Hazard action spectra 380-600nm

Xenon long arc lamp index 1blh	a(Z)=	1,01
Tungsten Halogen Lamp index 2blh	a(Z)=	0,99
Sun CEI IEC 904-3 index 3blh	a(Z)=	1,01
Hg+ index 4blh	a(Z)=	1,01
HgFe index 5blh	a(Z)=	1,03
HBO index 6blh	a(Z)=	1,03
Monitor index 7blh	a(Z)=	1,00
HMI index 8blh	a(Z)=	1,01
LED 450nm index 9blh	a(Z)=	1,03
LED white index 10blh	a(Z)=	1,00

Table 5 Uncertainty of values for BLH detector for wavelength range 380 to 600nm.

3.4 Retina Thermal hazard spectra 380-1400nm



Graph 8 Retina Thermal Hazard action spectra 380-1400nm realized with two detector heads

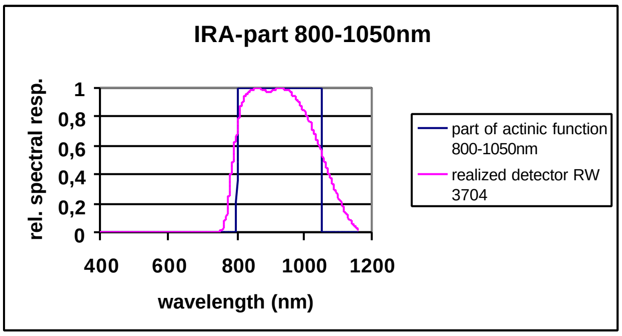
Xenon long arc lamp index 1rth	a(Z)=	1,05
Tungsten Halogen Lamp in sphere index 2rth	a(Z)=	1,01
Sun CEI IEC 904-3 index 3rth	a(Z)=	1,03
Planck 2856K index 4rth	a(Z)=	0,98
Planck 6500K index 5rth	a(Z)=	1,02
HBO index 6rth	a(Z)=	1,02
Planck 1500K index 7rth	a(Z)=	0,52
HMI index 8rth	a(Z)=	1,02
LED850nm index 9rth	a(Z)=	1,13
LED1000nm index 10rth	a(Z)=	1,06

Table 6 Uncertainty of values for RTH detectors for wavelength range 380 to 1400nm.

As we can see from the value above for the low temperature Planck irradiation, the given value will be to low. With this knowledge however we can do an accurate measurement also from this source.

3.5 Radiometric spectra 780-3000nm

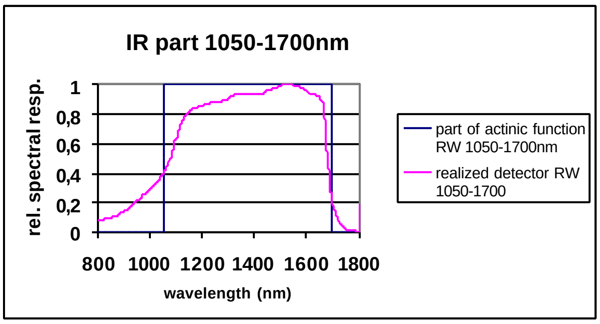
This detector is realized from 780-1700nm with two detector heads.



Graph 9 part of action spectra 780-3000nm

Xenon long arc lamp index 1rth	a(Z)=	0,92
Tungsten Halogen Lamp in sphere index 2rth	a(Z)=	1,00
Sun CEI IEC 904-3 index 3rth	a(Z)=	0,99
Planck 2856K index 4rth	a(Z)=	1,00
Planck 6500K index 5rth	a(Z)=	1,00
HBO index 6rth	a(Z)=	0,99
Planck 1500K index 7rth	a(Z)=	1,16
HMI index 8rth	a(Z)=	0,96
LED850nm index 9rth	a(Z)=	0,93
LED950nm index 10rth	a(Z)=	0,92

Table 7 Uncertainty of values for part of IRA detector for wavelength range 800 to 1050nm.



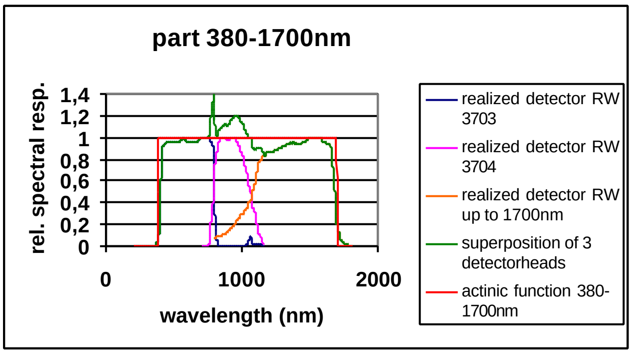
Graph 10 part of IR action spectra 780-3000nm

Tungsten Halogen Lamp in sphere index 2rth	a(Z)=	1,00
Sun CEI IEC 904-3 index 3rth	a(Z)=	1,04
Planck 2856K index 4rth	a(Z)=	0,97
Planck 6500K index 5rth	a(Z)=	0,99
HBO index 6rth	a(Z)=	1,11
Planck 1500K index 7rth	a(Z)=	0,94
HMI index 8rth	a(Z)=	1,06
LED1300nm index 9rth	a(Z)=	0,94
LED1550nm index 10rth	a(Z)=	1,02

Table 8 Uncertainty of values for part of IR detector for wavelength range 1050 to 1700nm.

3.6 Radiometric spectra 380-1000000nm

This detector is realized from 380-1700nm with three detector heads as a radiometric (flat response) unit.



Graph 11 part of action spectra 380-1000000nm

As not having spectral irradiance values for sources up to 1mm, we calculated a Planck radiator with 2856K up to 1mm.

nm	Planck2856K
380-1700	2,31E+08
380-10000000	3,77E+08
ratio (380-1700)/(380-10000000)	0,61

Table 9 Uncertainty of values for part of IR detector for wavelength range 380 to 1000000nm.

The given value from the integral detector heads measured from 380nm up to 1700nm will be for a real Plank radiator 39% to less. The normal sources however did not irradiate up to 1mm and therefore the given value from the meter will be better.

4. Conclusion:

With state of the art broadband detectors and the relative source spectra data it is possible to measure nearly all sources within 20% total additional uncertainty.
However, knowing the broadband detectors spectral mismatch factor is a must.

References:

BG-Information; BGI 5006, Expositionsgrenzwerte für künstliche optisch Strahlung. Oktober 2004

ICNIRP Guidelines; Guidelines on limits of exposure to broadband incoherent optical radiation (0,38 to 3µm); International Commission on Non-Ionizing Radiation Protection. Health Physics Vol. 73, No. 3, p. 539-554, September 1997

European Thematic Network for Ultraviolet Measurements – UVNEWS issue 6 Nov. 2000; “Characterizing the Performance of Integral Measuring UV-Meters“. Helsinki University of Technology, Metrology Institute, P.O. Box 3000, FIN-02015 HUT, Finland

European Thematic Network for Ultraviolet Measurements – UUNEWS issue 7 Nov. 2002; “Manufacturer´s view on UV meters with different action spectra “. Helsinki University of Technology, Metrology Institute, P.O. Box 3000, FIN-02015 HUT, Finland

Application & Product guide 2004/2005, Gigahertz-Optik GmbH