A comparison of Spectroradiometers to Radiometers for UV Radiation Measurements

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Abstract

Spectroradiometers and broadband radiometers, although quite different in their principles and purposes, are often used to perform the same task of monitoring biologically effective UV exposure. In this work we focus on the performance analysis of both types of instruments for this particular task, bearing in mind, that where the spectral resolution of irradiance is needed the spectroradiometer is essential. On the other hand, biologically effective dose is best measured with a radiometer. The complexity of the spectroradiometer makes preferable the convenient broadband instrument where spectral resolution is not required. Relevant specifications for both types of instruments are presented and their impact on the measurement process discussed.

1. History of UV monitoring

The spectroradiometer was presaged by Newton's refraction of a restricted beam of light through a prism in the 17th century. In 1801 UV radiation was discovered. By the 1870's scanning spectroradiometers were in use. The cutoff of solar radiation for wavelengths shorter than about 300nm. was discovered in 1879. The thickness of stratospheric ozone was deduced from spectroradiometric measurements in 1919. Regular ozone measurements (Dobson) with a specialized spectroradiometer began in 1926.

There have been many attempts to develop a UVB meter. With the development of the vacuum tube in the first decade of the 20th century and the recognition that photosensitive cathodes could be made, there were a number of efforts to develop such a UV sensitive tube. The best known effort was that of Rentschler in 1928. His tubes had most of their sensitivity in the UVB and had strongly increasing sensitivity with decreasing wavelength. Uniformity between detectors was poor, however, and they could not be used in sunlight where they became noisy. At GE a photobiological research team under Dr. Matthew Luckiesh developed a UV sensor utilizing the differential fluorescence of zinc sulfide when it was irradiated with and without an intervening glass plate. This wasn't commercialized.

I.G.Farben sold a liquid UV dosimeter in the 1930's whose color change indicated dose. This was not marketed after the second World War. Experience with other chemical dosimeters, however, has not been satisfactory. Spectral response and stability have been poor, dynamic range narrow, temperature effects usually large and readout requiring an optical meter.

2. Purpose of the UV-Monitoirng

In the late 1950's Dr. Donald Robertson developed a phosphor based meter which indicated the intensity of biologically effective UV radiation as an electrical signal. Stability, linearity and dynamic range are excellent, temperature sensitivity not excessive, intercomparability between meters is high, and the total cost modest. This first successful UV meter is the basis of the Robertson-Berger meter network which has established the UV climatology in over 40 sites worldwide since 1973. Purpose of UV-Monitoring UVB, radiation shorter than 320 nm., is important biologically. The high photon energy of the UVB can damage DNA. The effects of this damage varies with the specie, the UVB intensity, and with the total dose. The spectral response of a biological effect, also referred to as the action spectrum, is altered by the absorption and scattering of structures lying over the DNA. However, all effects due to DNA damage appear to have similar action spectra. This similarity of a large part of known action spectra enables a UVB radiometer to monitor the effects of highly variable sunlight on a variety of biological effects. This is one important UV monitoring purpose.

The UVB is also the spectral region where ozone absorption is a dominant factor. On a clear day the spectral irradiance at the earth's surface can be accurately modeled knowing stratospheric ozone thickness. The solar elevation is also needed since the apparent ozone thickness is affected by the angle at which sunlight passes through the atmosphere. This well established predictability makes it possible to obtain an important additional feature from the radiometer. An action spectrum which deviates sufficiently from the meter's spectral response to create an unacceptably large error can have that error eliminated by compensating each meter reading by a correction factor. The correction factor is deduced for each ozone thickness and solar zenith angle, a once daunting task made simple by the computer.

Although clear sky spectral irradiance can be modeled, the accuracy of that modeling is reduced by clouds, haze and pollutants. Consequently, spectroradiometric information is required to confirm the spectral irradiance. Because spectroradiometric measurements are subject to a variety of errors in spite of the greatest care, it is recommended that a UVB radiometer be run next to the spectroradiometer for confirmation.

3. Instrument selection

3.1. Based on the goal

Climatological studies are often concerned with spectral information to validate models. A spectroradiometer is needed.

