FULL OPTICAL CHARACTERISATION OF BIOLOGICAL DETECTORS

D. GILLOTAY AND D. BOLSÉE

Belgian Institute for Space Aeronomy
3, Avenue Circulaire B-1180 Brussels, Belgium

Abstract

There is particular concern for the risk of increased environmental UVB radiation as consequence of continuing ozone depletion with regard to human health. To assess the risk of increased human skin cancers, accurate and reliable dosimetric system that weight the relevant irradiance according to the biological response are required. The UV-dosimeters offer a real potential for field or personal dosimetry and they were studied in the frame of the BIODOS EC project (ENV4-CT95-0044). The main objective was to select the most suitable biological dosimeter according to a standard protocol. We have developed for that a flexible and powerfull characterisation facility based on a solar simulator in order to perform the complete radiometric characterisation including the determination of monochromatic or polychromatic action spectrum and the measurements of linearity, angular response and potential wavelength interactions. The BIODOS facility, presented hereafter has been used for the characterisation during the second laboratory intercalibration campaign included in the BIODOS project. The results of UV exposures of different dosimeters are not yet available (in charge of the BIODOS partners).

1. Introduction

The global climatology of UVB solar irradiance at the Earth's surface is affected by the significant stratospheric ozone reduction observed at mid and high latitudes in both hemispheres during the last decade because the interval 280-315 nm is strongly absorbed by stratospheric ozone. UVB wavelength interval induces important photo-reactions on biological system, therefore important efforts have been made since the mid-eighties to quantify future UVB changes on global and regional scales in order to investigate the modifications induced on the biosphere. The UV biological and chemical detectors offer a real potential for field and personal dosimetry because their spectral response is close to the other biological spectral responses (human skin). To transform UV biological or

chemical detectors into UVB dosimeters, a complete optical characterisation is required in order to determine accurately and in detail the own optical and ancillary characteristics of each type of detector. Without this characterisation, it is impossible to deduce from the biological or chemical processes involved in the detector an absolute UVB dose useful for other applications. Among the indispensable optical characteristics to be quantify, let us mention:

- The action spectrum
- The reciprocity law (linearity)
- The angular response
- The absolute response
- The potential polychromatic interactions.

It will be also useful to obtain accurate information on the temperature dependence, the humidity dependence and the long term stability of these detectors before they are qualified as UVB dosimeters. This important job has to be performed in a specialised optical laboratory where a specific facility is available. This specific calibration facility was developed during the EC project EV5V-CT93-0342 (biologically weighted dosimeter based on the biofilm [1]) and rebuilt for the BIODOS EC project (ENV4-CT95-0044). The objectives were to establish the state of the art for the potential of existing biological UV-dosimeters to measure the integrated biologically effective irradiance (E_{eff}) for key target and to characterise radiometrically the most suitable dosimeter for field or personal measurements. The characterisation was performed according to a protocol standardised during the BIODOS project including the following tasks:

- Determination of the absolute responsivity of the dosimeters under polychromatic radiation. Broadband filters in the UVA, UVB and global UV or special filters for the solar spectrum simulation were used for this purpose.
- Measurement of the relative spectral response (action spectrum) with interferentiel narrowband filters.
- Examination of the dosimeter linearity by means of neutral density filters.
- Measurement of the angular response of biological detectors, i.e. the deviation to the cosine law for solid flat (2 πsr) receivers.
- Detection of potential wavelength interactions (for example, synergistic effects between UVA and UVB) in the biological response by means of a special filtering system.

2. Instrumentation and Discussion

2.1. DESIGN OF THE CALIBRATION FACILITY

2.1.1. Illuminating Area and Artificial Light Sources

The existing dosimeters involved in the BIODOS EC project presented a wide diversity of shape and size. Most of them are solid, flat detector (biofilm, uracil thin layer, spore dosimetry [2-4]) but some of them are operating in liquid phase and hold in a quartz vessel (4 πsr detectors as vitamin D dosimeter, spore suspension [5, 6]). Nevertheless, the common characteristic of their geometry is the small size (maximum diameter of about 50 mm) as they were generally designed for personal dosimetry so that a collimated beam with such diameter is simply required for the characterisation. At the opposite, for plant UV exposure experiments where three dimensional biological "objects" are illuminated, the UV light sources must provide a wide illuminating area [7] simulating the real global (2 πsr) UV irradiance of the sky. In that case, artificial UV light sources as metal halide or Phillips TL12 lamps for example are more indicated. These lamps were not adequate for the BIODOS facility for which we had severe requirements about the homogeneity, stability, absolute calibration of the beam and a spectral composition providing a continuum in the UV as

