International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

PO104

AGEING PROPERTIES OF DEUTERIUM LAMPS USED IN CALIBRATIONS OF UV SPECTRORADIOMETERS

Tobias Schneider et al.

DOI 10.25039/x46.2019.PO104

from

CIE x046:2019

Proceedings
of the
29th CIE SESSION
Washington D.C., USA, June 14 – 22, 2019

(DOI 10.25039/x46.2019)

CIE Central Bureau
Babenbergerstrasse 9
A-1010 Vienna
Austria
Tel.: +43 1 714 3187
e-mail: ciecb@cie.co.at
www.cie.co.at

AGEING PROPERTIES OF DEUTERIUM LAMPS USED IN CALIBRATIONS OF UV SPECTRORADIOMETERS

Schneider, T.[1], Eder, B.[1], Renkl, G.[1], Bothschafter, E.[1], Bandreddi, M.[1]
[1] Instrument Systems GmbH, Munich, GERMANY

t.schneider@instrumentsystems.com

DOI 10.25039/x46.2019.PO104

Abstract

Deuterium (D_2) lamps are commonly used for relative spectral- and/or absolute calibration of spectroradiometers in the UV wavelength range, especially below 250nm. A significant contribution to the measurement uncertainties of those calibrations is the long term instability (ageing) of the spectral output of deuterium lamps which is significantly higher than for halogen lamps typically used for spectroradiometer calibrations in the visible wavelength range or in photometric applications.

We present an analysis of the ageing behaviour of an ensemble of D_2-lamps, identify typical characteristics of the ageing process and suggest simple strategies for monitoring of, and potentially correcting for, the temporal changes in the spectra of deuterium lamps.

Keywords: e.g. Radiometry, UV, ageing, deuterium lamp

1 Introduction

Light sources emitting radiation in the wavelength range from 200 nm to 400 nm have many important applications including fluorescence measurements in biology, material inspection, disinfection, curing of polymers, lithography and energy efficient visible light generation in e.g. fluorescent tubes. Also light sources commonly used because of their emission of visible light, like e.g. high power halogen lamps or fluorescent lamps, can emit significant amounts of UV-radiation. Development, characterization and assessment of light sources with UV spectral content, especially in the context of photo-biological safety, require accurate spectroradiometric measurements in the UV spectral range which in turn require stable and well characterized reference UV-sources for calibration of measurement instruments.

The most common reference UV light sources are low pressure discharge deuterium arc lamps (D_2-lamps) that emit radiation in the wavelength range from about 112 nm to 900 nm (Saunders1978). Of interest for calibration purposes is the continuum emission of D_2-molecules (outside the vacuum UV range) from about 200 nm to 400 nm. Fig.1 shows a measured emission spectrum and an image of a common commercial realization of a D_2-lamp. At a distance of 30 cm from the source (a typical distance used in spectral irradiance calibrations) a D_2-lamp like the one shown in Fig.1, operated at a current of 300 mA, has a maximum spectral irradiance of around 1 mW/(m^{2}nm) at 210 nm and a total irradiance of about 80 mW/m^2.

Manufacturers typically specify a lamp lifetime of a few thousand hours and a short term drift of the radiometric output of around 0.3%/h to 1%/h at some specific wavelength close to the maximum of the emission spectrum. Measurements like the ones shown in this paper indicate that the specified drift values are also typical for the short term drift of the total radiometric output. Long term drifts of several percent with respect to a primary irradiance scale have been reported (Sperfeld2003, BIPM2008).

The observed and specified drift values for the output of D_2-lamps are a significant contribution to the measurement uncertainties for calibrations of measurement instruments. Typical expanded measurement uncertainties for the calibration of spectral irradiance of D_2-lamps at National Metrology Institutes (NMI) in the UV range from about 1% for primary standards (Shaw 2007, Klein2018) to about 10% for working standards, depending on wavelength and calibration procedure.