Biologists need to know dose. Here the radiometer is most applicable. They also wish to determine action spectra. This usually requires indoor studies where the spectrum can be controlled. With artificial light sources a spectroradiometer is needed to define the radiant energy reaching the subject organism. The radiometer is needed to monitor the dose. The meter response to a series of spectrally different doses compared to the organism's responses determines the action spectrum.

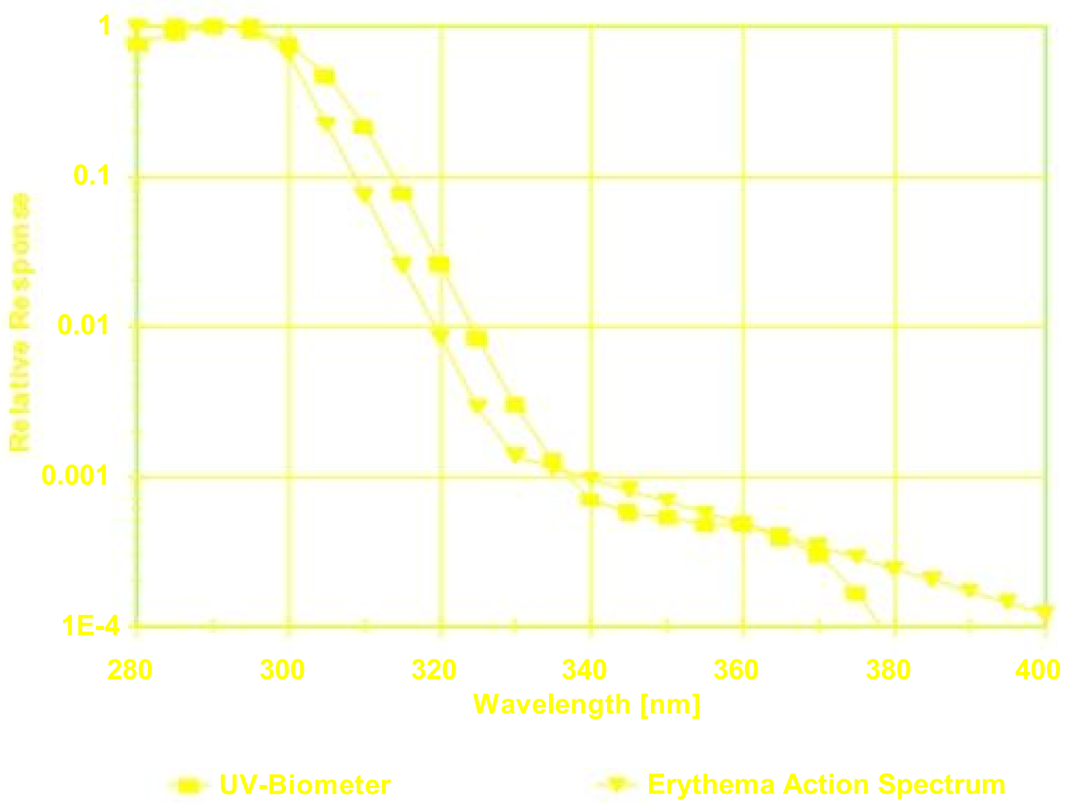

Figure 1. Spectral response of the radiometer and the McKinlay-Diffey erythema action spectrum

Dissemination of public information on daily UVB dose which can cause skin aging, sunburn and skin cancer, can be directly met by publicizing the radiometer's UVB output.

3.2. Based on the specifications

3.2.1. Spectral stability

The wavelength accuracy of the spectroradiometer must be checked frequently, sometimes for each run. The radiometer should be checked annually.

3.2.2. Slit function

The spectroradiometer slit must be narrow enough that the rapid change of intensity with decreasing UVB wavelength does not move the central wavelength enough to cause a significant increase in power. A 1 nm. FWHM is the widest the slit that should be specified. Even at that width errors of 5% can be anticipated at wavelengths at and below 300 nm.

