FINAL REPORT

ON THE

BILATERAL SUPPLEMENTARY COMPARISON

OF

CRYOGENIC RADIOMETERS

CCPR-S3

NPL – CMI

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1. Introduction

Following the decisions of the 1994 meeting of the Consultative Committee for Photometry and Radiometry (CCPR) the BIPM acted as pilot laboratory for an international comparison of cryogenic radiometers, later designated as a supplementary comparison, (CCPR-S3) carried out using silicon trap detectors as transfer devices. This comparison was completed in February 1999.

Following the completion of this comparison and the publication of the final report [1] the Czech Metrology Institute (CMI) of Prague, Czech Republic, expressed a wish to demonstrate its primary spectral responsivity measurement capabilities, in support of its CMC claims, through linkage to the CCPR-S3 comparison. NPL offered to organize a bilateral comparison with CMI following a similar protocol to that used in the original comparison. A formal protocol was subsequently written and approved by the CCPR working group on Key comparisons to facilitate this process. See Appendix 1 of this report.

The protocol required CMI to calibrate a set of three NPL supplied transfer trap detectors at a series of laser wavelengths, listed in Table 1, three of which were common (*) to the original CCPR-S3 comparison.

### Table 1 - Wavelengths selected for the comparison

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>356.4 nm</td>
<td>Krypton ion line</td>
</tr>
<tr>
<td>413.1 nm</td>
<td>Krypton ion line</td>
</tr>
<tr>
<td>476.2 nm</td>
<td>Krypton ion line</td>
</tr>
<tr>
<td>568.2 nm</td>
<td>Krypton ion line</td>
</tr>
<tr>
<td>647.1 nm</td>
<td>Krypton ion line</td>
</tr>
<tr>
<td>799.3 nm</td>
<td>Krypton ion line</td>
</tr>
</tbody>
</table>

2. Bilateral comparison with CMI

2.1 Time schedule

The trap detectors, designated CMI 1, 2 and 3, were first calibrated at NPL Sept 2005. They were then calibrated by CMI in Dec 2006, and returned to NPL where they were re-calibrated in July 2007. The date of the final calibration at NPL was timed to coincide with other similar comparisons.

2.2 Stability of the transfer detectors and transfer uncertainty of the comparison

The relative change in the responsivity of the trap detectors as measured at NPL ranged in value from \(-16.1 \times 10^{-4}\) in the blue to \(-0.8 \times 10^{-4}\) in the red, (Table 2) which is consistent with the long term stability of this type of detector. Each individual detector was corrected independently but for simplicity a single uncertainty value based on the worst case for each wavelength was used for subsequent evaluation. This leads to the transfer uncertainty, \(u_{\text{transfer}}\) of the comparison at each wavelength, which is calculated by Eq. (2.1), assuming a rectangular distribution:
\[ u_{\text{transfer}} = \frac{|\text{change}|}{2 \cdot \sqrt{3}} \]  

(2.1)

<table>
<thead>
<tr>
<th>Wavelength / nm</th>
<th>356.4</th>
<th>413.1</th>
<th>476.2</th>
<th>568.2</th>
<th>647.1</th>
<th>799.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10^4) x relative change in trap responsivity</td>
<td>-16.1</td>
<td>-9.5</td>
<td>-3.2</td>
<td>-0.2</td>
<td>-2.0</td>
<td>-0.8</td>
</tr>
<tr>
<td>(10^4) x transfer uncertainty due to relative change</td>
<td>4.6</td>
<td>2.7</td>
<td>0.9</td>
<td>0.1</td>
<td>0.6</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Table 2 - CMI average relative change in responsivity for 3 trap detectors after / before travel and transfer uncertainty of comparison

2.3 Report of pilot laboratory

2.3.1 Experimental conditions at NPL

- Cryogenic radiometer type: mechanically cooled, NPL design.
- Source: Kr Ion and HeNe gas laser
- Nominal power: 600 µW
- Beam diameter (1/e²): 4.0 mm
- Temperature: 20 °C ± 0.5 °C