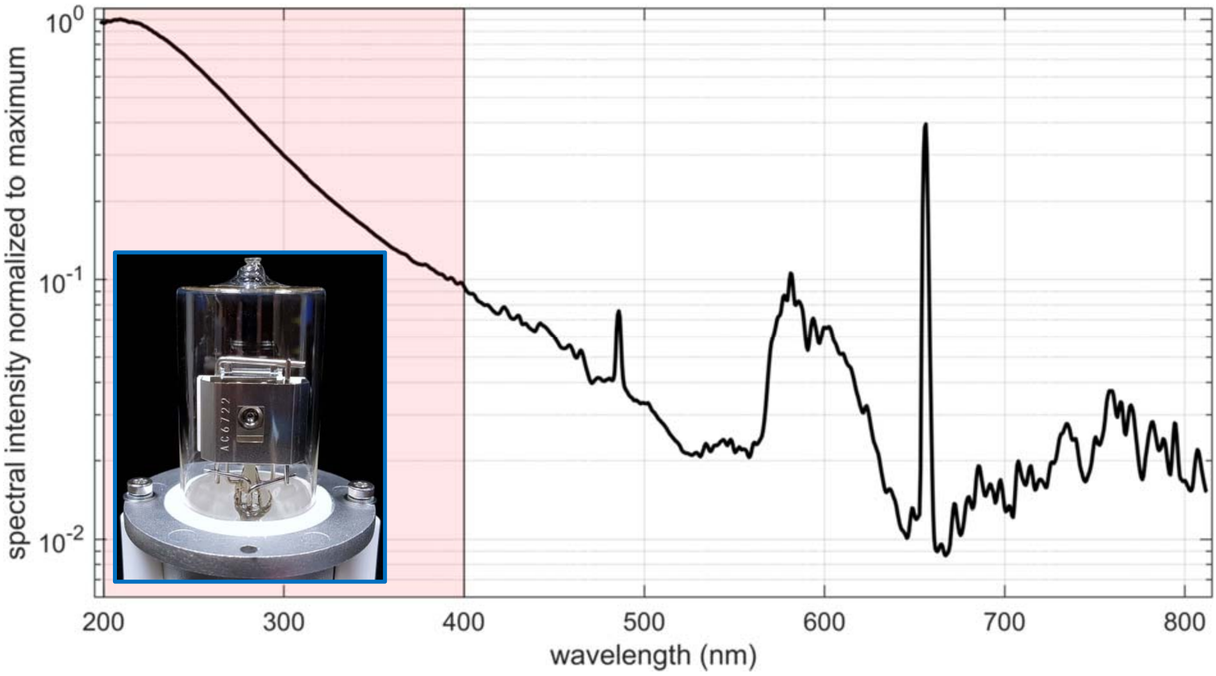

Figure 1 – Typical emission spectrum of a deuterium low pressure discharge lamp. Red shaded area indicates wavelength range typically used as reference spectrum for calibration purposes. Inset: Image of a common technical realization of a deuterium lamp.

2 Analysis of the ageing behaviour of an ensemble of D_2-lamps

Several studies of the ageing behaviour of deuterium lamps have been published previously, e.g. in (Sperfeld2003, BIPM2008, Zama1998, Zama2007) and technical improvements were discussed in the literature (see e.g. Key1980, Zama1996).

Here we investigate the ageing properties of an ensemble of 11 deuterium light sources used for spectral irradiance calibration purposes using lamps by two different manufacturers. 2 lamps were calibrated at the Physikalisch-Technische Bundesanstalt (PTB), the other are working standards calibrated against the PTB calibrated references.

Ageing is evaluated by looking at the differences in the spectral output of each lamp from one calibration to the next. Dividing the differences by the total burn time of the lamp between calibrations gives an estimate of the mean spectral changes in percent per hour and nanometer. The changes in the total radiometric output are calculated from the integrals over the measured spectra in the range of 200 nm to 400 nm.

Spectral measurements were done with an Instrument Systems CAS140D-157.

2.1 Total radiometric output

Fig.2 shows measurement results for 31 (re)calibration measurements of the 11 D_2-lamps. 50% of the measurements were at burn times less than 15 hours since the last calibration, the maximum burn time between calibrations was 30 hours.

Mean rates of change are for most lamps within manufacturer specifications. For the relatively short accumulated burn times of the lamps only a small systematic degradation of the lamp output was observed. The mean observed change in the spectrally integrated output averaged over all measurements was -0.1% with a standard error of the mean of 0.03%. Lamp drifts can be positive or negative on the time scale of several hours (see also section 4).

