Characterisation report of the travelling standard B5503

Julian Gröbner
European Reference Centre for UV radiation measurements (ECUV)
European Commission – Joint Research Centre
Ispra, Italy

With contributions from
M. Blumthaler and J. Schreder
Institute for Medical Physics
University of Innsbruck
Innsbruck, Austria
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Section 1

Performance of the travelling standard B5503 during the period May to October 2002
1.1 Introduction

The European Reference Centre for Ultraviolet radiation Measurements has developed a portable spectroradiometric system for solar irradiance measurements within the project QASUME (Quality Assurance of Solar Ultraviolet Measurements in Europe through the Development of a Transportable Unit). It consists of a double monochromator spectroradiometer (B5503) from the company Bentham (DM-150) (see Figure 1.1). The portable system also includes a calibrating unit using 100 W lamps to provide for an absolute sensitivity calibration of the spectroradiometer in the field. During the first year of operation, the system was tested at several sites in Europe. The following report describes the performance of the system during this period.
1.2 Responsivity

The responsivity of B5503 has been regularly determined with 1000 W FEL or 100 W Lamps within the laboratory or in the field using a portable calibrator. A total of 46 responsivity determinations were used to calculate the variations in responsivity, which are shown in Figure 1.2 and Figure 1.3. Figure 1.2 shows the spectral variations of the responsivity in the period May to October 2002, while Figure 1.3 shows the same data as the average over selected wavelength ranges. The responsivity variations below 400 nm are mostly constant with wavelength, while at longer wavelengths there are occasional variations, which are dependent on wavelength.

1.3 100 W Lamp performance

The individual 100 W lamp variations during each calibration are shown in Figure 1.4. For the most part, the variations of the three 100 W lamps are within 0.5% of the mean of all three. There are larger variations of up to 1% (in one case a difference between 2 lamps of nearly 2%) during the INSPECTRO\(^1\) campaign. Possibly the environmental conditions, wind, wet, are responsible for that.

\(^{1}\)INSPECTRO— INFLUENCE OF CLOUDS ON THE SPECTRAL ACTINIC FLUX IN THE LOWER TROPOSPHERE (Project EVK2-2001-00135)
Figure 1.3: Responsivity variations of B5503 during the period May - October 2002

Figure 1.4: Responsivity variations of individual 100 W Lamps during each calibration
Figure 1.5: Lamp voltage variations for all calibrations performed in 2002

The Lamp voltage variations over time are shown in Figure 1.5 for all of the 100 W lamps used during the year 2002.

Three of these, T53061, T53062 and T53063 were the usual calibration lamps. The burntime in hours of all lamps at the end of 2002 are the following:

T53061 12.31 hrs  
T53062 12.23 hrs  
T53063 11.62 hrs  
T57824 0.46 hrs  
T57825 1.71 hrs  
T38986 3.77 hrs

1.4 Slit function measurement

The slit function was determined with a Helium-Cadmium Laser at 325 nm using various neutral density filters placed in the path of the laserbeam. The full width at half maximum of the slit function of B5503 is 0.83 nm. At the end of the first round, i.e. October 2002, the middle slit of B5503 was increased from 2 mm to 4 mm. This should result in better stability. The resulting slit function is shown in Figure 1.7. The previous slit function with the narrow middle slit is also shown in the left figure of Figure 1.7.
1.5 Dispersion relation and wavelength calibration

The dispersion relation was measured with Mercury, Cadmium and Zinc spectral discharge lamps on April 10 and November 4, 2002. As can be seen in Figure 1.8, the residuals between the measurements and a quadratic fit through the measurements are nearly identical. This demonstrates the stability of the wavelength drive in B5503.

B5503 has two entrance ports, one of which is equipped with a Mercury lamp. On November 26, the 296.7 nm Hg emission line was measured alternatively with the internal and an external Hg lamp installed in front of the Teflon diffuser. Initially, measurements were done as fast as possible. After 10 UT (see Figure 1.9), the measurement cycle was decreased to 15 minutes. During the fast cycling before 10 UT, the instrument heated up because of the repeated SAM energisation and shifted the relative wavelength setting between the two ports. This effect was known but is now much smaller due to the larger middle slit. Once the cycling was decreased to 15 min, the instrument returned to a stable behavior. This is in contrast to what occurred with the smaller middle slit, where a cycling of 15 min was still too much. One conclusion is that now it may become possible to use the internal Hg lamp for wavelength calibration at the beginning of each solar spectrum measurement.\(^2\)

