National Physical Laboratory

CIPM Key Comparison K1-a

Spectral Irradiance 250 nm to 2500 nm

Final Report

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Table of Contents

1 Introduction

The Mutual Recognition Arrangement (MRA) was signed in 1999 with the objectives of establishing the degree of equivalence of national measurement standards and providing for the mutual recognition of calibration and measurement certificates issued by National Metrology Institutes (NMIs). Under the MRA the equivalence of national measurement standards maintained by the NMIs is determined by a set of key comparisons chosen and organised by the Consultative Committees of the International Committee for Weights and Measures (CIPM), working closely with the Regional Metrology Organisations (RMOs). The Consultative Committee of Photometry and Radiometry (CCPR) identified several key comparisons at its meeting in March 1997. One of these was the CCPR Key Comparison K1-a for Spectral Irradiance in the spectral region 250 to 2500 nm.

The National Physical Laboratory (NPL), the NMI of the United Kingdom, was asked to be the Pilot Laboratory for the CCPR K1-a Key Comparison and had the responsibility of organising the Key Comparison and of writing the Technical Protocol in discussion with a working group comprising representatives of NPL, the National Institute of Standards and Technology, USA (NIST) and the Physikalisch-Technische Bundesanstalt, Germany (PTB). The Pilot Laboratory was responsible for purchasing and distributing the technical artefacts, for collating the measurement reports from all participants and for analysing the results and preparing the Draft Reports.

This is the Final Report of the CCPR K1-a Key Comparison. It was approved by the CCPR on the 31st December 2005. The Draft A report submitted to participants on the 17th December 2004 was accepted, with minor changes, by the participants on the 18th February 2005. Following discussion by the CCPR WG-KC two additional appendices were added in Draft B-1: Appendix B clarifies the analysis approach and Appendix C suggests an alternative analysis. Draft B-2 was the same as Draft B-1, but had one paragraph removed as discussed at the CCPR WG-KC meeting on the 23rd October 2005. This report describes the comparison organisation (Chapter 2), the measurement methodology and uncertainties achieved at all the participants (Chapters 3 to 16), the method for analysis (Chapter 17) and the results of the comparison according to this method (Chapters 18 and 19, and Appendix A).

2 Organisation of the Key Comparison

2.1 Participants

Originally 14 NMIs (including the pilot) agreed to participate in the CCPR K1-a Key Comparison. However, the Council for Scientific and Industrial Research, National Metrology Laboratory (CSIR-NML) of South Africa withdrew from the comparison for technical reasons after the first pilot measurements of their lamps, but before they had made any measurements. The remaining 13 participants are listed in Table 2-1.

2.2 Comparison artefacts

The comparison artefacts for the CCPR K1-a Key Comparison were tungsten lamps. NMIs were required to use a minimum of three (with the option of up to four) tungsten halogen lamps designated “Type I” and given the option to use in addition tungsten lamps, “Type II”. The Type I lamps were mounted 1000 W FEL type lamps and were bought pre-selected, pre-aged and mounted from the manufacturer, Gigahertz Optik GmBH. This lamp consists of a double-coiled tungsten filament, supported at the top and bottom of the filament and operated in a bromine-filled quartz envelope.

Two NMIs also used the Type II lamps. These were manufactured by the Polaron group. These lamps were pre-aged at NPL.

Both types of lamp were operated at a constant direct current. The voltage drop across the lamp was monitored as an indicator of the stability of the lamp.

Table 2-1 Participants of the CCPR Key Comparison K1-a.

NMI Acronym	NMI Name	Country
Pilot NMI		
NPL	National Physical Laboratory	United Kingdom
Participant NMIs		
BNM-INM	Bureau National de Métrologie - Institut National de Métrologie	France
CENAM	Centro Nacional de Metrología	Mexico
CSIRO*	Commonwealth Scientific & Industrial Research Organisation	Australia
HUT†	Helsinki University of Technology	Finland
IFA-CSIC	Instituto de Física Aplicada (Consejo Superior de Investigaciones Científicas)	Spain
MSL-IRL	Measurement Standards Laboratory of New Zealand - Industrial Research Limited	New Zealand
NIM	National Institute of Metrology	China
NIST	National Institute of Standards and Technology	United States of America
NMIJ‡	National Metrology Institute of Japan	Japan
NRC	National Research Council	Canada
PTB	Physikalisch-Technische Bundesanstalt	Germany
VNIIOFI	All-Russian Research Institute for Optical-Physical Measurements	Russian Federation

* The CSIRO National Measurement Laboratory (CSIRO in this comparison) was recently combined with the Australian Government Analytical Laboratories and the National Standards Commission and placed within the Australian Government Department of Industry, Tourism and Resources to form the National Measurement Institute of Australia, and will in future be known internationally as NMIA

† Helsinki University of Technology (HUT in this comparison) and Centre for Metrology and Accreditation (MIKES) have established a joint laboratory in January 2005. The laboratory name will in future be abbreviated as MIKES.

