Diode Array Spectroradiometers: An evaluation of two instruments in a medical context

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Currently, the type of radiometer most commonly used in photomedicine is the filtered radiometer. These meters are robust and portable and their performance parameters are known and understood. With careful calibration and use of these meters, practical measurements can be made with an expanded uncertainty of ± 10 % [1,2]. This limit for accuracy is accepted within the medical community as errors in dosimetry at this level are clinically significant [3,4] and repeatable measurements facilitate the comparison of treatment regimes.

Figure 1. Left) 4D Controls, UV spectroradiometer, hereafter referred to as "Sola Scope." Right) Ocean Optics USB2000-UV-VIS, hereafter referred to as "Ocean Optics."

If the relatively new technology of the diode array spectroradiometer is to replace the filtered radiometer as the instrument of choice for medical measurements then it must perform at least equally well, if not better. This includes the instrument having an angular response (f_2 value) of 10 % or better [5,6]. Stray light performance is an additional factor which does not affect filtered radiometers but could have significant impact on the reproducibility of readings from a single grating instrument.

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During 2002, an evaluation of two diode array radiometers - an UV Spectroradiometer, Type SC-MP-A, from 4D Controls (Redruth, UK) and an USB2000-UV-VIS spectrometer from Ocean Optics (Duiven, NL) was carried out at the Photobiology Unit, University of Dundee (Figure 1).

The Sola Scope consists of a domed Teflon diffuser forming the input optics to the spectrometer. A hand held unit provides a user interface for initiating measurement and visualising collected spectra. The instrument is supplied pre-calibrated "traceable to NPL".

The Ocean Optics has a flat Teflon diffuser that is coupled to an optical fibre which in turn provides the input optics to the spectrometer. The spectrometer connects to a laptop PC via a USB port and the spectrometer can then be controlled using supplied (OOIBase32) software. This instrument is designed for use as a comparative spectrometer and as such all measurements can be compared with a standard lamp of known colour temperature. For the purposes of this investigation the Ocean Optics was calibrated for wavelength against a low-pressure mercury lamp. Signal level calibration was achieved using a 1 kW FEL lamp to derive a sensitivity factor at each wavelength:

$$SF_\lambda = \frac{E_\lambda}{R_\lambda}, \qquad (1)$$

where SF_λ is the sensitivity factor at a given wavelength, E_λ is the lamp irradiance at the same wavelength, and R_λ is the instrument response at that wavelength. A similar gain calibration was carried out on the Sola Scope.

Angular Response

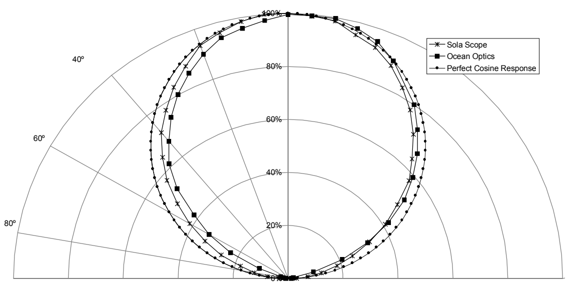

Figure 2. Angular response of the instruments, represented as a polar plot (response as a percentage of the maximum) at incident radiation angles from 90° to –90°.

f_2 values (±60°) for the instruments were: Sola Scope: 5.9 % across two planes-parallel and perpendicular to the grating. Ocean Optics: 7.8 % where no definable plane exists due to the optical fibre coupled to the input diffuser.

Stray Light

The stray light in the instruments was assessed using a xenon arc lamp and a WG320 Schott glass filter. The stray light in the reading can then be expressed as a percentage of the maximum signal. There is a method recommended to remove the stray light from the Sola Scope's measurements. This involves placing an orange filter in front of the input optics and measuring a stray light "profile" for the source about to be measured. The resulting spectrum can then be subtracted from the subsequent measurement. This considerably improves the stray light in the signal. Application of the calibration data to the Ocean Optics' results also reduces the inherent stray light.

Table 1. Stray light ratios from the diode array instruments. The percentage value expressed is the ratio of the signal at 250 nm to that at 430 nm.

Instrument	Without compensation or calibration	With compensation or calibration
Sola scope	13%	2.0%
Ocean Optics	39%	0.4%

Calibration

The calibration of the instruments must be traceable to national standards and should agree with a calibrated, double grating, bench based spectroradiometer [7]. The unit has a Bentham DM150 with a cooled photomultiplier tube (-20°C ± 2°). The calibration of the Bentham is traceable to NPL and has an estimated expanded uncertainty at the 95 % confidence level, of 5.72 % in UVB and 3.48 % in UVA. In accordance with guidelines, the Unit's IL1400 radiometer is calibrated against sources with similar spectral outputs to those to be measured [8], in direct comparison with the Bentham spectroradiometer.

Thus, in order to test the diode array instruments' calibration, various phototherapy light sources were measured in comparison with the Unit's filter radiometer or Bentham spectroradiometer.