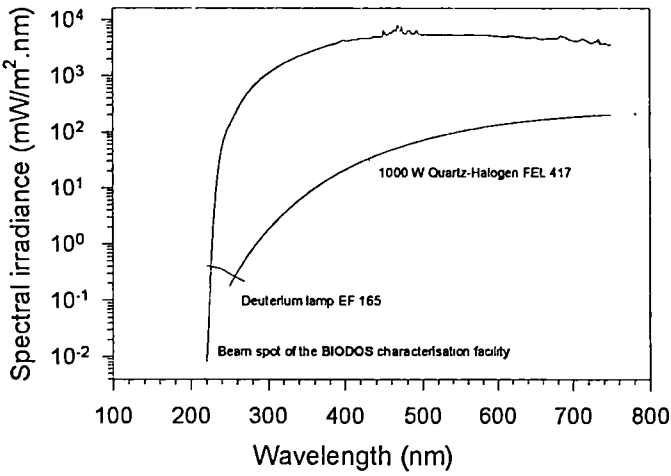

Figure 1. Comparison between the arc Xenon lamp and common standards of spectral irradiance.

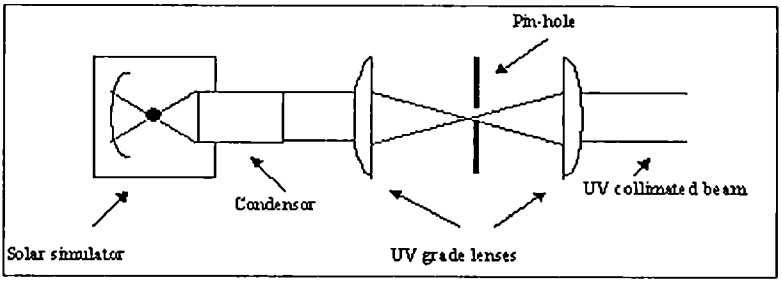

Figure 2. Schematic diagram of the collimating system.

much as possible free of spectral lines. These quality criteria conjugated to the small size of the biological receptors have turned the choice into other kind of lamps : standards of spectral irradiance (deuterium and Quartz-Halogen lamps) or 1000 W Xenon arc lamp. The Figure 1 shows the comparison between the typical spectra produced by the three selected lamps.

Due to the low sensitivity of existing biological dosimeters, both deuterium and Quartz-halogen lamps were rejected in spite of their very good stability and absolute calibration and the BIODOS facility was finally built around the 1000 W Xenon arc lamp (ORIEL solar simulator).

2.1.2. Collimation of the Beam

The diverging beam produced by the Xenon arc lamp is collimating by the following lens combination: first, the image of the arc is focused onto a pinhole by the solar simulator condenser and one additional UV grade lens to minimise of optical aberrations (Figure 2). Only the central and uniform part of the arc image is transmitted by the pinhole and the diverging beam is finally defocused into a parallel beam by another UV grade lens. The homogeneity of the beam spot is of course greatly dependant of the pinhole alignment onto the centre of the arc image. Uniformity of the beam spot irradiance of about 10% can be easily obtained.