The radiometer has no slit but by analogy the effective slit width is that of a photon, i.e. is vanishingly narrow, so that there is no error due to the rapid wavelength change in the UVB.

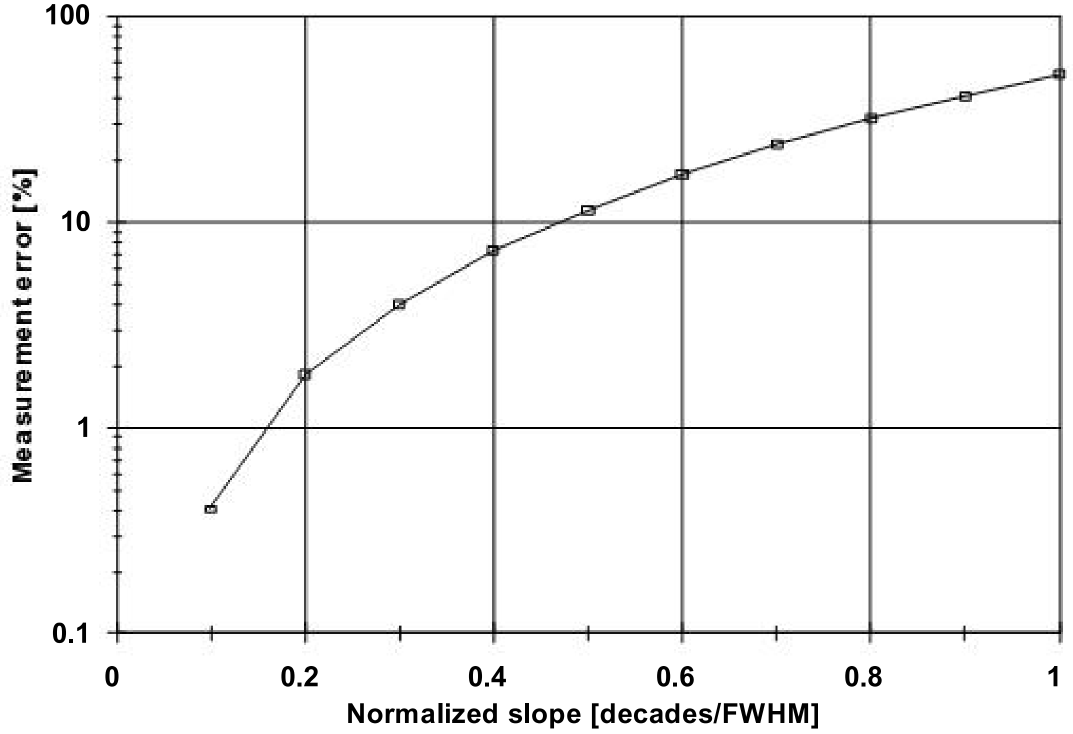

Figure 2. Error due to slit width in relation to radiation intensity change

3.2.3. Scan time

The time required to scan through all of the wavelengths varies with the instrument and with the radiation intensity. At the minimum, the range from 290 to 330 nm. should be covered in 0.5 nm. steps. This requires from 2 to 12 minutes. During this period changes in radiation may occur producing errors from atmospheric variables and the sun's position. The error due to solar position change is least for a high sun. To minimize this error the spectroradiometric readings in a scan should be referenced to the radiation intensity at which the first wavelength reading was obtained. This radiation intensity can be obtained from a radiometer.

