FINAL REPORT

ON THE

SUBSEQUENT BILATERAL COMPARISON

OF

CRYOGENIC RADIOMETERS

BIPM – IEN

CCPR-S3

BIPM

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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 (CCPR-S3) carried out using silicon trap detectors as transfer instruments. The circulation of the transfer detectors started in July 1996 and ended in February 1999.

After the publication of the final report [1] on this comparison, the Istituto Elettrotecnico Nazionale (IEN, Italy) expressed the wish to repeat the exercise. It was then decided that the BIPM would organize a subsequent bilateral comparison with this laboratory, following the same guidelines as for CCPR-S3[1].

The IEN was asked to calibrate a set of transfer detectors at a series of laser wavelengths listed in Table 1. A minimum of three wavelengths, including 514.536 nm, were to be chosen from the list.

476.243 nm	(Krypton line)
487.986 nm	(Argon line)
514.536 nm	(Argon line), recommended common wavelength
568.188 nm	(Krypton line)
632.817 nm	(Helium-Neon line)
647.089 nm	(Krypton line)

Table 1 - Wavelengths selected for the comparison

The characterization of the transfer detectors, the description of the experimental procedures used at the BIPM and the detailed BIPM uncertainty budget, will not be repeated here. For more information, please refer to [1].

1. Bilateral comparison with the IEN

1.1 Time schedule

The BIPM transfer detectors were sent to Italy on 11 December 2000, and returned on 04 July 2001. The IEN results were received on 13 July 2001 and confirmed in the IEN final report received on 03 August 2001. After re-calibration of the transfer detectors at the BIPM, a preliminary BIPM report on the comparison was sent to the IEN on 01 August 2001, on which the laboratory agreed after minor corrections.

1.2 Stability of the transfer detectors

The relative change in the responsivity of the trap detectors as measured at the BIPM ranged in average from -3.3×10^{-4} in the blue to -1.1×10^{-4} in the red, which is consistent with the long-term stability of this type of detector.

[1] Originally also the NMIJ (Japan) participated in a subsequent bilateral comparison with the BIPM. Since they experienced severe problems with their cryogenic radiometer the results were withdrawn with the approval of the CCPR.

Wavelength / nm					
476	488	515	568	633	647
$10^4 \times$ Relative change in trap responsivity					
− 3.3	−3.3	−2.7	−2.1	−1.1	−1.1

Table 2 - IEN: average relative change in responsivity for three trap detectors after/before travel.

1.3 Report from the participating laboratory

1.3.1 Experimental conditions at IEN

- Cryogenic radiometer type: Radiox, from Oxford Instruments Ltd.
- Source: Ar/Kr mixed gas laser
- Nominal power: 400 µW
- Beam diameter ($1/e^2$): 2 mm
- Temperature: 24 °C ± 1 °C

1.3.2 IEN uncertainty budget

Source of uncertainty	$10^4 \times$ Relative standard uncertainty
Electrical power measurements	0.1
Brewster window transmittance	1.0
Cavity absorption	0.2
Scattered light	1.0
Repeatability	2.0
Total	**2.5**

Source of uncertainty	$10^4 \times$ Relative standard uncertainty
Photocurrent measurement	2.0
Trap positioning	1.0
Total	**2.2**

Combined relative standard uncertainty u_{IEN}	**3.3**

Table 3 - IEN uncertainty budget for the calibration of the BIPM transfer detectors.

The probability distribution assigned to each component is assumed to be gaussian, and the total uncertainty is obtained by quadratic sum.

1.3.3 Correction factors

The IEN results were corrected for the temperature difference between the BIPM (20.5 °C) and the IEN (24 °C), using the temperature coefficients given in [1].

1.3.4 Comparison with the BIPM calibrations

The BIPM calibration values R_{BIPM} for the same detectors are calculated as the mean of the BIPM calibrations before and after travel to the IEN.

The difference Δ_{IEN} is calculated as $\Delta_{\mathrm{IEN}} = (R_{\mathrm{IEN}} - R_{\mathrm{BIPM}}) / R_{\mathrm{BIPM}}$.
The results are summarized in Table 4 and shown in graphical form in Fig. 1.

	Wavelength / nm					
	476	488	515	568	633	647
Transfer detector	$10^4 \times$ Relative difference in trap calibration					
T7		– 3.4	+ 2.1			– 4.6
T8		– 5.2	0.0			– 3.4
P6		– 3.3	+ 0.1			– 3.8
average		**– 4.0**	**+ 0.7**			**– 3.9**
1998 comparison		*– 17.6*	*– 11.0*		*+ 0.7*	

Table 4 - IEN/BIPM: relative difference in trap calibrations $(R_{\mathrm{IEN}} - R_{\mathrm{BIPM}}) / R_{\mathrm{BIPM}}$.