The larger variability of the wavelength determination of the UV port is unexplained. This needs to be investigated further. Possibilities could be the optical

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\(^2\)18 February 2003: During several measurement days on the JRC platform the routine measurement of the Hg line before every solar spectrum did not disturb the instrument and was able to provide very valuable information on the stability of the wavelength drive of the spectroradiometer.
Figure 1.8: Residuals from measurements of spectral lines from discharge lamps Hg, Cd, and Zn on April 10 and November 4, 2002

Figure 1.9: Internal and external Hg lamp measurement of the 296.7 nm line in the laboratory
Figure 1.10: Differences in irradiance scales between three 1000 W FEL Lamps traceable to PTB. F330 was calibrated by Gigahertz Optik, while F304 and F324 were directly calibrated at the facilities of PTB.

Path differences due to fiber and entrance slit geometry, the SAM mirror position when unenergised (UVport position: In this case the SAM Mirror is used).

1.6 Irradiance scale

The Irradiance scale used by B5503 was based on the 1000 W FEL lamp calibrated by Gigahertz Optik (F330) in February 2002. In October 2002, two new 1000 W FEL lamps calibrated directly by PTB were brought to ECUV. One, F324, belongs to ECUV and was hand carried from Braunschweig to the JRC. The second, F304 belongs to Univ. Hannover and was delivered to ECUV for the duration of the QASUME project. It was hand carried from Hannover to ECUV, via a conference in Greece. The three lamps were measured in the Laboratory of ECUV on two following days. The differences are shown in Figure 1.10.

The irradiance of F304 is between 1 and 2.5% higher than the lamps F330 and F324. This is within the stated uncertainties of ±3% of the certificates delivered by PTB and Gigahertz Optik. Since the two lamps belonging to ECUV show differences below 0.5%, no change in irradiance scale is foreseen.
Figure 1.11: Directional response deviations from a cosine response of the entrance optic in use during the 2002 round showing the largest measured difference between the two opposite planes (azimuth dependence)

Figure 1.12: Deviations of the directional response of the optimised Input optic from a cosine response which will be used in 2003. Shown is the largest measured difference between the two opposite planes (azimuth dependence)

1.7 Azimuth dependency of the entrance optic

Since the beginning of 2002 there have been indications that the entrance optic of B5503 had an azimuth effect which resulted in diurnal variations of up to possibly 5%. This was investigated in September 2002 after the INSPECTRO campaign and before the Greece campaign. Measurements at Innsbruck showed variations of 5-7% in the azimuth (see Figure 1.11). In January 2003, the directional response of the entrance optic was optimised to decrease the observed azimuth effect. The new directional response is shown in Figure 1.12. The largest observed difference between various azimuth angles are below 2% and are within the uncertainties of the measurement accuracy of the directional response.
1.8 Temperature sensitivity study

In November 2002 the complete spectrometer system was installed in a climate chamber of the JRC to investigate the effect of temperature variations on the whole system, including the Peltier-box. The results are discussed in chapter 2 of this report. The major findings were:

- The entrance optic has a temperature sensitivity of $-1.6 \pm 0.2\%$ per $10^\circ$C for the investigated temperature range 33 to 50$^\circ$C. Between 27 and 33$^\circ$C there seems to be no temperature sensitivity. 3

- An upper bound for the temperature sensitivity of the spectrometer system was established. It is $-4 \pm 1\%$ per $10^\circ$C, and is independent on wavelength longer than 400 nm. It is not known how the system behaves for wavelengths shorter than 400 nm.

1.9 Hardware changes of B5503 between 2002 and 2003

Middle slit One major change occurred in October 2002 and represented the increase of the width of the middle slit from 2 to 4 mm. This should result in a much higher stability of the instrument especially with respect to temperature.

entrance optic Since the INSPECTRO campaign in September 2002, the entrance optic is heated to minimize effects due to humidity. As of 2003 a PT100 sensor will monitor the temperature of the entrance optic. An improved levelling system to be mounted on the tripod has also been constructed.

Temperature monitoring Additional PT100 temperature sensors have been included in the system to monitor the temperature of the spectrometer at various locations to investigate temperature gradients. Currently there are 3 PT100 sensors located at the PMT, the entrance slit and inside the spectrometer on the base plate of the optical mount (motor side). A fourth PT100 sensor is used to monitor the temperature of the entrance optic.