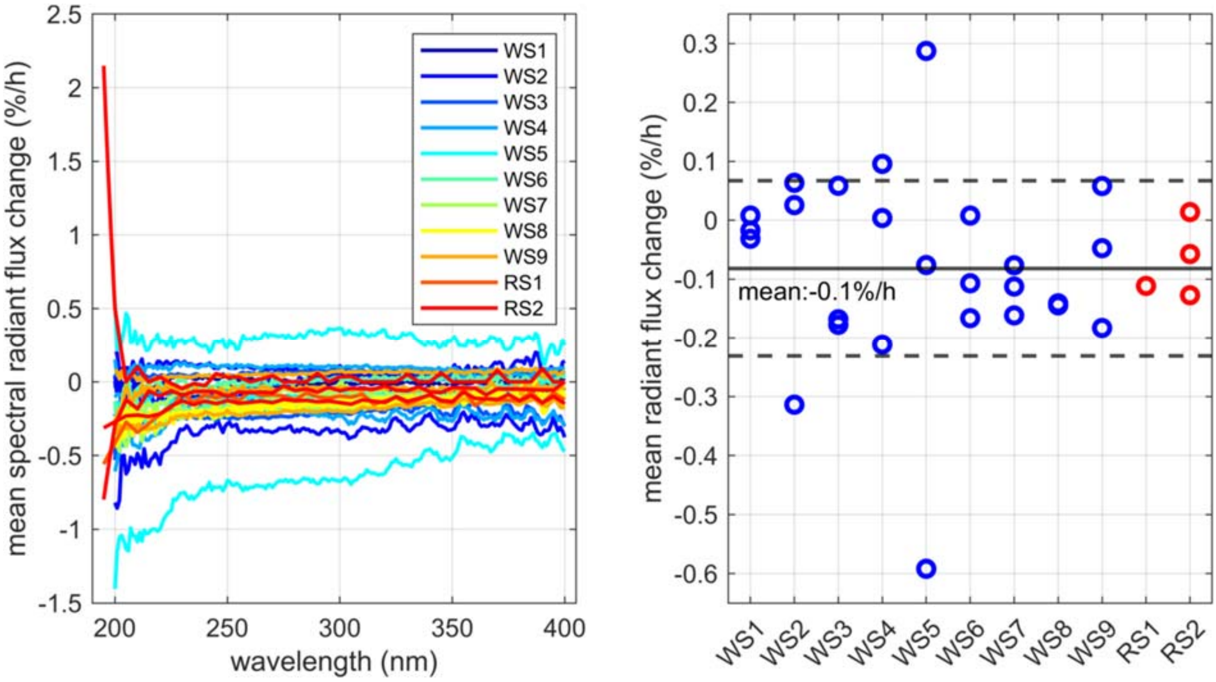

Figure 2 – Change of spectral lamp output between (re)calibrations. Left: change in spectral radiant flux. Right: Change in total radiant flux. Working standards are labelled WS, reference standards are labelled RS.

2.2 Spectral tilt

Looking at Fig.2, it appears as if most of the spectral changes in the output of the deuterium lamps could be described by a combination of a global scaling (change in radiometric integral) and a linear spectral tilt ($\%h^{-1}nm^{-1}$). Fig.3 shows an evaluation of the spectral tilt defined as the slope of a linear fit to the data from Fig.2 over the wavelength range from 230 nm to 380 nm. As for the change in radiometric integral, the mean tilt of 3.9e-4 $\%h^{-1}nm^{-1}$ with a standard error of 1.2e-4 $\%h^{-1}nm^{-1}$ is very small and can also have positive or negative sign.