‡ At the start of this comparison the Electrotechnical Laboratory (ETL) was a participant of this comparison. The metrology groups at ETL and NRLM merged in April 2001 to create a new institute: The National Metrology Institute of Japan.

2.3 Comparison philosophy

Because of the fragile nature of lamps, the comparison was organised as a star comparison. Any individual lamp was measured by the pilot and by one participant NMI only. Lamps were sent in batches of three to each participant. The pilot was required to measure each lamp on at least two occasions and the relevant participant was also asked to make measurements on two occasions. In some cases a participant was only able to measure a lamp once.

The built in redundancy was designed so that it would be expected that at least one lamp for each NMI would have a successful Pilot – NMI – Pilot or NMI – Pilot – NMI measurement sequence. In other words, it was expected that at least one lamp for each participant would survive two successive transportations without significant drift. In the more general case where all four measurements of a lamp could be used and/or multiple lamps were transported without degradation, it was expected that the uncertainties due to the comparison itself could be reduced by averaging multiple measurements.

2.4 Analysis philosophy

The fundamental outcomes of a key comparison are the Degrees of Equivalence (DoEs) between the pairs of NMIs and between each NMI and the Key Comparison Reference Value (KCRV). In this case these DoEs are to correspond to a measurement (at each wavelength) by each participating NMI of a single typical lamp. The determination of the KCRV for this comparison was made according to the guidelines of the CCPR and is based on the weighted mean with "cut-off" of each NMI's bilateral comparison with a stable reference scale established by the pilot. The philosophy of this analysis has been to provide such a KCRV and the corresponding DoEs in a way that ensures that each NMI is treated equitably and that the results do not depend on the number of lamps measured by any NMI.

The measurements at each wavelength were treated as an entirely independent comparison for the purposes of the analysis.

The analysis was based on a model that assumes that each lamp has a stable spectral irradiance and that the measurements of each NMI are systematically biased by a factor applied to all that NMI's measurements. The measurement by an NMI is an estimate, (hopefully) consistent with the declared uncertainty associated with the NMI's random effects, of the lamp irradiance multiplied by the systematic bias factor. The aim of the analysis was to determine an estimate of the systematic factor for each NMI. This was achieved by solving, by least squares adjustment, a set of linked equations that relate the NMI measurements to the lamp irradiances and systematic factors under a constraint that ensures that these systematic factors have a weighted geometric mean (with cut-off) of unity.

The unilateral DoE for an NMI is the difference from unity of the typical ratio of the measurement according to that NMI's scale and the spectral irradiance of a lamp. The best estimate of the value of this unilateral DoE for any NMI is the difference between the estimated systematic factor for that NMI and unity. The unilateral DoE uncertainty (which is quoted at a 95% level of confidence) can also be evaluated from the model. Since the comparison consists of many separate artefacts, the KCRV is itself unrelated to a physical artefact. The choice of KCRV is mathematically arbitrary, but to meet the metrological requirements of the CCPR KCWG, it is assigned here as the value unity, corresponding to the weighted geometric mean (with cut-off) of these estimated systematic factors. Bilateral DoEs are calculated from the unilateral DoEs.

The analysis is described in more detail in Chapter 17.

2.5 Measurement structure and timetable

The sequence of measurements is given in Table 2-2. For most NMIs there were two measurements by the pilot (round 1 and round 2) and two measurements by the participant. Additionally there was a pilot round 3 for some lamps. The reasons for these variations are discussed in Section 2.7.