1.10 General enhancements

100 W Calibration system A RS-232 to Ethernet interface is now in use in the lamp calibration system. This allows the control computer (Laptop) to be used at much larger distances, in effect removing the need to move it close to the calibration setup.

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3\footnote{February 2003: A temperature change of the entrance optic from 18 to 26$^\circ$C induced a change in sensitivity of +1.3\% which is opposite to the observed behavior at temperatures above 33$^\circ$C.}
Backup batteries A system consisting of 4 car batteries, a DC to AC transformer and a battery charger is being designed to allow the spectrometer system to be turned on during transportation. The autonomy should reach more than 24 hours. This should allow the system to stabilise itself before arriving at a comparison site and reduce considerably the initial warm-up time. This should be ready for the 2003 round.
Section 2

Characterisation of the temperature sensitivity of the travelling standard B5503
2.1 Introduction

The system to be characterised consists of a DM-150 double monochromator spectrometer system within its temperature stabilised box (cooled using two peltier elements), the optical quartz fiber and the entrance optic connected to it. The main component of the entrance optic is a shaped Teflon diffuser, which weights the incoming radiation with the cosine of the incident angle relative to normal incidence. A quartz dome protects the Teflon diffuser. During normal conditions, the temperature is stabilised to within ±0.05°C, at a temperature of about 24°C.

The aim of this study was to quantify the temperature dependence of the whole system by simulating a diurnal temperature variation of about 25°C. To this end, the whole system was put within a climate chamber whose front consisted of a glass plate (see Figure 2.1). A stable 1000 W DXW type quartz halogen Lamp was set-up outside of the climate chamber, at about 20 cm from the input optic as shown in Figure 2.2.

The system was installed on the afternoon of the day before the actual characterisation took place. The measurements were started at 8:30 UT and lasted until 15:30 UT without interruption. The reference lamp was left on during the whole
Figure 2.2: The setup of the 1000 W lamp in front of the Entrance optic head of B5503 behind the glass front of the climate chamber
Figure 2.3: The current and voltage of the 1000 W DXW-type lamp used as radiation source. The bottom figure shows the shunt temperature used to measure and control the current.

period. As can be observed in Figure 2.3, the lamp voltage decreased rapidly by 0.3 V after turn on and decreased very slowly during the remaining measurement period.

The first spectral measurements were used to define the usable spectral range for the subsequent measurements. Since the glass plate absorbed strongly all radiation below 300 nm (see Figure 2.4), only spectral measurements between 310 and 500 nm were performed, at wavelength intervals of 5 nm. The measurement protocol consisted in measuring spectra continuously, each starting with a dark current measurement. Each spectrum was measured within 52 seconds for a total of 306 spectra.

The temperature was monitored with two PT100 sensors. One sensor monitored the climate chamber temperature and was glued on the outside of the spectrometer enclosure (ambient temperature). The other temperature sensor within the spectrometer enclosure was glued to the spectrometer body, close to the photomultiplier tube (internal temperature). It is located opposite to the peltier elements and is therefore protected from direct air flow. Earlier tests with a second PT100 probe on the spectrometer body facing the peltier elements have shown a slightly higher variability in temperature (±0.1°C versus ±0.05°C) but no systematic difference; this rules out any significant temperature gradients within the spectrometer enclosure.
2.2 Temperature behavior

The ambient temperature of the climate chamber and the internal temperature of the temperature stabilised spectrometer enclosure are shown in Figure 2.5.

2.2.1 Climate chamber temperature

As can be seen in Figure 2.5, the initial temperature at 8:20 UT within the climate chamber was about 25°C. It increased steadily to 30.1°C within about 30 min because of the heat of the spectrometer system. Subsequently the temperature of the climate chamber was gradually increased in several steps to 54°C with two plateaus at 35°C and 47°C. These plateaus lasted for about 15 to 20 min each. The final plateau at 54°C was reached at 11 UT and lasted for 2 hours. Then the heating was turned off and the temperature gradually decreased, reaching 45°C at 15:30 UT when the measurements were stopped. During the temperature increase, the temperature gradient of the climate chamber was +1°C every 2 min. The temperature decrease after 13 UT was much slower and followed an exponential decay (see Figure 2.5).

2.2.2 Spectrometer temperature (internal temperature)

The temperature within the peltier cooled spectrometer enclosure remained stable until 9:30 UT (see Figure 2.5). At this stage, the ambient temperature had reached the second plateau at a temperature of 47°C. After about 20 min the heating of the climate chamber was turned on again which proved too much for the cooling
power of the peltier elements. This resulted in a continuous increase of the internal temperature which reached a maximum of 30.6°C at 13:38 UT. It is interesting to note that the maximum of the internal temperature was reached about 30 min later than the corresponding maximum in ambient temperature.