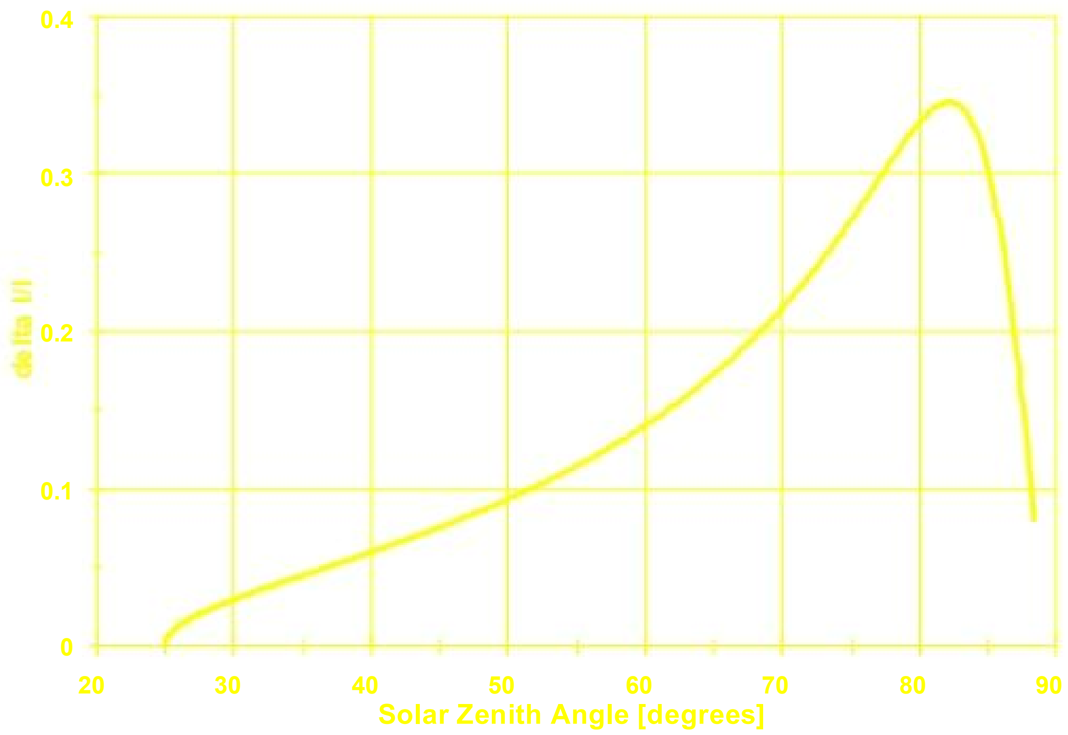

Figure 3. Change of erythemally weighted solar radiation in 10 minute intervals related to its value in the middle of its interval

3.2.4. The wavelength accuracy

Spectroradiometers can maintain a wavelength accuracy of much less than 1nm between calibrations. Radiometers having spectral characteristics extending over the UVB and into the UVA can be specified in terms of how well one tracks a reference radiometer in sunlight over solar zenith angles from 0 - 80°. Tracking must be within ±1% from 0° to 55°.