*Table 2-2 Sequence of comparison measurements. The results marked with a * were ignored for analysis purposes as described in Section 2.7*

Date	Measurements at pilot	Measurements at participants
2000	Round 1 measurements of lamps for BNM-INM*, HUT*, NIST*, PTB*. Uncertainties were much higher than subsequent measurements and results ignored	Round 1 measurements by BNM-INM, HUT, NIST, PTB
March – June 2001	Round 1 measurements for CENAM, NIM, NMIJ* (and an NMI that pulled out)	
June – December 2001	Round 1 measurements for CSIRO, IFA-CSIC, MSL-IRL, NRC, VNIIOFI	Round 1 measurements by CENAM, NIM*
January – July 2002	Round 2 measurements for BNM-INM, HUT, NIST, PTB	Round 1 measurements by CSIRO, IFA-CSIC, MSL-IRL, VNIIOFI, NMIJ*
August – December 2002	Round 2 measurements for CENAM, NIM, NMIJ	Round 2 measurements by BNM-INM, HUT, PTB, NRC, NMIJ
January – May 2003	Round 2 measurements for CSIRO, IFA-CSIC, MSL-IRL, NRC, VNIIOFI	
June – August 2003	Round 3 measurements for BNM-INM, HUT, PTB, NMIJ	Round 2 measurements by MSL-IRL
September – November 2003		Round 2 measurements by CSIRO, NIM*, IFA-CSIC, NIST
November 2003	Round 3 measurements for NIST	Round 3 measurements by NMIJ
December – February 2004		Round 3 measurements by NIM
March 2004	Round 3 measurements for NIM	

2.6 Analysis and communication timetable

As the measurements of this comparison were nearing completion, the CCPR KCWG was drafting new rules for the analysis and reporting of key comparisons. This comparison has tried to follow those rules as the draft has been written. The steps undertaken are given in Table 2-3.

Table 2-3 Analysis timetable

Date	Analysis activity
January – April 2004	Preparation of measurement reports by each NMI, including a full description of measurement technique and a full uncertainty budget as well as the final results of each NMI. Preparation by the pilot of the pre-draft A report detailing the measurement technique and uncertainty budgets of all participants.
1 May 2004	Pilot sent pre-draft A report to all participants. All participants asked to comment on each NMI's uncertainties.
21 May 2004	Pilot sent each NMI information on the relative stability of each lamp as measured by the participant and as measured by the pilot. Discussions begun with individual NMIs about which measurements of which lamps to include in the analysis. Pilot sent each NMI an Excel sheet summarising the irradiance values and uncertainties supplied by the participant to the pilot to check any copying errors by the pilot. Participants began sending in comments about their and other NMIs' uncertainties. Participants began sending in comments about the accuracy of their data as summarised by the pilot. Pilot asked all NMIs to separate the correlated and uncorrelated effects in their uncertainties.
14 June 2004	Pilot sent each NMI relative stability of each lamp data in order to show up any significant difference between lamps. NMIs continued to send in comments about their and others' uncertainties and their data.
2 July 2004	Comments on uncertainties were received from all NMIs. Changes to the measurement report, uncertainties and comments about the pilot's summary of the data came in from participants.
5 July 2004	Pilot sent 'Comments on Pre-draft A' report to all participants. Participants asked to reply to those comments.
July 2004	Pilot had one-to-one discussions with most NMIs to ensure that the uncertainty separation requirements are well-understood and consistent. Pilot ensured all NMIs were satisfied with the final Excel spreadsheet prepared by the pilot for that NMI.
2 August 2004	Pilot sent 'Replies to Pre-draft A comments' to all participants. All data was considered final from this point.
August – September 2004	Pilot developed analysis technique for the Key Comparison and reviewed all individual measurement chapters to make them consistent. Pilot agreed changes to measurement chapters with the participants.
September – October 2004	Pilot reviewed, tested and checked analysis technique.

5th November 2004	Pilot sent participants description of analysis technique and "blind information" on results. Participants encouraged to discuss this.
7th December 2004	Analysis comments received from all participants.
8th December 2004	NPL submitted replies to comments to all participants and proposed a slight modification to the analysis technique.
15th December 2004	Deadline for final responses from participants.
17th December 2004	NPL submitted Draft A report to all participants.
18th February 2005	Deadline for comments on Draft A.
15 March 2005	NPL submitted Appendix with Bilateral degrees of equivalence to all participants.
30 March 2005	NPL submitted Draft B report to CCPR Key Comparison Working Group.

2.7 Problems and their solutions

During the course of this comparison a number of problems occurred, these are discussed, along with the chosen solution, here.