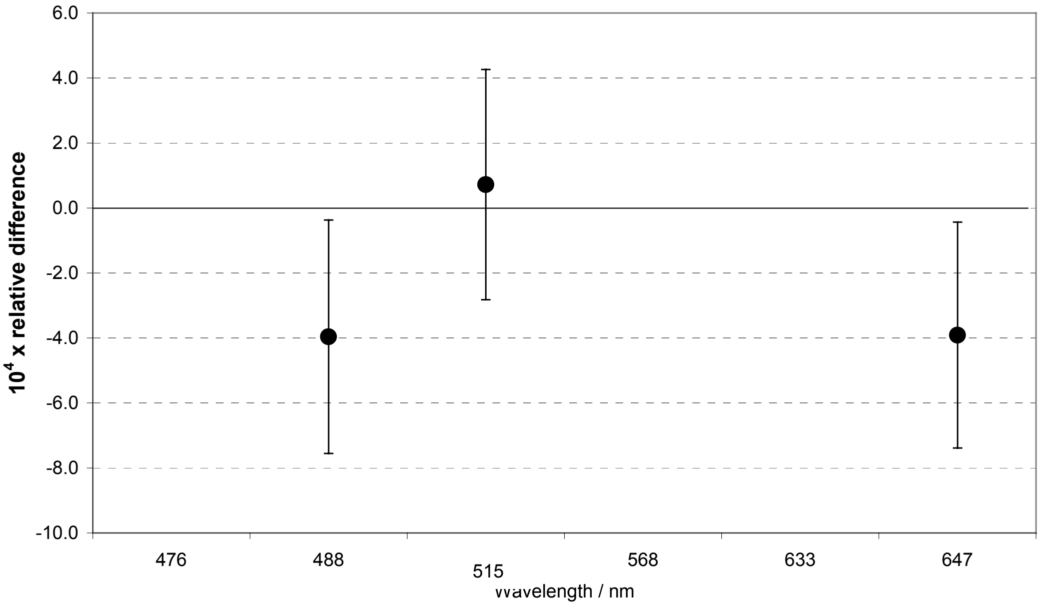

Figure 1- IEN – BIPM: relative difference in the calibration of the transfer detectors (average value for three detectors)

The relative combined standard uncertainty of the comparison IEN/BIPM is calculated as : $u_{C,b} = 3.6 \times 10^{-4}$.

Source of uncertainty	$10^4 \times$ Relative standard uncertainty
IEN calibration u_{IEN}	3.3
Long-term drift and temperature corrections	1.0
BIPM standard uncertainty	1.0
Relative combined standard uncertainty of the comparison (quadratic sum)	**3.6**

Table 5 - Uncertainty of the IEN – BIPM comparison.

2. Link with CCPR-S3

The new results obtained by the IEN can be linked to the CCPR-S3 reference value via the BIPM results. For a given wavelength, the difference Δ_{Ref} from the CCPR-S3 reference value is

$$\Delta_{Ref} = \Delta_{IEN} + \Delta_{BIPM}$$

where $\Delta_{IEN} = (R_{IEN} - R_{BIPM}) / R_{BIPM}$ and Δ_{BIPM} is the deviation of the BIPM result from the CCPR-S3 reference value at this wavelength. The results are given in Table 6.

The reference value and its associated uncertainty u_R are not modified by the results obtained from subsequent bilateral comparisons. This reference value was calculated as the weighted mean of the relative differences from the BIPM value in the calibration of the transfer detectors.

The uncertainty u_C associated with Δ_{Ref} combines the uncertainty $u_{C,b}$ associated with the bilateral comparison and the uncertainty $u_{C,BIPM}$ associated with Δ_{BIPM}.

The use of the BIPM as a link between the two exercises will introduce some correlation, but as the repeatability component brings the largest contribution in the BIPM uncertainty, the correlation between $u_{C,b}$ and $u_{C,BIPM}$ is estimated to be small enough to calculate u_C according to:

$$u_C = \sqrt{u_{C,b}^2 + u_{C,BIPM}^2}$$

	488 nm		515 nm		647 nm	
	$10^4 \times \Delta_{Ref}$	$10^4 \times u_C$	$10^4 \times \Delta_{Ref}$	$10^4 \times u_C$	$10^4 \times \Delta_{Ref}$	$10^4 \times u_C$
IEN	– 4.6	3.7	0.0	3.7	– 4.8	3.7

Table 6 - Difference Δ_{Ref} from the CCPR-S3 reference value in the calibration of the transfer detectors, calculated at each wavelength. The uncertainty u_c combines the relative standard uncertainty associated with the bilateral comparison and the uncertainty associated with the reference value.

3. Conclusions

Since the last comparison CCPR-S3, the IEN has gained more experience in the use of its cryogenic radiometer facility. The BIPM and the IEN calibrations agree within the expanded uncertainties with a standard uncertainty of 3.6 parts in 10^4, and differences ranging from – 4.0 parts in 10^4 to +0.7 part in 10^4.

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References

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1 R. Goebel, M. Stock and R. Köhler, Report on the international comparison of cryogenic radiometers by means of transfer detectors. Rapport BIPM-2000/9, September 2000 (available on the BIPM website www.bipm.org).