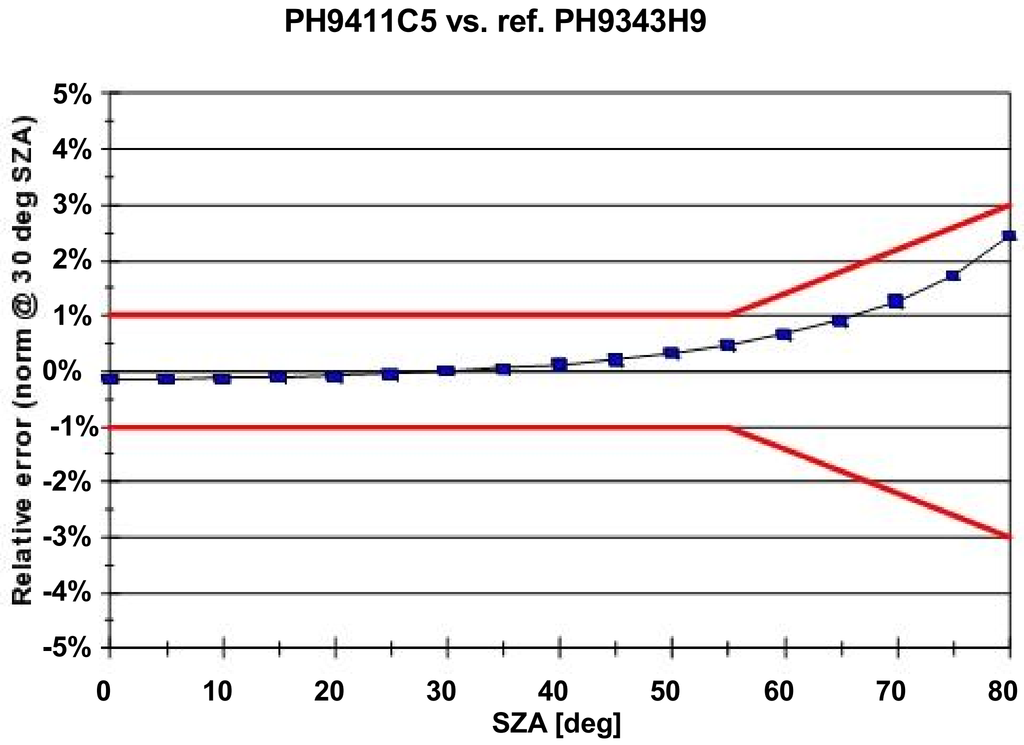

Figure 4. Radiometer tracking a reference PH9411C5 vs. PH9343H9

3.2.5. Sensitivity stability

The sensitivity of the spectroradiometer can be affected by several factors, but particularly by photomultiplier sensitivity changes. Frequent calibration is, therefore, required.

Sensitivity changes in the radiometer can arise from drifts in the photodiode, or change in filter transmission. Annual calibrations would indicate any change.

3.2.6. Angular response

From the measured cosine responses of a series of spectroradiometers using different types of input optics the specification that the best could meet was 15% error at 60°, and 30% at 75°.

The radiometer has a cosine error of not more than 5% at 60°, and 30% at 75°.