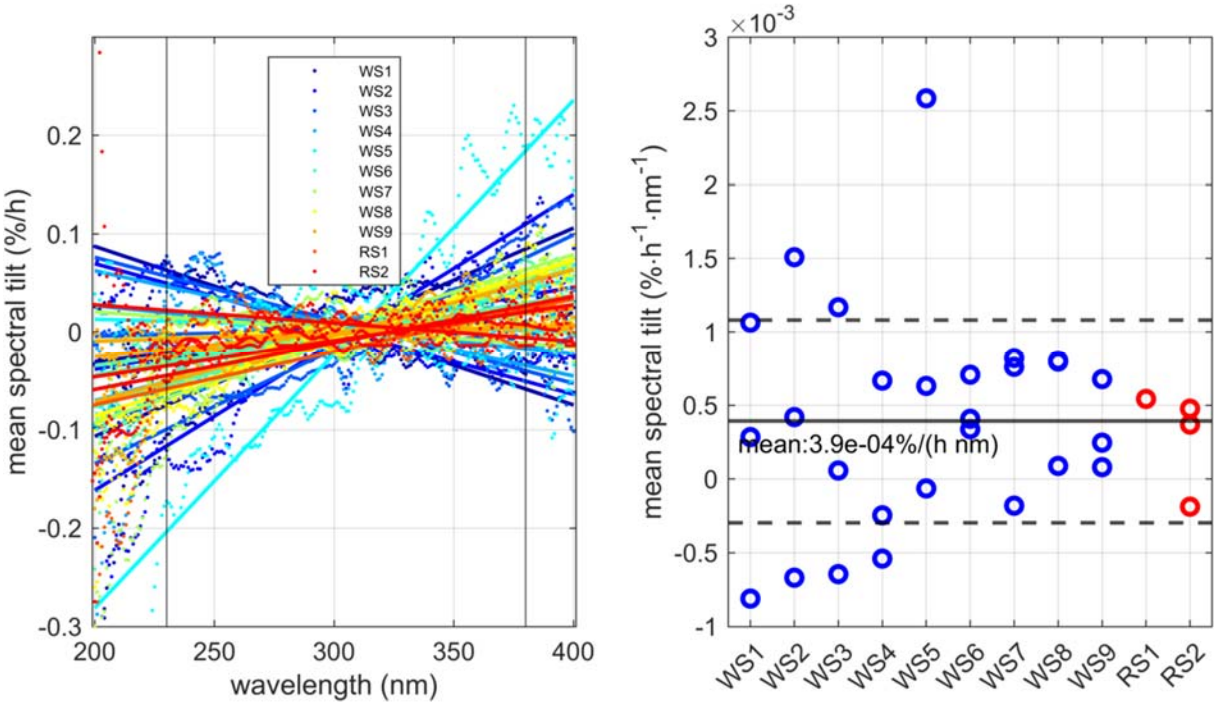

Figure 3 – Linear fits to the spectral change of D_2-lamp output. Left: data and fits. Right: tilt results defined as slopes of the linear fit.

2.3 Empirical ageing models

A slightly more elaborate empiric model for the changes of the D_2-lamp spectral output consists of a global scaling factor, a constant wavelength shift and a 3rd order polynomial. Fig.4 shows that this still rather simple model describes most of the measured data for the working standards quite well. Comparing the linear terms of the full model to the slopes from the linear fits from the previous section gives consistent results, so most of the change in output can be described by a linear spectral tilt and a global scaling.