The Sola Scope was found to have negligible error in its wavelength scale but significant differences were seen when using the supplied calibration to measure phototherapy sources. Using the calibration derived from the 1 kW FEL lamp, however, reduced the errors to within ±12 %. The Ocean Optics was found to have insufficient sensitivity to measure all but one phototherapy source.

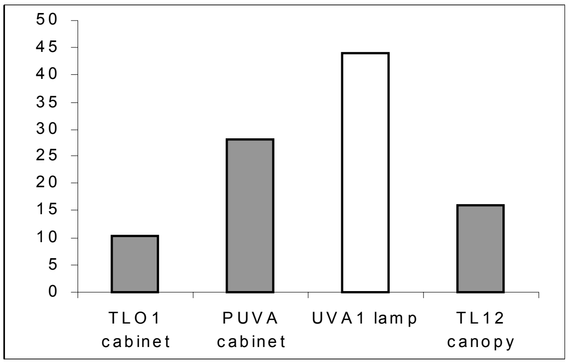

Figure 3. Graph to show the percentage differences in measured irradiances when comparing manufacturer calibrated Sola Scope with IL1400 radiometer and, in the case of the UVA1 lamp, the Bentham spectroradiometer.

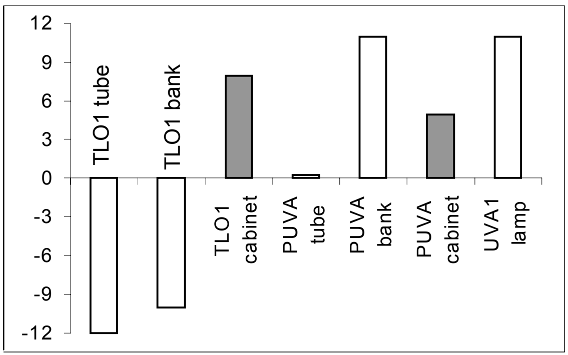

Figure 4. Graph to show the percentage differences in measured irradiances when comparing self calibrated Sola Scope with Bentham spectroradiometer and, in the case of the cabinets, an IL1400 radiometer.

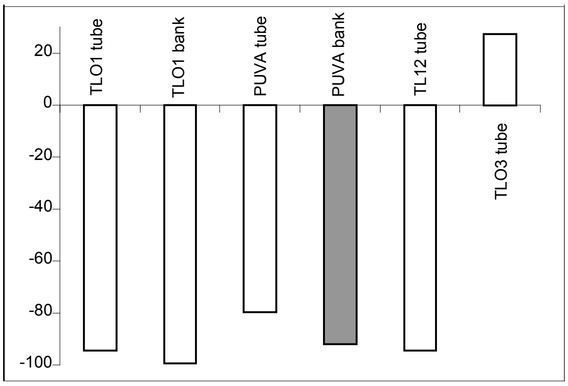

Figure 5. Graph to show the percentage differences in measured irradiances when comparing calibrated Ocean Optics with Bentham spectroradiometer and, in the case of the PUVA bank, an IL1400 radiometer.

Acknowledgements

The authors would like to thank Dr Neil Harrison of NPL for advice and continued interest and Andrew Ridyard of 4D Controls and Kees Van de Steeg of Ocean Optics BV for the loans of the instruments. Thanks also go to David Gibbs, Emma Woolliams and Julie Smyth for all the invaluable comments and assistance. Hannah Oliver would like to acknowledge the EPSRC and the National Physical Laboratory who fund her engineering doctoral research (EngD, Brunel University, Uxbridge).

References

1. P.G. Norris, J.L.M. Hawk, C. Baker, D. Bilsland, B.L. Diffey, P.M. Farr *et al*, "British-Photodermatology-Group Guidelines for PUVA," *British Journal of Dermatology* **130**, 246-255 (1994).

2. B. Diffey and G. Hart, *Ultraviolet & blue-light phototherapy - principles, sources, dosimetry and safety* (IPEM Report 76, York, 1997, pp. 25-26).

3. A.B. Hansen, N. Bechthomsen, and H.C. Wulf, "Erythema after irradiation

with ultraviolet-b from Philips TL12-tube and TLO1-tube," *Photodermatol. Photoimmunol. Photomed.* **10**, 22-25 (1994).

4. H. Moseley, R. Thomas, and M. Young, "UVB Lamps - A burning issue," *British Journal of Dermatology* **128**, 704-706 (1993).

5. S.D. Pye and C.J. Martin, "A study of the directional response of ultraviolet radiometers: I. Practical evaluation and implications for ultraviolet measurement standards," *Physics in Medicine and Biology* **45**, 2701-2712 (2000).

6. H. Moseley, "Scottish UV dosimetry guidelines, 'ScUViDo'," *Photodermatol. Photoimmunol. Photomed.* **17**, 230-233 (2001).

7. A.J. Coleman, M. Collins, and J.E. Saunders, "Traceable calibration of ultraviolet meters used with broadband, extended sources," *Physics in Medicine and Biology* **45**, 185-196 (2000).

8. Commission Internationale de l'Eclairage. *The Spectroradiometric measurements of light sources* [CIE 63 (TC-1.2) CIE, Paris, 1984].