2.3.2 NPL uncertainty budget

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Wavelength / nm</th>
<th>356.4</th>
<th>413.1</th>
<th>476.2</th>
<th>568.2</th>
<th>647.1</th>
<th>799.3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(10^4) x relative standard uncertainty</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Cavity absorption</td>
<td></td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Brewster window transmittance</td>
<td></td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Brewster window scatter</td>
<td></td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Sensitivity of radiometer</td>
<td></td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Electric power measurement</td>
<td></td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Changes in scattered and thermal radiation</td>
<td></td>
<td>0.51</td>
<td>0.24</td>
<td>0.18</td>
<td>0.16</td>
<td>0.29</td>
<td>0.27</td>
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<tr>
<td>Measurement repeatability</td>
<td></td>
<td>0.7</td>
<td>0.56</td>
<td>0.56</td>
<td>0.54</td>
<td>0.56</td>
<td>0.6</td>
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</tbody>
</table>

Table 3 - NPL uncertainty budget for optical power measurement by cryogenic radiometer
The combined standard uncertainty is obtained by the root sum square.

2.4 Report from the participating laboratory

2.4.1 Experimental conditions at CMI

- Cryogenic radiometer type: mechanically cooled, NPL design.
- Source: Kr Ion gas laser
- Nominal power: 500 µW to 600 µW
- Beam diameter (1/e²): from 3.0 mm to 4.0 mm
- Temperature: 20 °C ± 0.5 °C

2.4.2 CMI uncertainty budget

Table 4 - NPL uncertainty budget for the calibration of transfer trap detectors

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Wavelength / nm</th>
<th>356.4</th>
<th>413.1</th>
<th>476.2</th>
<th>568.2</th>
<th>647.1</th>
<th>799.3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10⁴ x relative standard uncertainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optical power measurement by cryogenic radiometer</td>
<td></td>
<td>0.7</td>
<td>0.56</td>
<td>0.56</td>
<td>0.54</td>
<td>0.56</td>
<td>0.6</td>
</tr>
<tr>
<td>Detector DVM calibration</td>
<td></td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Detector DVM drift</td>
<td></td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Amplifier calibration</td>
<td></td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Amplifier drift</td>
<td></td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Beam size</td>
<td></td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Positional reproducibility</td>
<td></td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
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<tr>
<td>Measurement repeatability</td>
<td></td>
<td>0.11</td>
<td>0.25</td>
<td>0.19</td>
<td>0.16</td>
<td>0.26</td>
<td>0.23</td>
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<tr>
<td>Combined standard uncertainty (u_{NMC})</td>
<td></td>
<td>1.05</td>
<td>0.97</td>
<td>0.96</td>
<td>0.94</td>
<td>0.95</td>
<td>0.98</td>
</tr>
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</table>

Table 5 - Detailed CMI uncertainty budget for optical power measurement by cryogenic radiometer

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Wavelength / nm</th>
<th>356.4</th>
<th>413.1</th>
<th>476.2</th>
<th>568.2</th>
<th>647.1</th>
<th>799.3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10⁴ x relative standard uncertainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity absorption</td>
<td></td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Brewster window transmittance</td>
<td></td>
<td>0.3</td>
<td>0.6</td>
<td>0.2</td>
<td>0.2</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Brewster window scatter</td>
<td></td>
<td>0.08</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Electric power measurement</td>
<td></td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Non-equivalence of optical and electrical power</td>
<td></td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Measurement repeatability</td>
<td></td>
<td>0.25</td>
<td>0.75</td>
<td>0.21</td>
<td>0.33</td>
<td>0.52</td>
<td>0.54</td>
</tr>
<tr>
<td>Combined standard uncertainty</td>
<td></td>
<td>0.46</td>
<td>0.99</td>
<td>0.40</td>
<td>0.77</td>
<td>1.32</td>
<td>0.62</td>
</tr>
<tr>
<td>Source of uncertainty</td>
<td>Wavelength / nm</td>
<td>$10^4 \times$ relative standard uncertainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>----------------</td>
<td>---------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>356.4</td>
<td>413.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>476.2</td>
<td>568.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>647.1</td>
<td>799.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optical power measurement by cryogenic radiometer</td>
<td>0.46</td>
<td>0.99</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detractor DVM accuracy</td>
<td>0.03</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplifier calibration</td>
<td>0.58</td>
<td>0.58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positional reproducibility</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement repeatability</td>
<td>0.56</td>
<td>0.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combined standard uncertainty ($u_{NMC}$)</td>
<td>0.95</td>
<td>1.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 - CMI uncertainty budget for the calibration of NPL transfer detectors

The combined standard uncertainty is obtained by the root sum square.