2.7.1 Variations between protocol drafts – wrong operating currents

The original protocol for the comparison was circulated on 24th February 1999. A second version was circulated on 16th August 2000 to correct largely typographical errors. The most important differences between the protocols were that the first protocol specified 8.3 A for the current for the Type I lamps which was corrected in the second protocol to 8.1 A. The second difference was that the first protocol specified that the 500 mm distance to the lamp should be to the filament and the second protocol specified that the distance should be to the front plate of the lamp. However, both protocols made clear that the operating parameters of the lamps would be supplied with the lamps, so that any changes caused in transport (e.g. operating voltage due to filament movements) could be identified.

NMIs were also asked, in both protocols, to confirm that that the lamp was operating at the correct voltage and to contact the pilot immediately if a problem were found. In addition, NMIs were asked to supply their data, including the operational voltage of the lamp within six weeks of the measurements. In hindsight it would have been useful to have a clear box on the acknowledgement form which required the participants to state the operating voltage of the lamps as a confirmation of their performance, rather than a simple 'Y/N' option.

Unfortunately, at least three NMIs reported not receiving the second version of the protocol and these three operated the lamp at the wrong current because of that. NIM also reported not receiving the current and voltage sheet in either of the two main rounds. CENAM also aligned the lamp according to the original protocol and therefore at the wrong distance. The other two NMIs aligned the lamp correctly.

These problems were notified to all participants and appropriate solutions (as detailed below) agreed. The solutions varied according to the available time before completion of the comparison following notification to the pilot.

2.7.1.1 NMIJ

When NMIJ collected the lamps for their second round, they noticed the sheet with the current and voltage and realised that the first round measurements were made at the wrong current because of the missing protocol. Because this was discovered relatively early, it was possible to introduce a third round at both NMIs within the normal comparison timescale and the first measurements by each NMI were ignored. This was formally notified to the CCPR in June 2003.

2.7.1.2 NIM

NIM operated the lamps at the wrong current in both rounds, as in addition to not receiving the second protocol they also reported that they did not receive the normal operating conditions sheet. The problem was not realised until after the comparison was complete when NIM submitted their measurement reports for both rounds. To solve this problem, NIM remeasured the lamps at the correct current and then returned the lamps to NPL. NPL measured these lamps for a third time in March 2004 to confirm that the transport to NIM and the operation at a high current had not adversely affected the lamps.

2.7.1.3 CENAM

CENAM had measured the lamps on only one occasion and for these measurements had strictly followed the original protocol, both in terms of the wrong current and the wrong distance. Unfortunately this was not realised until after the completion of the comparison and the publication of pre-draft A, partially because they had answered “yes” to the question of whether the voltage agreed with that specified. There was a misunderstanding in what this meant. By the time the problem was realised, it was too late to perform any additional experimentation. CENAM developed a model to correct the data both for current and for distance. The corrected results are presented here, but because of the uncertainty on the correction, CENAM’s results will not be used for the calculation of the KCRV. (See Chapter 17.)

The description of this correction is given in Chapter 5.

2.7.2 Damage to lamps

During the comparison, a number of lamps exhibited instabilities or suffered damage: at the participant, in transit and at the pilot. The affected lamps are discussed in the appropriate NMI descriptions below. The following summarises the principal problems that occurred during transportation or at the participant:

- Operation without removing the alignment jig. Some lamps were damaged because they were operated before the alignment jig was removed. This is a mistake that is surprisingly easy to make unless the operational procedure in the NMI includes a clear step to check that the jig has been removed before the lamp is turned on.
- Damage to the lamp during transportation. Some lamps were destroyed during transportation and arrived clouded at the participant NMI. Other lamps were damaged more subtly and it was only the poor reproducibility of the measurements that showed that the change had occurred.

Lamps that were damaged at the participant or in transportation were not replaced. It was because such damage was anticipated that the comparison was designed with the built in redundancy.

FEL 244, belonging to NIST, was damaged at the pilot when the lamp was operated in reverse electrical polarity. NPL re-aged the lamp in the correct polarity for 25 hours, during which a filter radiometer was used to monitor the re-aging process. During the first 12 hours, the lamp changed by 0.5 % at 800 nm and following that there was a 0.05 % change in the remaining time. FEL 244 was returned to NIST in May 2002, and NPL announced the mistake at the CCPR working group meeting held at that time. In addition NPL wrote formally to NIST offering a new lamp. NIST did not ask for any additional lamp or lamp measurements and remeasured FEL 244, along with the other lamps, in November 2003.