2.2.3 Spectrometer dark current

As mentioned earlier, the dark current of the spectrometer was measured before every spectrum. These dark current measurements are shown in Figure 2.6 together with the internal temperature. There is a very good correlation between the two parameters, which demonstrates that the internal temperature is a valid indicator for the temperature changes of the photomultiplier. A noticeable time lag of 25 minutes between a change in temperature and the corresponding change in dark current is evident in the figure. This indicates a slower response of the photomultiplier and quite likely of the spectrometer system as a whole than the temperature sensor. If the time lag between the internal temperature and the ambient temperature is also taken into account, it seems that the spectrometer system is decoupled from the outside world with a time constant of about 1 hour.
Figure 2.6: Internal temperature and dark current as measured before every spectrum.

Figure 2.7: Radiation measurements at 400, 430, 450, 470 and 500 nm, normalized to the last measurement. The internal temperature is also shown (axis on right).

Figure 2.8: Same as picture on left with the ambient temperature.
Figure 2.9: Selected spectra versus wavelength normalized to the first 6 measurements.

2.3 Discussion and results

The normalised irradiances measured by the spectrometer at several wavelengths are shown in Figures 2.7 and 2.8 together with the internal and ambient temperatures respectively. In addition Figure 2.9 shows several suitably chosen spectra versus wavelength.

2.3.1 Spectral temperature dependence

The spectra shown in Figure 2.9 were normalised to the 6 initial spectra measured at an ambient temperature of about 28°C. The most obvious feature of these ratios is the strong dependence on temperature for wavelengths shorter than 360 nm. Even within the 6 first scans there are changes of the order of 5% at 320 nm. Later and at higher temperatures, the measured radiation decreases by up to 35% at 320 nm and shows a marked slope with wavelength. The wavelength dependence of the observed decrease in radiation is strongly correlated with the spectral glass transmission of the climate chamber. This marked spectral temperature dependence of the measured radiation is believed to be mainly due to a change in the glass absorption and not to the spectrometer system for the following reasons:

- All solar spectra measured simultaneously with other instrumentation of different design and manufacture, for a variety of atmospheric conditions including large temperature variations similar to the ones encountered in this study have
shown wavelength dependent effects below 10% down to wavelengths of 300 nm;

- the radiation at 330 nm measured before 9:30 changes by more than 30%, while the spectrometer system is still working well within its limits as documented by its internal temperature;

- the observed changes in radiation are nearly perfectly correlated with the ambient temperature without any noticeable time lag between the two which rules out a spectroradiometric origin.

The conclusion is that the glass transmission depends significantly on temperature at least for wavelengths shorter than 400 nm and thus for the remainder of the study only wavelengths longer than 400 nm will be analysed.

2.3.2 Temperature dependence of B5503

The normalised irradiance measurements shown in Figures 2.7 and 2.8 decrease by 7% independently of wavelength. This decrease starts immediately after lamp turn on and continues more or less continuously with time until 13 UT when the ambient temperature starts again to decrease. It is very interesting to note that before 11 UT, this decrease is much better correlated to the ambient temperature than to the internal (spectrometer) temperature. Especially the temperature plateaus at 35° and 47°C are clearly visible in the normalised irradiance measurements and show nearly no time lag as would be expected if the cause of the temperature dependence would be inside of the temperature controlled spectrometer box. A similar behavior is seen during the temperature decrease after 13 UT, when the measured irradiance starts to decrease even earlier than the internal temperature.

Clearly, these two effects can only be explained by a change occurring outside of the spectrometer box. One possibility would be a change in the glass transmission as was discussed previously. A second possibility would be a change of one or more components of the spectrometer system residing outside of the temperature stabilised box and therefore directly exposed to ambient temperature variations.

In fact, two elements of the spectrometer are not temperature stabilised, the first being the entrance optic with the shaped Teflon diffuser, the second the quartz fiber linking the entrance optic to the spectrometer. In the following two sections these two elements will be discussed separately.