2.4.3 Correction factors
No additional correction factors were applied to the results other than as part of the calibration process.

2.4.4 Comparison with NPL calibrations
The NPL calibration values $R_{NPL}$ for the same detectors are calculated as the mean of the NPL calibrations before and after travel to CMI.

The relative difference between CMI and NPL, $\Delta_{CMI-NPL}$, is calculated thus:

$$\Delta_{CMI-NPL} = \frac{R_{CMI} - R_{NPL}}{R_{NPL}}$$

(2.2)

where $R_{CMI}$ are the CMI calibration values.

The relative combined standard uncertainties of the comparison CMI / NPL are calculated by:

$$u_{CMI-NPL} = \sqrt{u_{CMI}^2 + u_{NPL}^2 + u_{transfer}^2}$$

(2.3)

The results are summarized in Table 7 and Table 8 and shown graphically in Figure 1. Note that the error bars in Figure 1 are one sigma.
Table 7 – CMI / NPL relative difference in trap calibrations $A_{CMI-NPL}$

<table>
<thead>
<tr>
<th>Transfer detector</th>
<th>Wavelength / nm</th>
<th>$10^4 \times$ relative difference in trap calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>356.4</td>
<td>413.1</td>
</tr>
<tr>
<td>CMI 1</td>
<td>-9.3</td>
<td>6.7</td>
</tr>
<tr>
<td>CMI 2</td>
<td>2.7</td>
<td>2.4</td>
</tr>
<tr>
<td>CMI 3</td>
<td>-6.5</td>
<td>5.8</td>
</tr>
<tr>
<td>average</td>
<td>-4.4</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Table 8 – Relative combined standard uncertainty of the CMI – NPL comparison

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Wavelength / nm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>356.4</td>
</tr>
<tr>
<td></td>
<td>$10^4 \times$ relative standard uncertainty</td>
</tr>
<tr>
<td>CMI calibration $u_{CMI}$</td>
<td>0.95</td>
</tr>
<tr>
<td>NPL calibration $u_{NPL}$</td>
<td>1.05</td>
</tr>
<tr>
<td>Temperature variation of labs</td>
<td>0.3</td>
</tr>
<tr>
<td>Transfer uncertainty of comparison $u_{transfer}$</td>
<td>4.6</td>
</tr>
<tr>
<td>Relative combined standard uncertainty of the comparison ($u_{CMI-NPL}$)</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Figure 1: CMI – NPL comparison results - average value for 3 detectors – one sigma error bars
3. Link with CCPR-S3

The results obtained by CMI at wavelengths 476.2 nm, 568.2 nm and 647.1 nm can be linked to the CCPR-S3 reference values via the NPL results. Results at 356.4 nm, 413.1 nm and 799.3 nm were not part of the original CCPR-S3 comparison.

For a given wavelength, the difference $\Delta_{\text{CMI-Ref}}$ from the CCPR-S3 reference value is given by:

$$\Delta_{\text{CMI-Ref}} = \Delta_{\text{CMI-NPL}} + \Delta_{\text{NPL-Ref}}$$

(3.1)

where $\Delta_{\text{CMI-NPL}}$ is defined by equation (2.2) and $\Delta_{\text{NPL-Ref}}$ is the deviation of the NPL result from the CCPR-S3 reference value at this wavelength.