2.1.3. Stabilisation and calibration of the light source

Xenon arc lamps are not as stable as Quartz-halogen lamps. Even if the arc lamp is rated at constant power, a short term noise of about 4 or 5% peak to peak can be observed (Figure 3). A long term trend is also unavoidable due to the ageing of the lamp (electrodes erosion) which reduces gradually the UV irradiance of the arc. Moreover, any change in arc position (between the electrodes) due to this ageing will influence the uniformity and global UV irradiance of the beam spot through the arc image misalignment on the pinhole ! It is then

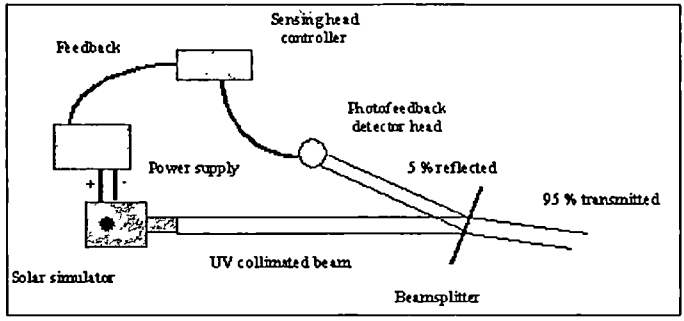

Figure 3. Schematic diagram of the photofeedback system.

absolutely necessary to stabilise the lamp and to balance the ageing effects. A very powerful and recent solution is the use of a photofeedback system operating as follows: an UV enhanced silicon photodiode monitors a part of the lamp output. The controller of this photodiode constantly compares the recorded signal to the set level. If necessary, the power supply settings are changed to keep the measured signal at the set level. In our device, around 5% of the lamp output is reflected by a wedged beamsplitter and monitored by the Silicon detector head (Figure 3). The remaining ~95% are transmitted to the dosimeters under calibration. By this way, the irradiance of the beam can be stabilised within 1 or 2% during many hours and the short term noise is also reduced up to 2 or 3% pp (Figure 4).

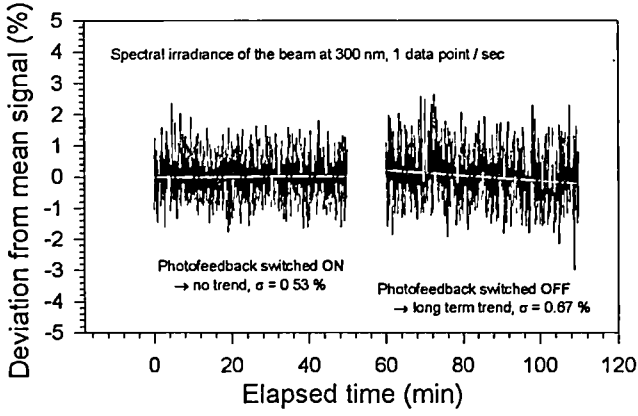

Figure 4. Photofeedback system: typical residuals observed at a single wavelength (300 nm) with and without the stabilisation.

The radiometric characterisation according to our protocol implies a very accurate determination of the spectral irradiance of the beam because of the necessity to know exactly the doses and dose rates transmitted to the dosimeters. Unfortunately, the Xenon arc lamp is not a standard of spectral irradiance which means that a physical radiometer is required for the calibration of the collimated beam. We used an absolute calibrated double monochromator providing at least 6 orders of magnitude for the dynamical range as benefit of the very high straylight rejection. The entrance slit was aligned exactly in the same spatial position than the dosimeter by means of a He-Ne laser. The absolute measurements were essential for the detection of possible side transmission and accurate determination of the cut-off of the broadband and narrowband filters. The estimations of the exposure times required before any dosimeter characterisation were obtained from the measured spectral irradiance convoluted by the action spectrum of the dosimeter under investigation.

2.1.4. Monitoring of the Beam

When the selected lamp is stabilised, any dose transmitted to biological dosimeters becomes proportional to the exposure time because of the constant dose rate assumption. In our protocol of measurement, the dose rate was determined from the spectral irradiance of the beam measured by the spectroradiometer just before the beginning of the exposures and we assumed effectively that the dose rate remained constant during the exposures. This was generally proved by the signal of the photofeedback detector head. Nevertheless it was only a spectrally integrated signal from the photodiode. Spectral information's about the stability of the lamp is more interesting and for that reason we have integrated the possibility to check the main beam spectral irradiance by means of a monitoring system as follows: a part of the beam derived from the photofeedback system is collected and transmitted to the double monochromator by a fiber optic. Scans in relative units are recorded for example every 10 minutes during the dosimeter exposure. Common results shown a stability as good as 2 or 3% for all wavelength during many hours. Nevertheless, it was observed that some Xenon arc lamps were less stable than the other ones. It is also clear that the secondary beam reflected by the wedged beamsplitter and used for the photofeedback and the monitoring system must be take after passing through the filtering system described hereafter to take into account the ageing of the filters. The schematic diagram off all the BIODOS facility is presented in the Figure 5.