Temperature dependence of the quartz fiber

The temperature dependence of the quartz fiber was not investigated in this study. A study performed with a similar fiber in another laboratory has not been able to observe any temperature dependence for the temperature range -20 to +20°C. A conservative upper limit of 1% per 20°C change can be assumed from this investigation (personal communication, M. Blumthaler).
Temperature dependence of the entrance optic

The temperature dependence of the entrance optic was measured several days after this study to assess its contribution to the temperature variations observed in the climate chamber. The spectrometer system was temperature stabilised at its usual internal temperature of 24°C with an ambient temperature of about 21 ± 1°C. The aim was to expose only the entrance optic to varying temperatures. To this end the entrance optic was heated either using its proper heating element (approximately 7 W heating power) or by additional heating using a manually controlled fan. The temperature of the entrance optic was monitored with a PT100 sensor glued onto the body of the entrance optic. The results are displayed in Figure 2.10 and 2.11.

A distinct temperature dependence of the entrance optic can be observed in the data shown in the two figures. The sensitivity decreases with increasing temperature, similar to the measurements obtained in the climate chamber. The measurements were only performed at 400 nm, so no information on possible spectral effects is available. However as the cause of the change is most likely geometrical it is expected to be independent of wavelength. The investigated temperature range was between 27 and 51°C and the maximum observed sensitivity change was 3.2%. As can be seen from Figure 2.11 there are some inconsistencies of the order of 0.5% between the various temperature regimes. Indeed, the measurements suggest that for temperatures below about 33°C the entrance optic might not be sensitive to temperature. Also, the input optic seems to react differently to increasing or decreasing temperatures. This latter effect might be due to the larger inertia of the entrance optic body with respect to the temperature sensor and the resulting time lag between the two.

The following determination of the temperature coefficient will be done only for
temperatures above 33°C, assuming that at temperatures between 27 and 33°C, the entrance optic is unsensitive to temperature. Obviously, it is not known how the entrance optics reacts to temperatures below 27°C. The temperature coefficient determined from the initial temperature increase (Figure 2.10, before 14 UT) is -1.8% per 10°C. The temperature coefficient corresponding to the subsequent temperature decrease is -1.5% per 10°C. Thus the mean temperature coefficient used for the following study will be $-1.6 \pm 0.2$ per 10°C.

### 2.3.3 Attributable temperature dependence of B5503

Especially due to the unknown temperature dependence of the Glass front above 400 nm, only an upper limit for the temperature dependence of the complexive spectrometer system can be inferred from the measurements in the climate chamber. Other uncertainties include a possible drift of the lamp irradiance or a gradual change of the spectrometer sensitivity with time, independent of temperature. These possibilities were investigated by repeating part of the measurements on the next day (see section 2.3.4); I estimate an overall uncertainty in the measurements of 0.5% from a comparison of these two days.

For the following discussion it will help to distinguish between two regimes, one which is known to be caused by elements outside of the peltier cooled box, the other by changes within. Thus, we will define the first regime as the two periods when

1. the internal temperature was stable, i.e. before 9:30 UT,
2. the ambient temperature started to decrease, i.e. after 13:20 UT.

The second regime is the remaining time in between the periods defined previously, i.e. between 9:30 and 13:20 UT, when the internal temperature rose continuously by 6.6°C.

#### First regime

Within the first regime, the ambient temperature initially increased by 19°C (from 28 to 47°C) and the measured radiation decreased by 3%. This decrease with temperature corresponds to a large extent to the one expected from the entrance optic (-2.3%, see section 2.3.2). Similarly, during the temperature decrease after 13:20 UT, a decrease of 9°C resulted in an increase in measured radiation of 1%. The change attributable to the input optic would be +1.5%, leaving an unexplained 0.5% which is within the estimated uncertainties of the measurement setup.

#### Second regime

The internal temperature started to increase consistently after 9:30 UT as the peltier elements became unable to stabilise the internal temperature at the nominal setpoint of 24°C. This resulted in an internal temperature increase of 6.6°C during which time
Figure 2.12: Radiation measurements at 400, 430, 450, 470 and 500 nm for the first (shown is only a subset) and second day (symbols). Both are normalised to the first measurement of the first day.

The measured radiation decreased by 4% (±0.5%). Simultaneously to the change in the internal temperature, the ambient temperature also increased by 8°C, which resulted in a change of 1.3% attributable to the entrance optic (see previous discussion). Thus 2.7 ± 0.7% of the radiation decrease remain to be explained by a change in the spectrometer system itself. Since the internal temperature increased by 6.6°C, and assuming that the system reached thermal equilibrium, the temperature sensitivity of the spectrometer would be −4 ± 1% per 10°C. Incidentally, this temperature dependence of the spectrometer is in reasonable agreement with a previous study using a similar instrument setup (−6% per 10°C, Gröbner, 1996).