2.7.3 NPL's year 2000 measurements

NPL started the measurements for the comparison in early 2000 and sent lamps during 2000 to BNM-INM, HUT, NIST and PTB. The progress was slowed by a number of major failures of the equipment at NPL, including two fires. While the system was redesigned for improved safety, other experimental improvements were made. These meant that the measurement reproducibility was improved by approximately a factor of two. Because of this, it was decided in the best interests of the participants whose lamps had already been measured, that these year 2000 round measurements were ignored and an additional round added at the end. This meant that the sequence would not be Pilot – Participant – Pilot – Participant, but would change to Participant – Pilot – Participant – Pilot. Otherwise there would be no difference. The pilot had not received any results from any of these participants at the time this decision was made. All the participants affected by this agreed to this change and the year 2000 results are not included in this analysis or report.

3 Measurements at the pilot laboratory

3.1 Establishing a Comparison Scale

It is important to understand the fundamental difference between a scale used to compare participants: “a comparison reference scale” and the pilot’s own primary scale in any comparison. The requirements of the comparison scale are that it should be stable throughout the entire period of the comparison.

The pilot’s primary scale is the scale that the pilot wishes to compare in the comparison. This may be the same or a different scale.

The comparison scale for this comparison was held on reference lamps that were calibrated during each year of the key comparison. NPL started to disseminate a new primary scale in May 2003 and it is this scale that NPL has submitted for comparison with participants. The measurements prior to May 2003 for this comparison were made on the same facility as the new NPL primary scale and therefore in this particular comparison, the comparison scale and the pilot’s primary scale are almost identical.

However, one important difference arises between the requirements of realising a primary scale on a small number of lamps and the requirements of calibrating lamps almost continuously over a four-year period. This means that the uncertainty in the comparison lamps is somewhat higher than the uncertainty in NPL’s primary scale.

NPL’s primary scale realisation is discussed in Chapter 13. This section discusses the comparison scale.

3.2 Stability of comparison scale

The comparison scale was maintained on a set of FELs regularly calibrated during the comparison. Originally four reference lamps were used, but one of these lamps showed a change from year to year that was far greater than the other three and therefore only the three “stable” reference lamps are considered here. The measurements made during 2001 and 2003 have been compared with the measurements made during 2002. The results are shown in Figure 3-1 along with the calculated uncertainty for the comparison between the 2001 and 2002 rounds, taking into account the uncorrelated and the yearly correlated uncertainties only.

The change from round 1 to round 2 (year 2001 to year 2002), although within the uncertainties, is clearly systematic. The 2001 results at NPL have all been “corrected” by the change seen here. This has two advantages. The first is that it removes systematic differences between different rounds of the comparison, for example between NMIs whose lamps were measured in 2001 and 2002 and NMIs whose lamps were measured in 2002 and 2003. Secondly it ensures that the comparison reference scale is the same as the scale that NPL supplies to its customers – the reference standards of which were calibrated in late 2002 and early 2003.

The change from 2002 to 2003 is less significant and based on a smaller number of reference lamp measurements in 2003. Therefore no correction has been made to NPL’s 2003 data.