2.1.5. Filtering System

Many different filters had to be used for a complete radiometric characterisation according to the protocol described before. The BIODOS facility was then designed with a very flexible filtering system in order to achieve all the calibration work package with the same optical bench. The device has been equipped with a filtering system operating in two modes.

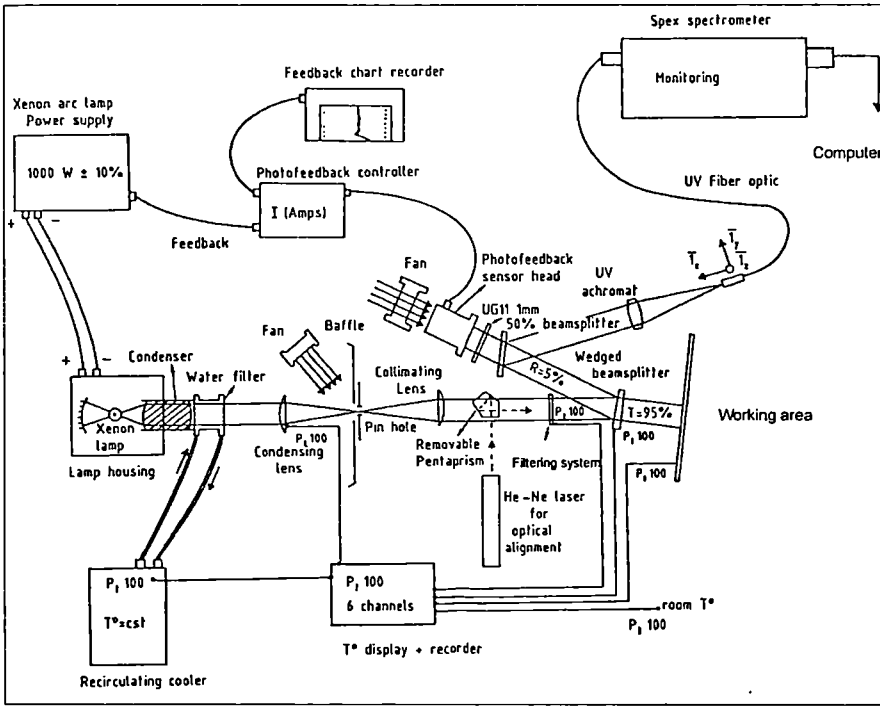

Figure 5. Schematic diagram of the BIODOS characterisation facility.

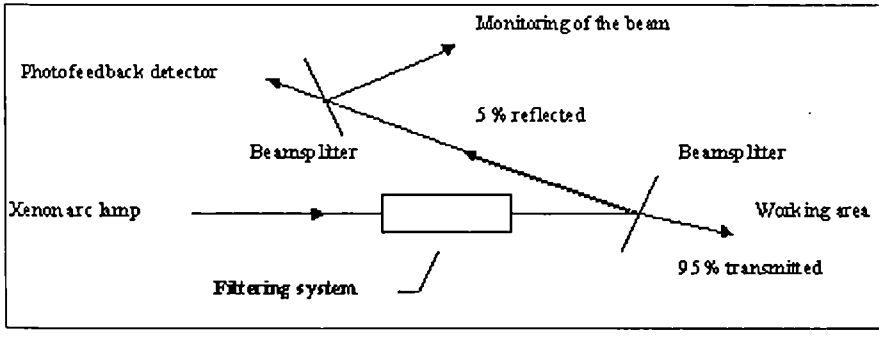

Figure 6. Filtering system in 'direct beam configuration' (single optical path).

The first mode called 'direct beam configuration' presents a unique and linear optical path for which the different filters are inserted in serial (Figure 6).