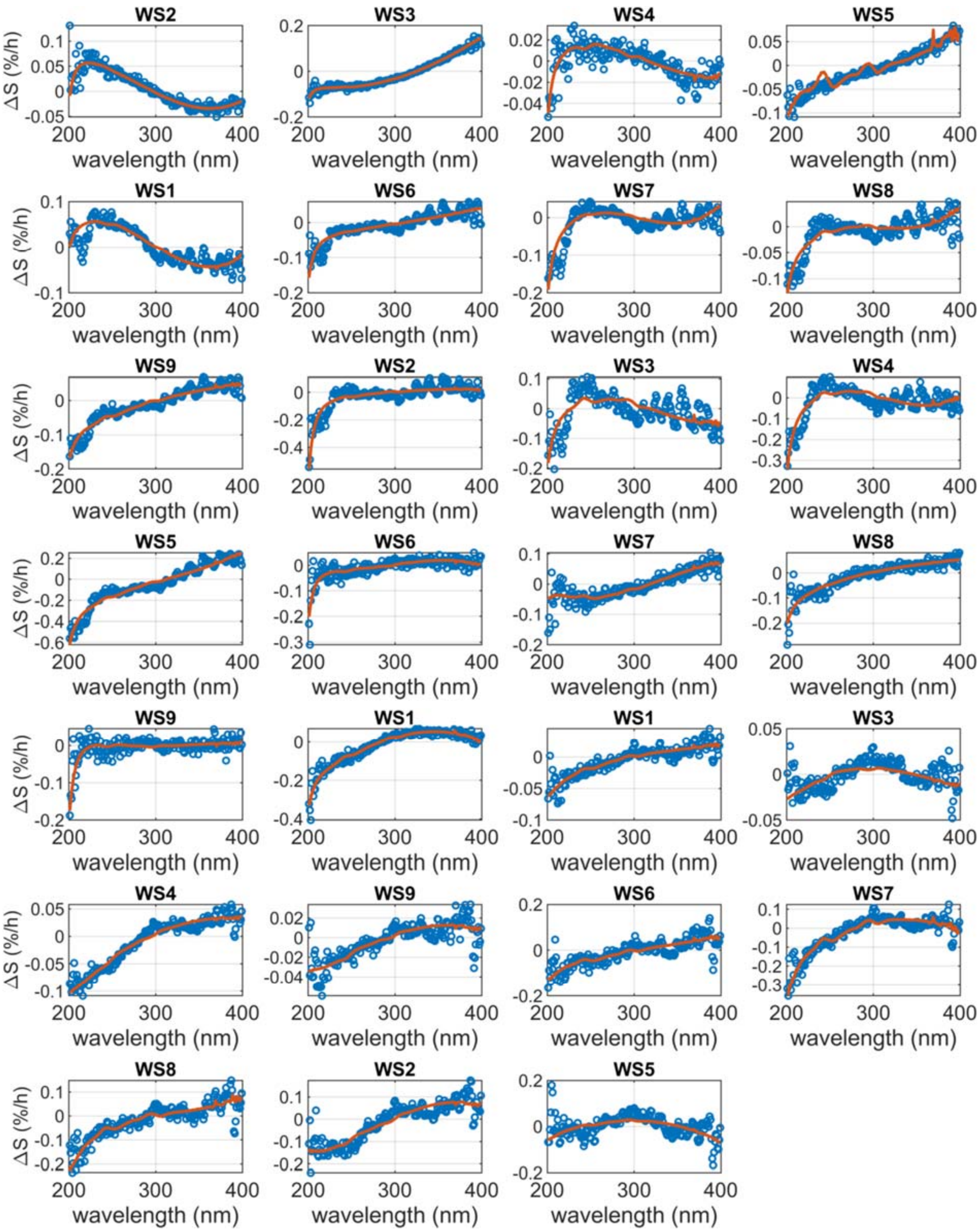

Figure 4 – Measured spectral changes for the working standards (circles) and fits of empiric 3rd order model (lines). Individual lamps appear multiple times, once for each measurement.

3 Characterization of a D_2-lamp

The previous sections showed that the output of a D_2-lamp can undergo significant changes on the time scale of a few hours. The sign and magnitude of the change can vary with time for each lamp as well as between lamps which makes it difficult to predict the future behaviour of a given lamp from past measurements. For this reason, reliable corrections of measurement results for effects of ageing based on past measurements of the lamp cannot be applied.

In order to better understand the lamp behaviour and evaluate the possibility of measuring the change in spectral output quantitatively in real time, we measured the dependence of the output of one D_2-lamp on its two main electrical operating parameters: current and filament heating voltage. Measurements were done simultaneously with a spectrometer and a photodiode.

3.1 Lamp output vs operating current

Fig.5 shows the result of a measurement of the D2-lamp output as a function of the lamp current I_{Anode} around the nominal current of 300mA. The lamp output was simultaneously measured with a spectrometer and a photodiode (PD). Both the spectrally integrated spectrometer signal and the photodiode signal increase linearly with current with very similar slopes. This already indicates that the spectral distribution of the lamp output changes only little with current and the current affects mostly the radiant flux output. Looking at the changes in the spectral distribution of the output with current confirms that the change in relative spectral distribution is small compared to the mean spectral change in the wavelength range of interest.

Based on the results shown in Fig.5 active stabilization of the total radiant flux output of a D2-lamp should be straight forward. Compensation of output drifts of up to 2% percent would require changes in current of less than 10mA, which would in turn cause changes in the relative spectral distributions of only 0.1% or less. A stabilization based on active feedback to the lamp current will require a power supply with a current resolution well below 1 mA and a relative current instability well below $<10^{-3}$.