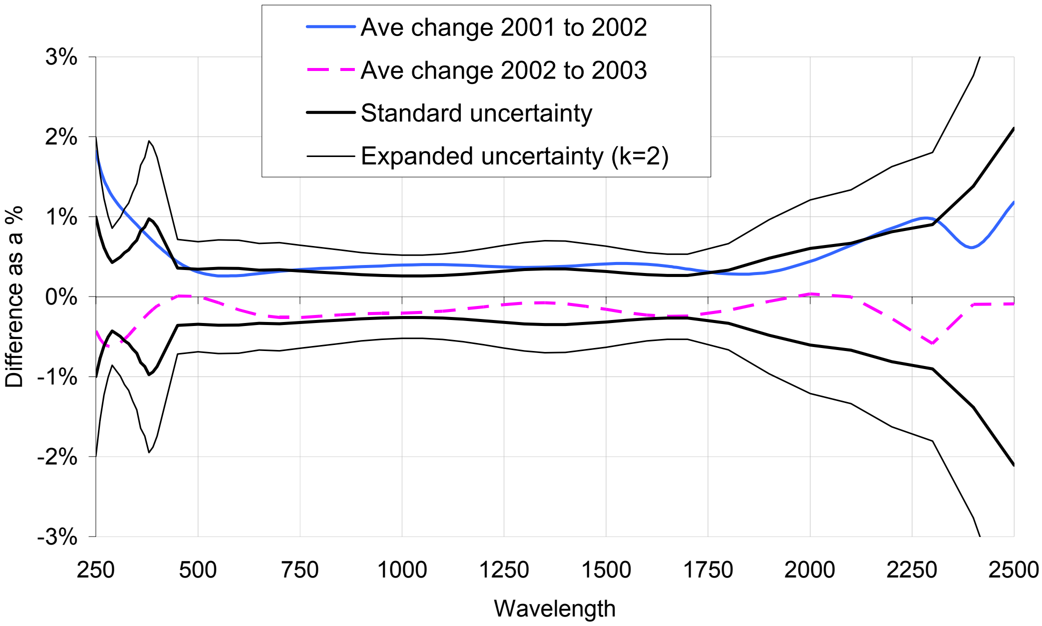

Figure 3-1 Stability of scale maintained on reference lamps

3.3 Comparison uncertainty

The uncertainty described in Chapter 13 is the uncertainty on NPL's primary scale. The requirements of the key comparison have not allowed that uncertainty to be realised continuously for all the measurements.

3.3.1 2001 uncertainties

Two major improvements were made between 2001 and 2002. The first is that the blackbody was operated at a lower temperature following our identification of an absorption problem in the near UV spectral region associated with the blackbody. The 2001 results therefore have a higher uncertainty in the wavelengths of blackbody absorption. The second improvement was in the long wavelength region where the InSb detector is used. The InSb detector shows some drift over the course of a few hours. In late 2001 this was solved by changing the measurement technique to perform "interleaved scans" where the blackbody and lamp were compared at each wavelength. This was not done in 2001, and therefore, for wavelengths above 1600 nm, the system repeatability uncertainty was higher in the 2001 measurements.

There is also an uncertainty caused by the 2001 to 2002 correction. This has been calculated as the standard error on the mean change from 2001 to 2002 for the three reference lamps.

3.3.2 2002 uncertainties

The 2002 uncertainties were very similar to NPL's primary scale uncertainties. There were slight increases because the filter radiometers could not be "freshly calibrated" throughout such a long time period.

3.3.3 2003 uncertainties

Early 2003 uncertainties were as for 2002.

June to August 2003 was an exceptionally hot summer in London. The laboratory air-conditioning was not designed to deal with such outside temperatures. Unfortunately due to time pressures, the measurements had to continue despite the air-conditioning failure. This means that the measurements made in June to August 2003 have higher uncertainties because of, for example, the temperature sensitivity of the detectors and the change in room temperature between the blackbody and lamp measurements.

3.3.4 Uncertainties

The uncertainties that were uncorrelated for wavelength for one lamp (mostly the Type A uncertainty due to system stability) were reduced through modelling the lamp spectra, as discussed in Section 13.6.3. The uncertainties have been grouped according to the correlations. This grouping is shown in Table 3-1 for 2001 to 2002 and in Table 3-2 for 2002 to 2003. From this it is clear that the blackbody absorption uncertainty is correlated between 2002 and 2003, because the blackbody was operated at the same temperature in those years, but not in 2001, when the temperature was higher. Also the temperature measurement in 2001 and 2002 used the same filter radiometer, but a different filter radiometer was used in 2003, hence the correlation in 2001 to 2002, but not in 2002 to 2003.

Table 3-1 Uncertainty components for 2001 and 2002, grouped according to correlation

Uncorrelated between all lamp measurements	Correlated for lamps in 2001	Correlated for lamps in 2002	Correlated between 2001 and 2002
Measurement repeatability (reduced by model)	Blackbody absorption	Blackbody absorption	Blackbody radiance
Lamp alignment	2001 correction		Linearity
Lamp current			Wavelength accuracy and bandwidth
			UVFW modelling

Table 3-2 Uncertainty components for 2002 and 2003, grouped according to correlation

Uncorrelated between all lamp measurements	Correlated for lamps in 2002	Correlated for lamps in 2003	Correlated between 2002 and 2003
Measurement repeatability (reduced by model)	Blackbody radiance (temperature)	Blackbody radiance (temperature)	Blackbody absorption
Lamp alignment			Linearity
Lamp current			Wavelength accuracy and bandwidth
			UVFW modelling

The wavelength-by-wavelength uncertainty in each year is given in Table 3-3. This table separates the uncertainties according to whether the effects that cause them are correlated. The uncorrelated components have been calculated individually for each lamp, but typical values are given here.