The uncertainty $u_{\text{CMI-Ref}}$ associated with $\Delta_{\text{CMI-Ref}}$ is determined by the uncertainty of this bilateral comparison ($u_{\text{CMI-NPL}}$) and the uncertainty associated with $\Delta_{\text{NPL-Ref}}$ in CCPR-S3 ($u_{\text{NPL-Ref}}$):

$$u_{\text{CMI-Ref}} = \sqrt{u_{\text{CMI-NPL}}^2 + u_{\text{NPL-Ref}}^2}$$

(3.2)

The use of NPL as a link between the two comparisons will introduce some correlation, but as the transfer standard stability component brings the largest contribution to the overall comparison, the correlation between $u_{\text{CMI-NPL}}$ and $u_{\text{NPL-Ref}}$ is estimated to be negligible.

The relative differences of the NPL results to the reference values of CCPR-S3 and associated uncertainties, as reported in BIPM Report BIPM-2000/9 P54, are given in Table 9.

<table>
<thead>
<tr>
<th>Wavelength / nm</th>
<th>476.2</th>
<th>568.2</th>
<th>647.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^4 \times \Delta_{\text{NPL-Ref}}$</td>
<td>-0.4</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>$10^4 \times u_{\text{NPL-Ref}}$</td>
<td>1.0</td>
<td>0.9</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table 9 – Relative differences and associated uncertainties of NPL results to CCPR-S3 reference values

The relative difference between the CMI value and the CCPR-S3 reference value, $\Delta_{\text{CMI-Ref}}$, at each wavelength and the associated uncertainty $u_{\text{CMI-Ref}}$, can be calculated using Eqs.3.1, 3.2 and data given in Tables 7, 8 and 9 - see Table 10.

<table>
<thead>
<tr>
<th>Wavelength / nm</th>
<th>476.2</th>
<th>568.2</th>
<th>647.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^4 \times \Delta_{\text{CMI-Ref}}$</td>
<td>-0.2</td>
<td>0.1</td>
<td>-2.7</td>
</tr>
<tr>
<td>$10^4 \times u_{\text{CMI-Ref}}$</td>
<td>1.9</td>
<td>1.7</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 10 – CMI results linking to CCPR-S3 comparison reference values.
4. Conclusions

The results of this comparison demonstrate agreement between CMI and the CCPR-S3 comparison reference values, in the selected wavelength range, to better than 2.7 parts in $10^4$ with a combined standard uncertainty ($k = 1$) of 2.2 parts per $10^4$ or better.

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Appendix 1

Technical protocol

References

APPENDIX 1

Bureau International des Poids et Mesures

CCPR supplementary S3

Comparison of Cryogenic radiometers

Technical protocol

Protocol for bilateral comparison of cryogenic radiometers
by calibration of Trap detectors

April 2004
1 Background

The CCPR decided during its 13th session in September 1994 to undertake an international comparison of cryogenic radiometers by means of circulating transfer standards. The comparison was conducted at a set of laser wavelengths, using traps as transfer standards. The protocol for this comparison was relatively simple and will be essentially the same as used for this bilateral comparison. Consequently, the protocol as described herein remains simple and has only been modified where necessary to meet any specific technical changes.

2 Participants

This comparison should be considered as a bilateral comparison between the pilot (NPL) and the participant. The link to the existing comparison will be provided by the Pilot, who was a participant in the full comparison. The participant listed in this protocol obtained a cryogenic radiometer after the completion of the original S3 and now wish to have a formal link to it.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Contact</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPL:</td>
<td>Malcolm White</td>
<td>Queens Road</td>
</tr>
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</tr>
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<td></td>
<td>United Kingdom</td>
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<tr>
<td></td>
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<td>Tel: + 44 208 943 6472</td>
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3 Comparison protocol (original)

The protocol for this comparison will be as follows:

3.1 Each laboratory will receive 3 three-element reflection trap devices built according to a design of NPL. Each detector can be mounted from the front, which is of a circular diameter of 50.0 mm. Electrical connections will be via a BNC connector at the rear. All detectors will be prepared and characterized by NPL. Each laboratory should calibrate all three detectors.
3.2 The CCPR decided that the comparison should be restricted to laser wavelengths. However, the measurements may be done using a monochromator-based source, at the same wavelengths. Each of the detectors should be calibrated at as many of the wavelengths as possible, preferably with a minimum of three. The original comparison proposed a total of six wavelengths from either argon, krypton or helium-neon lasers. This list has been restricted to those indicated by a * for the purpose of this bilateral. Additional wavelengths may be selected with agreement of the pilot but to allow linkage to the existing comparison only those selected from the list below will be included as part of the formal bilateral comparison.