2.3.4 Second day measurements —Reference lamp stability

As can be seen from Figure 2.3 the reference lamp was in use for nearly 6 hours during which time the lamp voltage decreased continuously by about 0.15 V. To investigate the possibility of the lamp radiation output changing over this time period, a second set of measurements was obtained on the following day in conditions as similar as possible to previously. The aim was to check that the system had returned to its initial state after cooling down over night. The initial measurements of both days are shown in Figure 2.12 versus the ambient temperature. Whereas the heating of the climate chamber was turned on at a temperature of 31°C on the first day, on the second day no additional heating was used and the rise in temperature is only due to the heat of the spectrometer system.
The data displayed in the figure shows clearly an agreement between the two days of 0.5%, even though the slopes of each measurement series versus ambient temperature are slightly different. These slightly different slopes are difficult to explain since the conditions should have been identical which however could not be accomplished. Indeed, the initial ambient temperature was different, 26 versus 31°C, the amount of burning of the lamp before measurements was 15 minutes on the first day versus 5 on the second which implies a different heat load on the glass front for example.

The main conclusion that can be obtained from this data is that the lamp remained stable to within 0.5% and no lamp drift corrections need to be applied to the measurements.

2.4 Conclusion and recommendations

The measurements in the laboratory and in the climate chamber have been able to provide upper bounds for the temperature dependence of the spectrometer and the associated entrance optic. The largest uncertainty is related to the unknown temperature behavior of the glass front of the climate chamber which could lead to an overestimation of the temperature coefficient of the spectrometer system.

2.4.1 Entrance optic

The temperature dependence of the entrance optic was measured in the laboratory and was found to be $-1.6 \pm 0.2\%$ per 10°C within the temperature range 33 to 50°C. Between 27 and 33°C, there seem to be no temperature dependence but further measurements are required to clarify the temperature behavior at different temperature regimes. During regular operating conditions in summer, diurnal temperature variations can easily exceed 20°C, which would result in a fictive daily variation in the measured solar irradiance of 3% due to this effect. This is an important finding not only for this instrument system since identical copies of this diffuser are in use at a number number of UV monitoring stations in Europe.

2.4.2 Spectrometer

The temperature dependence attributable to the spectrometer has led to two independent and important conclusions: First, as long as the internal temperature within the spectrometer box is stable, no indication of any temperature dependence could be found. This rules out any effect due to internal temperature gradients induced by the strong cooling of the peltier elements. The second conclusion is that an upper bound for the temperature coefficient of the spectrometer of $-4 \pm 1\%$ per 10°C was found, which is independent on wavelengths longer than 400 nm.

The recommendations that can be deduced from these results are the following:
1. It is crucial to monitor the temperature of the entrance optic and to keep it as constant as possible. This is true not only during measurements, but also during calibrations. This can be achieved by always using the heating element at 24 V which should guarantee a temperature of the entrance optic of about 40°C since it is self regulating.

2. The internal temperature of the spectrometer should stay within ±1°C of its nominal temperature to achieve a measurement stability of ±0.5%. From past experience this seems achievable.

Acknowledgments

I wish to thank the Renewable energies Unit for allowing me to use their facilities and in particular Tony Sample for his support.

References

Section 3

Conclusion
Several problems and discrepancies were discovered during the first year of operation of the travelling reference B5503. The most troublesome was the azimuth dependency of the entrance optic which caused diurnal variations of up to 5% depending on the time of day, but also on the prevailing atmospheric conditions during the measurement. This problem was discovered during joint solar measurements between several spectroradiometers and B5503. This dependence could be verified and quantified in the laboratory. Subsequent adjustments have reduced this dependence to less than 2%, which is the uncertainty in the directional response measurement itself.

Another problem was the narrow middle slit in the spectroradiometer which caused a high temperature sensitivity of the spectroradiometer. This was seen during laboratory measurements on the two entrance ports of the spectroradiometer. Possible diurnal variations during solar measurements were masked by the azimuth effect discussed previously. For the next round in 2003, the width of the middle slit has been increased to make the instrument less sensitive to temperature fluctuations. With this new middle slit, it has become possible to use the second entrance port of the spectroradiometer for wavelength alignment checks before every solar measurement.

The calibrator and the 100 W lamps have performed according to the expectations, and no improvement to this part of the system is foreseen for the next round.
Mission of the JRC

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.