This configuration was especially dedicated to the biological spectral response (with broadband or narrowband filters), cosine response and linearity measurements (items 1 → 4). For example, for the determination of the linearity in the UV, a combination of broadband UV and additional neutral density filters were used (Figure 7).

For the action spectrum determination, the set of interferentiel filters, shown in Figure 8 are available

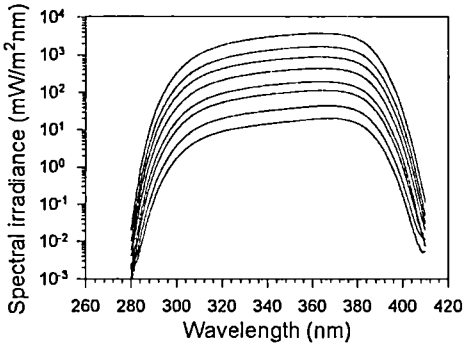

Figure 7. Irradiance produced by global UV filter and combined neutral density filters.

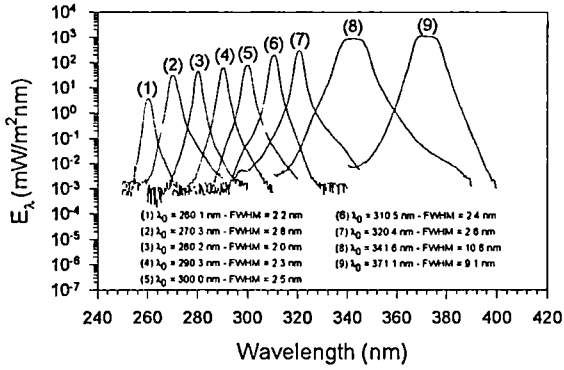

Figure 8. Monochromatic UV irradiance produced by combination of narrowband interferentiel filters and arc Xenon lamp.

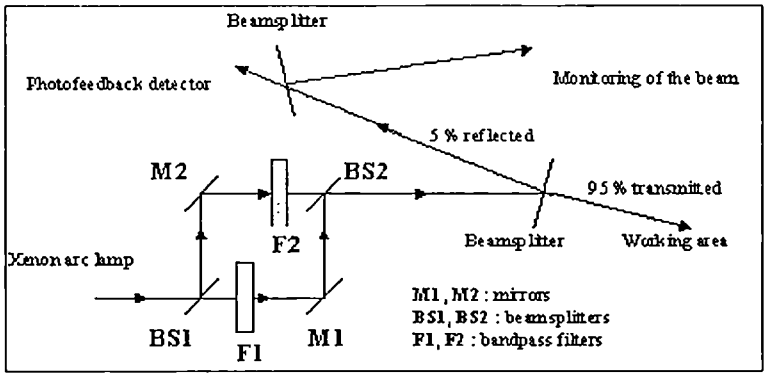

Figure 9. Filtering system in 'beam conjoiner configuration' (split optical beam).

The real shape of the solar spectrum (mainly the ozone cut-off) can also be simulated by means of a cellulose di-acetate foil combined with the unfiltered xenon irradiance. The main disadvantage is the fast changes in transmission characteristics of the cellulose di-acetate during UV exposure [8], in contradiction with the stabilisation (constant dose rate) required for the collimated beam. The simulation of the solar spectrum should be improved by means of solid glass cut-off filters

The filtering system was improved for the detection of potential wavelength interactions (item 5) and a second mode called 'beam conjoiner configuration' [9] has been implemented (Figure 9).

In that case, two beamsplitters are used to equally divide the beam in two parts so that two series of filters may be inserted in parallel allowing the addition of their respective bandpass. Both secondary beams are finally recombined in a main collimating beam by means of an optical component. The addition of two bandpass filters is a very powerful tool for the studies of possible synergistic effects in any dosimeter response, for example, between the UVA and UVB spectral range. These effects can not be taken into account when the action spectrum is determined by a monochromatic and tuneable light source. The consequences are evident for field intercomparison campaign where measured and calculated biological effective doses are compared. Even if the entrance optic between the physical spectroradiometer used for the intercomparison and the dosimeter exposure box are the same, even if the radiometer is well calibrated and the monochromatic action spectrum is accurately determined, the ratio between calculated and measured dose will never be equal to 1 if synergistic effects exist [1]. The beam conjoiner configuration offers then an unique opportunity to quantify these effects for example, between global UVB and