356.4 nm (Kr)
406.7 nm (Kr)
476.2 nm (Kr) *
568.2 nm (Kr) * (recommended common wavelength)
647.1 nm (Kr) *
799.3 nm (Kr)

Original:
476.2 nm (Kr) *
488.0 nm (Ar)
514.5 nm (Ar) * (recommended common wavelength)
568.2 nm (Kr) *
632.8 nm (He-Ne)
647.1 nm (Kr) *

3.3 To ensure that a direct comparison is possible between all participants, it was recommended that each laboratory should calibrate the detectors at the krypton laser wavelength, 568.2 nm. The other two wavelengths should preferably include one blue line and the red krypton line at 647.1 nm. This scheme has been chosen to avoid laboratories having to purchase a new laser source, if they had previously used only one ion-laser.

3.4 The maximum effective open aperture diameter of the reflection trap device is 8 mm and the usable f-number for monochromator imaging optics depends on the spot-size chosen for the trap. For example, for a 3 mm spot focused on the innermost photodiode a beam divergence of about 5° full angle is acceptable. We strongly recommend the use of laser beams with the detectors, with a parallel beam of diameter not more than 4 mm. The optical power should be kept below 600 μW.

3.5 The comparison will be performed as an independent bilateral, with each participant receiving its own set of detectors.

3.6 Each participant will have 3 months to make the calibrations and return the detectors back to NPL. One month is allowed for the administrative / customs procedure and the actual shipping.
3.7 The timetable for the comparison is presented below:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Start Date</th>
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</thead>
<tbody>
<tr>
<td>Full protocol agreed with participants</td>
<td>Sep 2006</td>
</tr>
<tr>
<td>Protocol and notification of comparison sent to BIPM</td>
<td>Sep 2006</td>
</tr>
<tr>
<td>Detectors sent to participants</td>
<td>Nov / Dec 2006</td>
</tr>
<tr>
<td>Detectors returned to NPL</td>
<td>Mar / Apr 2007</td>
</tr>
<tr>
<td>Repeat calibrations at NPL</td>
<td>June 2007</td>
</tr>
<tr>
<td>Draft A</td>
<td>Dec 2007</td>
</tr>
<tr>
<td>Comments on Draft A</td>
<td>Jan 2008</td>
</tr>
<tr>
<td>Draft B submitted to CCPR</td>
<td>Mar 2008</td>
</tr>
</tbody>
</table>

4 Handling of artefacts

4.1 The detectors should be examined immediately upon receipt at the final destination. However, care should be taken to ensure that the detectors have sufficient time to acclimatise to the rooms’ environment thus preventing any condensation etc. The condition of the detectors and associated packaging should be noted and communicated to the pilot laboratory if found to be damaged.

4.2 The detectors should only be handled by authorized persons and stored in such a way as to prevent damage.

4.3 During operation of the detectors, if there is any unusual occurrence, e.g. change of sensitivity etc the pilot laboratory should be notified immediately before proceeding.

4.4 Please inform the pilot laboratory via e-mail when the measurement on the detectors are completed to arrange a suitable date for dispatch.

4.5 After the measurements, the detectors should be repackaged in their original transit cases. Ensure that the content of the package is complete before shipment. Always use the original packaging. A copy of the provisional results should be included in the package.
5  Transport of artefacts

5.1 It is of utmost importance that the artefacts be transported in a manner in which they will not be lost, damaged or handled by un-authorized persons.

5.2 Packaging for the artefacts has been made which should be suitably robust to protect the artefacts from being deformed or damaged during transit.

5.3 The artefacts are sufficiently robust to be sent by courier. The packages should be marked as ‘Fragile’. If the possibility arises to hand-carry the packages this should be done.

5.4 The artefacts will be accompanied by a suitable customs carnet (where appropriate) or documentation identifying the items uniquely. The packaging will be lockable e.g. by clasp, but is easy to open with minimum delay to allow customs inspections to take place.