Table 3-3 Uncertainty of comparison measurements by pilot. Uncorrelated components have been calculated individually for each lamp. This table gives typical values.

Wave-length	Uncorrelated 2001	Uncorrelated 2002	Uncorrelated 2003	Correlated year 1 but not with year 2	Correlated year 2 but not with year 1	Correlated year 1 to year 2	Correlated year 2 but not to year 3	Correlated year 3 but not to year 2	Correlated year 2 to year 3	Overall standard uncertainty 2001	Overall standard uncertainty 2002	Overall standard uncertainty 2003
250	2.37%	0.46%	1.25%	0.32%	0.00%	2.06%	0.48%	0.45%	2.00%	3.15%	2.11%	2.40%
260	1.73%	0.36%	0.93%	0.32%	0.00%	2.05%	0.46%	0.43%	2.00%	2.70%	2.08%	2.25%
270	1.28%	0.28%	0.71%	0.31%	0.00%	2.05%	0.44%	0.41%	2.00%	2.44%	2.07%	2.16%
280	0.97%	0.24%	0.56%	0.29%	0.00%	1.56%	0.43%	0.40%	1.50%	1.86%	1.58%	1.65%
290	0.77%	0.20%	0.46%	0.27%	0.00%	1.08%	0.41%	0.38%	1.00%	1.35%	1.10%	1.17%
300	0.64%	0.18%	0.40%	0.33%	0.15%	0.45%	0.40%	0.37%	0.25%	0.85%	0.50%	0.60%
310	0.55%	0.17%	0.36%	0.38%	0.20%	0.43%	0.39%	0.36%	0.28%	0.80%	0.51%	0.58%
320	0.50%	0.16%	0.32%	0.43%	0.25%	0.37%	0.37%	0.35%	0.25%	0.76%	0.48%	0.54%
330	0.46%	0.15%	0.30%	0.47%	0.28%	0.36%	0.36%	0.34%	0.28%	0.75%	0.48%	0.53%
340	0.41%	0.15%	0.28%	0.53%	0.33%	0.35%	0.35%	0.33%	0.33%	0.76%	0.50%	0.54%
350	0.41%	0.14%	0.26%	0.58%	0.36%	0.34%	0.34%	0.32%	0.36%	0.78%	0.52%	0.55%
360	0.38%	0.13%	0.25%	0.67%	0.43%	0.33%	0.33%	0.31%	0.43%	0.84%	0.56%	0.58%
370	0.36%	0.13%	0.23%	0.72%	0.46%	0.32%	0.32%	0.30%	0.46%	0.86%	0.58%	0.60%
380	0.34%	0.13%	0.22%	0.81%	0.52%	0.31%	0.31%	0.29%	0.52%	0.93%	0.62%	0.64%
390	0.32%	0.13%	0.22%	0.78%	0.50%	0.31%	0.31%	0.29%	0.50%	0.90%	0.60%	0.62%
400	0.30%	0.12%	0.21%	0.72%	0.46%	0.30%	0.30%	0.28%	0.46%	0.84%	0.56%	0.58%
450	0.27%	0.12%	0.21%	0.31%	0.10%	0.27%	0.27%	0.25%	0.10%	0.49%	0.31%	0.34%
500	0.23%	0.11%	0.19%	0.31%	0.00%	0.24%	0.24%	0.22%	0.01%	0.46%	0.26%	0.29%
550	0.20%	0.10%	0.16%	0.33%	0.00%	0.22%	0.22%	0.20%	0.00%	0.45%	0.24%	0.26%
555	0.20%	0.10%	0.15%	0.33%	0.00%	0.22%	0.22%	0.20%	0.00%	0.45%	0.24%	0.25%
600	0.19%	0.09%	0.14%	0.33%	0.00%	0.20%	0.20%	0.19%	0.00%	0.43%	0.22%	0.23%
650	0.17%	0.09%	0.14%	0.32%	0.00%	0.18%	0.18%	0.17%	0.00%	0.41%	0.20%	0.22%
700	0.21%	0.09%	0.13%	0.31%	0.00%	0.17%	0.17%	0.16%	0.00%	0.41%	0.19%	0.21%
750	0.19%	0.08%	0.13%	0.30%	0.00%	0.16%	0.16%	0.15%	0.01%	0.39%	0.18%	0.20%