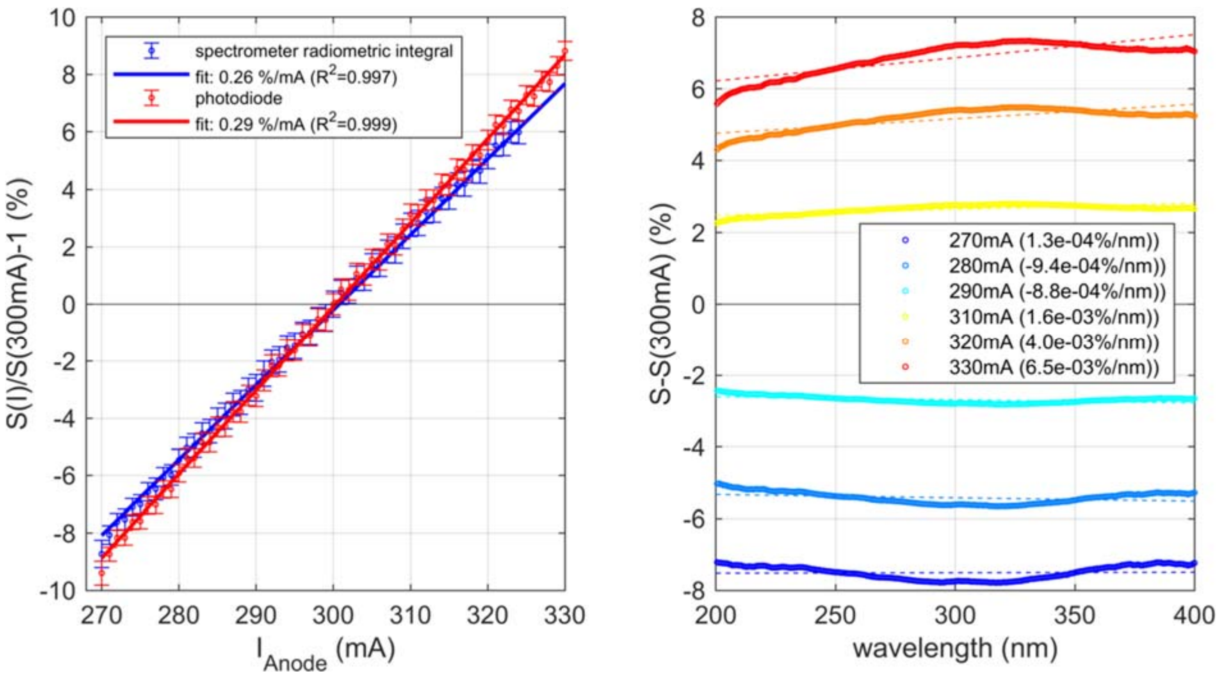

Figure 5 – D2-lamp output vs current. Left: radiant flux. Errorbars indicate 1σ standard deviations of the data taken at a given current. Right: Change in spectral distribution. Dashed lines are linear fits to the data from 200 nm to 400 nm.

3.2 Lamp output vs filament heating voltage

Fig.6 shows the result of the lamp output as a function of the filament heating voltage V_{heat}. The nominal heating voltage is 1V, the specified maximum rating for the lamp is 2V. The radiant flux output is again linear over a wide range of voltages. In contrast to the data from Fig.5, slope and overall linearity are different for spectrometer and photodiode measurements. The effect of the heating voltage on the output is about one order of magnitude smaller than the effect of a change in current shown in Fig.5 for the parameter ranges investigated. The relative change in the spectral distribution with respect to the mean spectral change is larger than in the case of changing current.

In principle, feedback to the heating voltage would allow to compensate parts of the change in the relative spectral distribution. The accompanying change in total radiant flux could be compensated by changing the lamp current. Unfortunately, the sensitivity of the output to changes in heating voltage are too small compared to the sensitivity to current to allow for an independent compensation of changes in the relative spectral contribution larger than about 0.1%.