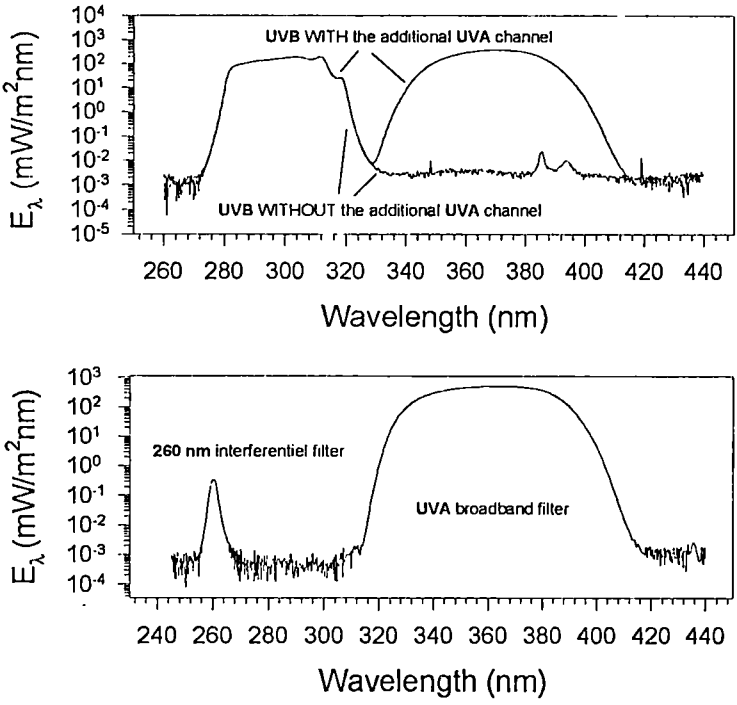

Figure 10. Example of spectra produced by the combination of two filters.

UVA radiation or between one UVC nominal wavelength and global UVA (Figure 10), etc. The non-additivity is detected in the laboratory when the biological response under UV dose coming from the channels A+B (opened together) is different to the response obtained from the same global dose but transmitted by the channels A and B opened separately.

3. Results

The second laboratory intercalibration campaign for biological dosimeters included in the BIODOS program was hold in Brussels during 1997 and 1998. The different dosimeters have been characterised according to the standard protocol described in the introduction as follows:

- Biofilms from DLR (Germany) [2] : items 1, 2, 3 and 5

- Spores suspension from IMP/HI (Austria) [6] : items 1 and 2
- Spore dosimeters from NCCRI (Japan) [3] : items 1, 3 and 5
- Vitamin D dosimeter from IP (Ukraine) [5] : items 1, 2 and 4

In opposite to electronic detectors, the biological response of the dosimeter is never available immediately due to the specific biological process (incubation, etc.) required for the analysis of each dosimeter. The results of the intercalibration campaign are now evaluated by each respective BIODOS partners and will be published in the next future.

4. Conclusions

We have tested and proved the ability of solar simulator equipped with arc Xenon lamps for performing very accurate and reliable radiometric characterisation of biological dosimeters. The very high UV irradiance produced by these lamps can ideally balance the generally low absolute sensitivity of biological detectors (in comparison with electronic receivers). Nevertheless, it is absolutely necessary to stabilise the output of the lamp to remove or reduce any long term trend and short term noise. Moreover, the beam must be calibrated in absolute radiometric units by a spectroradiometer. We also have a severe geometrical requirement induced by the size of commercial filters used in the powerful filtering system: only biological receivers of about 2 or 3 cm of diameter can be characterised by the BIODOS facility. We will keep this optical bench operational for the future and opened for any collaboration with photobiologist after the BIODOS EC project.

Acknowledgement: This work was supported by the EC contract ENV4-CT-0044: development of biological dosimetry systems for monitoring the impact of solar UVB radiation on the biosphere and human health (BIODOS).

6. References

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