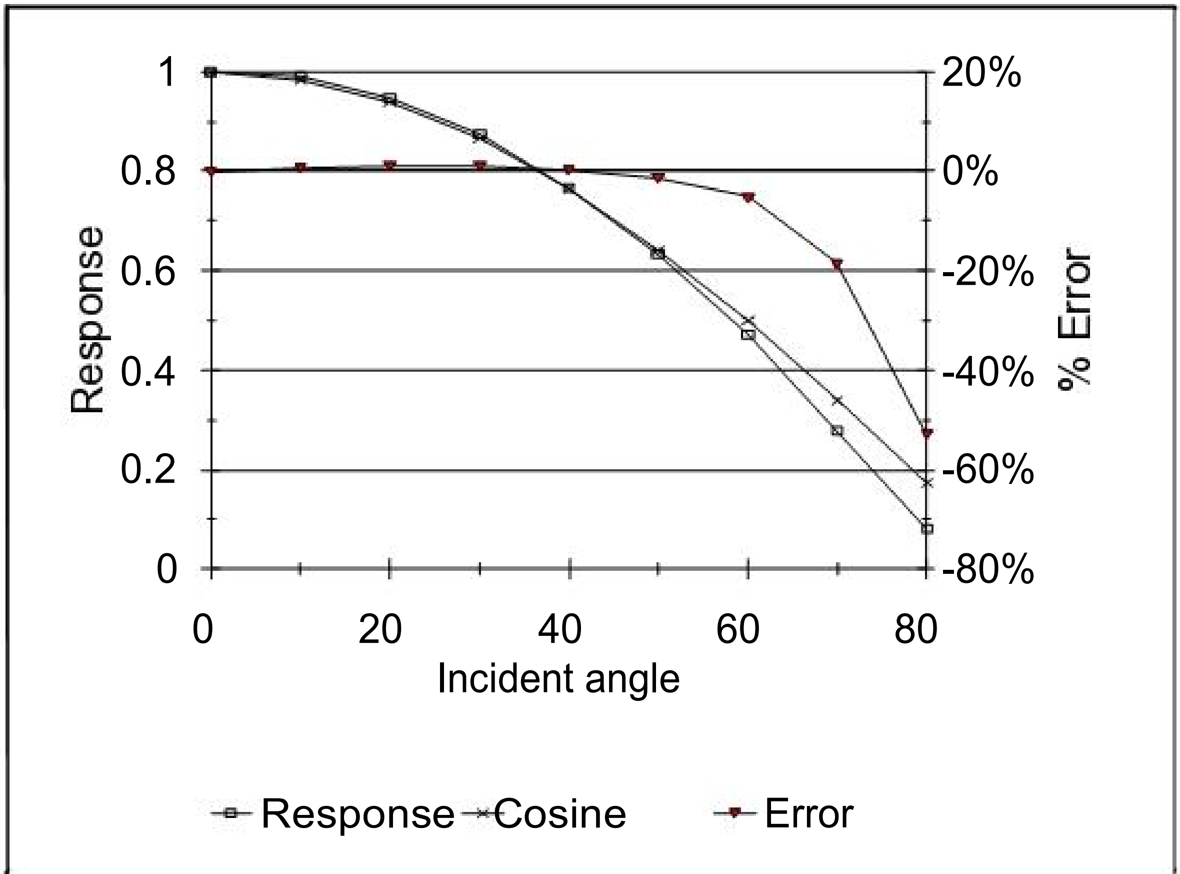

Figure 5. Cosine response of a radiometer PH9413C

3.2.7. Response time

The scan time for a spectroradiometer is as short as 2 minutes and as long as 12 minutes. The scan time will also depend on intensity, increasing with decreased intensity.

The radiometer responds to an input within microseconds.

3.2.8. Power requirement

Power for these equipments depends primarily on the temperature stabilization. The next largest power need is for the spectroradiometer wavelength drive. Least power demanding are the photodetector and data handling requirements. Spectroradiometers would require at least 100 watts and perhaps 250 watts for temperature stabilization because of their large volumes, whereas the smaller radiometer requires 10 watts maximum.

3.2.9. Stray light

The spectroradiometer must have a stray light level of not more than 10^{-6} watts/m2/nm.

Stray light affects the weakest wavelength measurements, which, because they are the most biologically effective can produce significant error.