5.5 Transportation is each laboratory’s responsibility and cost. Each participating laboratory shall cover the cost for its own measurements, transportation and any customs charges as well as damages that may have occurred within its country. The pilot laboratory covers the overall cost of the organisation of the comparison. The pilot laboratory has no insurance for any loss or damage of the standards during transportation.

6  Measurement instructions

6.1 Traceability

6.1.1 Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

6.1.2 Electrical measurements should be independently traceable to the latest realisation of the Ampere and Volt.

6.2 Measurand

6.2.1 The measurand is the spectral responsivity of a detector, i.e. its responsivity as a function of the wavelength of the quasi-monochromatic radiation centred onto its sensitive area. The measurements should be performed in suitable laboratory accommodation maintained at a temperature as close as possible to 20.0 °C. The exact temperature of the laboratory during the time of the measurements must be reported.

6.2.2 Each independent measurement should consist of the detector being realigned in the measurement facility. It should be noted that each independent measurement may consist of more than one set of measurements, the exact number should be that normally used by the participating laboratory to obtain the appropriate accuracy as limited by the noise
6.3 Measurement instructions

6.3.1 Before aligning the detectors they should be inspected for damage or contamination. Any damage should be documented and communicated to NPL.

6.3.2 The operational conditions and alignment procedure for each detector should be followed according to the detail described in the notes supplied with each detector package. A summary is presented in section 8 of this document.

6.3.3 After alignment and before starting measurements, sufficient time should be allowed to let the detectors reach thermal equilibrium.

6.3.4 The spectral responsivity of the transfer standards should then be measured for each selected wavelength by comparison to its cryogenic radiometer.

6.3.5 No other measurements are to be attempted by the participants nor any modification to the operating conditions during the course of this comparison. In particular, the detectors must never be intentionally exposed to radiation below 280 nm nor above 1100 nm. They must never be placed under vacuum. If used with a laser source the optical power should be lower than 300 µW for a 2 mm diameter beam (1/e² diameter). The transfer standards used in this comparison should not be used for any purpose other than described in this document nor given to any party other than the participants in the comparison.

6.3.6 Any information obtained relating to the use or any results obtained by a participant during the course of the comparison shall be sent only to the pilot laboratory as quickly as possible who will be responsible for co-ordinating how the information should be analysed and reported. No communication whatsoever regarding any details of the comparison other than the general conditions described in this protocol shall occur between any of the participants or any party external to the comparison without the written consent of the pilot laboratory. The pilot laboratory will in turn seek permission of all the participants. This is to ensure that no bias from whatever accidental means can occur.

7 Reporting of results

7.1 On completion of the measurements by the participating laboratory the provisional results of these measurements should be sent to the pilot laboratory with the transfer detectors.
7.2 As soon as possible the final results should be communicated to the pilot laboratory and at the latest within six weeks.

7.3 The report on the calibrations should contain a comprehensive uncertainty budget, comprising all the contributions to the total uncertainty. The uncertainty of measurements shall be estimated according to the ISO Guide to the Expression of Uncertainty in Measurements.

7.4 The report on the calibrations must include a description of the participants measurement facility. It would be useful for a schematic diagram of the facility to be included.

7.5 Following receipt of all measurement reports from the participating laboratories (bilateral), the pilot laboratory will analyse the results and prepare a first draft report on the comparison. This will be circulated to the participants for comments, additions and corrections. Subsequently, the procedure outlined in the BIPM Guidelines will be followed.

8 Alignment procedure for the reflection trap

8.1 At NPL, the alignment is made using the laser beam to be measured, so that the weak beam reflected from the trap can be observed.

8.2 Rotate the trap detector so that the identification mark is at the top and lying in a vertical plane parallel to the polarisation axis of the laser radiation.

8.3 Translate the trap along the x and y axis to align the central hole in the beam. Then adjust the translation until the peak signal is obtained. There will usually be a plateau area (an area which is constant) and the centre of this should be selected. Note: this is not necessarily the geometric centre of the trap entrance hole.

8.4 Adjust tilt of the trap so that the weak residual reflected beam is approximately collinear with the input beam.

8.5 Repeat steps 8.3 to 8.4 to check both the position and the orientation.