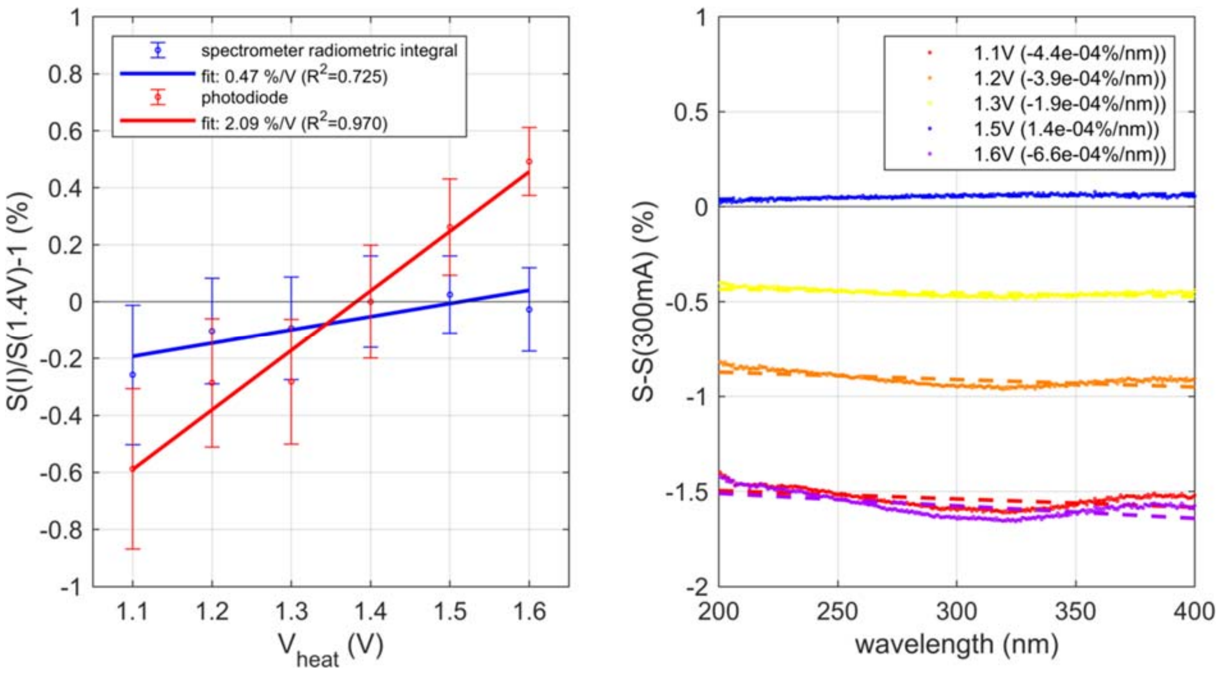

Figure 6 – D2-lamp output vs filament heating voltage. Left: radiant flux. Errorbars indicate 1σ standard deviations of the data taken at a given voltage. Right: Change in spectral distribution. Dashed lines are linear fits to the data from 200 nm to 400 nm.

4 Monitoring- and active stabilization strategy

The measurements shown in section 2 and section 3 suggest that the temporal instability of the output of a typical deuterium lamp in the wavelength range from 200 nm to 400nm can be described to large degree by a global scaling and a linear spectral tilt of the spectral power distribution. A simple method to monitor those changes would then be to monitor some part of the lamp output with two photodiodes equipped with narrow optical bandpass filters with center-wavelengths separated by well more than the bandwidth of the filters. After scaling the signals to compensate for different spectral responsivity of the two detectors, a change of the sum of the two PD-signals should be proportional to a change in total radiant flux output while a change in the difference of the PD-signals indicates a change in spectral tilt.