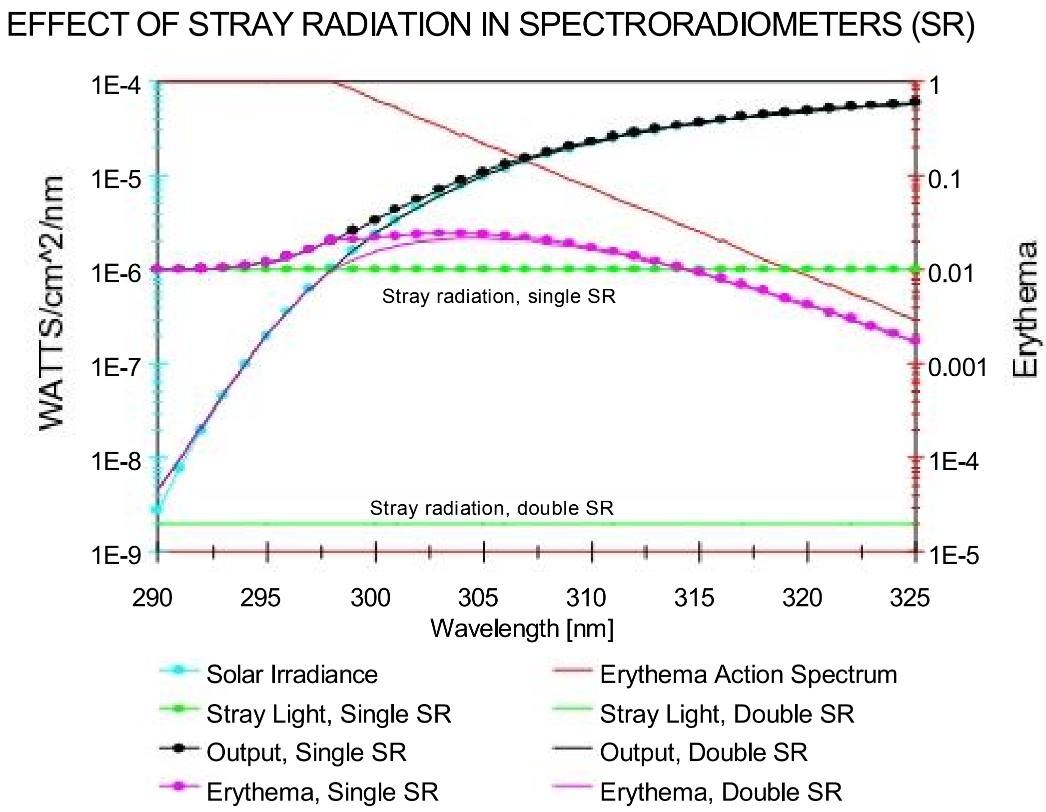

Figure 6, Stray light in the spectroradiometer

The radiometer also has weak unwanted, or stray radiation. This radiation adds to the total but is of no significance for even low sun where its total contribution is below 1.0

3.2.10. Portability

The spectroradiometer should be a double to minimize stray light in the UVB. This increases size. The requirement that the spectroradiometer be extremely rigid results in a thick supporting base, substantially increasing weight. Spectroradiometers built for the UVB are in the range of 40 pounds. The UVB radiometer weights 4 pounds.

3.2.11. Maintenance

The spectroradiometer requires a well-trained operator to run it. The radiometer runs unattended. Wiping the dome weekly, and plugging I the calibrating meter annually is all the normal maintenance needed

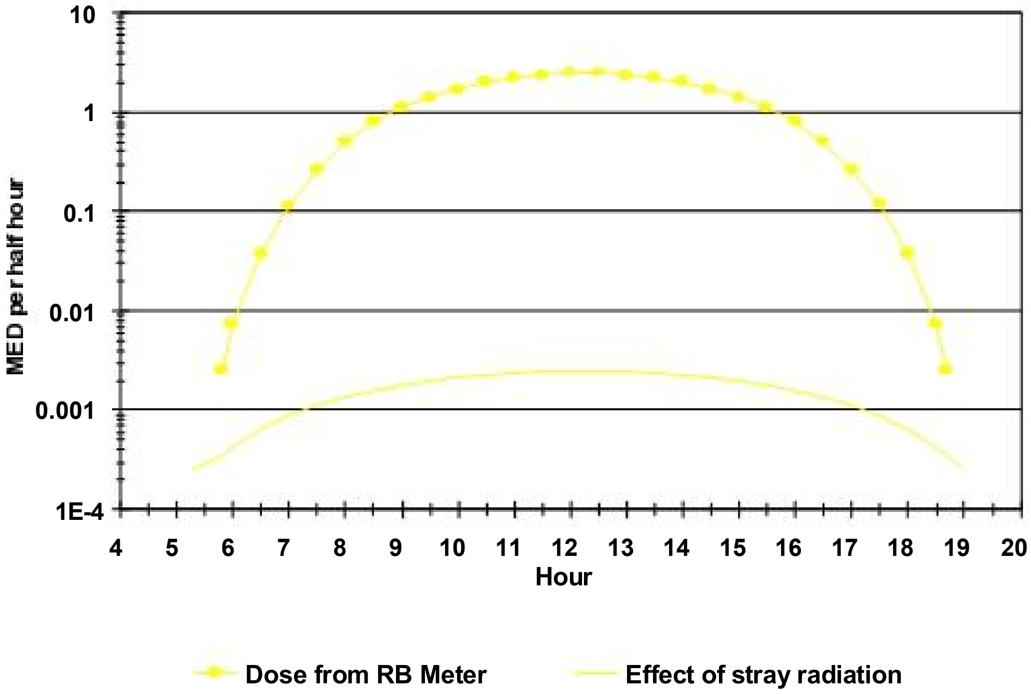

Figure 7. Stray light in the radiometer

3.2.12. Cost

The spectroradiometer costs between $40,000 and $150,000. The radiometer costs $4,000 without a recorder but suitable for use with a data logger, and $6,000 with a recorder.

4. Conclusions

There are measurement protocols which unequivocally require either a spectroradiometer or a radiometer, as noted previously. In situations, such as dose measurements, where spectral resolution is not needed the radiometer should be used. A UVB spectroradiometer should always be accompanied by a UVB radiometer.