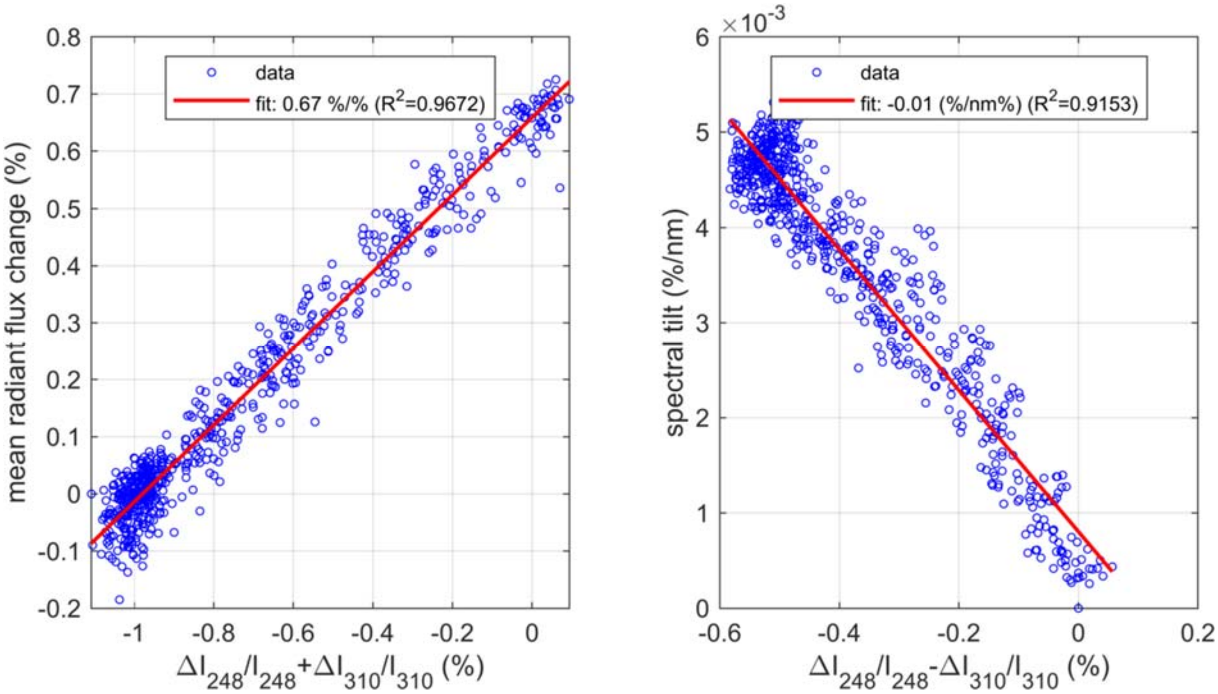

Figure 7 – Measurement with two photodiodes (PD) equipped with bandpass filter centered around 248 nm and 310 nm respectively. Left: Change in radiant flux as a function of the sum of the relative PD-current changes. Right: linear component of the spectral change in output as a function of the difference of the relative PD-current changes.

Fig.7 shows the result of a corresponding measurement with two photodiodes and bandpass filters centered around 248 nm and 310 nm.

The measurements show the expected behaviour. The sum of the PD-signals is very well correlated with the total radiant flux output while the difference correlates well with the linear component of the change in the spectral distribution of the output calculated as the slope of a linear fit to the spectral data in the wavelength range from 230 nm und 380 nm (see also section 2.2).

Measurements like the one shown in Fig.7 can be used to calculate more reliable corrections for the results of measurement relying on deuterium lamps as spectral references. Also active stabilization of the total radiometric output by feedback to the lamp current should be straight forward. Active compensation of changes in the relative spectral distribution of the lamp output is more challenging. Long term measurements of the temporal evolution of the spectral distribution of the lamp with active stabilization of the total radiant flux output via current feedback will be performed. Depending on the results, no additional compensation of spectral tilt might be necessary, an active tilt compensation by feedback to the heating voltage might be possible or no compensation might be possible with feedback to the basic electrical operation parameters.

References

SAUNDERS, R., D., OTT, W., R., BRIDGES, J., M., 1978. *Spectral irradiance standard for the ultraviolet: the deuterium lamp*. Applied Optics, 17 (4), 593-600.

SPERFELD, P., ET AL., 2003 . *Characterization and use of deuterium lamps as transfer standards of spectral irradiance*. Metrologia, 40 (1), S111-S114.

BIPM 2008. CCPR-K1.b. *Report of the CIPM Key Comparison CCPR-K1.b Spectral Irradiance 200 nm to 350 nm*. Paris: BIPM.

ZAMA, T., ONUKI, H., 1998. *Aging Characteristics of Deuterium Lamps*. Journal of the Spectroscopical Society of Japan, 47 (3), 129-135.

ZAMA. T., 2007. *Measurement of Long-Term Variation on Deuterium Lamp and Evaluation of Discharge Variation*. Japanese Journal of Applied Physics, 46 (1), 3A.

KEY, P., J., PRESTON, R. J., 1980. *Magnesium fluoride windowed deuterium lamps as radiance transfer standards between 115 and 370 nm*. Journal of Physics E, 13 (8), 866-870.

ZAMA, T., ONUKI, H., AWAZU, K., 1996. *Improvement of the aging characteristics of deuterium lamp*. Journal of Electron Spectroscopy and Related Phenomena, 80, 493-496.

SHAW, S.-P., ET AL., 2007. *Synchrotron radiation-based irradiance calibration from 200 to 400 nm at the Synchrotron Ultraviolet Radiation Facility III*. Applied Optics, 46 (1), 25-35.

KLEIN, R., ET AL., 2018. *PTB’s radiometric scales for UV and VUV source calibration based on synchrotron radiation*. Metrologia, 55, 386-391.