Wave-length	Uncorrelated 2001	Uncorrelated 2002	Uncorrelated 2003	Correlated year 1 but not with year 2	Correlated year 2 but not with year 1	Correlated year 1 to year 2	Correlated year 2 but not to year 3	Correlated year 3 but not to year 2	Correlated year 2 to year 3	Overall standard uncertainty 2001	Overall standard uncertainty 2002	Overall standard uncertainty 2003
800	0.17%	0.08%	0.12%	0.29%	0.00%	0.15%	0.15%	0.14%	0.00%	0.37%	0.17%	0.19%
850	0.15%	0.07%	0.12%	0.28%	0.00%	0.14%	0.14%	0.13%	0.00%	0.35%	0.16%	0.18%
900	0.13%	0.07%	0.12%	0.26%	0.00%	0.13%	0.13%	0.12%	0.00%	0.32%	0.15%	0.17%
950	0.13%	0.07%	0.13%	0.25%	0.00%	0.13%	0.13%	0.12%	0.01%	0.31%	0.14%	0.17%
1000	0.13%	0.07%	0.13%	0.25%	0.00%	0.12%	0.12%	0.11%	0.01%	0.30%	0.14%	0.17%
1050	0.14%	0.07%	0.14%	0.25%	0.00%	0.12%	0.12%	0.11%	0.01%	0.31%	0.14%	0.18%
1100	0.16%	0.07%	0.16%	0.25%	0.00%	0.11%	0.11%	0.10%	0.01%	0.32%	0.13%	0.19%
1150	0.17%	0.08%	0.17%	0.27%	0.00%	0.11%	0.11%	0.10%	0.01%	0.34%	0.13%	0.20%
1200	0.19%	0.09%	0.18%	0.28%	0.00%	0.10%	0.10%	0.09%	0.02%	0.36%	0.14%	0.20%
1250	0.20%	0.10%	0.18%	0.30%	0.00%	0.10%	0.10%	0.09%	0.00%	0.38%	0.14%	0.20%
1300	0.22%	0.10%	0.18%	0.32%	0.00%	0.09%	0.09%	0.09%	0.00%	0.40%	0.14%	0.20%
1350	0.23%	0.11%	0.18%	0.33%	0.00%	0.10%	0.09%	0.09%	0.03%	0.42%	0.15%	0.20%
1400	0.23%	0.12%	0.18%	0.33%	0.00%	0.09%	0.09%	0.08%	0.01%	0.41%	0.15%	0.20%
1450	0.22%	0.12%	0.18%	0.32%	0.00%	0.09%	0.09%	0.08%	0.00%	0.39%	0.15%	0.20%
1500	0.21%	0.11%	0.17%	0.30%	0.00%	0.08%	0.08%	0.08%	0.01%	0.38%	0.14%	0.19%
1550	0.20%	0.11%	0.16%	0.28%	0.00%	0.08%	0.08%	0.08%	0.00%	0.35%	0.13%	0.18%
1600	0.19%	0.10%	0.16%	0.26%	0.00%	0.08%	0.08%	0.07%	0.01%	0.33%	0.13%	0.17%
1650	0.21%	0.11%	0.17%	0.24%	0.00%	0.09%	0.08%	0.07%	0.04%	0.33%	0.14%	0.19%
1700	0.31%	0.12%	0.19%	0.23%	0.00%	0.08%	0.07%	0.07%	0.01%	0.39%	0.14%	0.20%
1800	0.78%	0.14%	0.23%	0.21%	0.00%	0.08%	0.07%	0.07%	0.02%	0.81%	0.16%	0.24%
1900	1.39%	0.16%	0.27%	0.23%	0.00%	0.07%	0.07%	0.06%	0.02%	1.41%	0.17%	0.27%
2000	1.81%	0.18%	0.31%	0.29%	0.00%	0.08%	0.07%	0.06%	0.05%	1.84%	0.20%	0.32%
2100	2.09%	0.18%	0.29%	0.38%	0.00%	0.07%	0.06%	0.06%	0.02%	2.13%	0.19%	0.30%
2200	2.68%	0.19%	0.28%	0.45%	0.00%	0.06%	0.06%	0.06%	0.00%	2.72%	0.20%	0.29%
2300	3.00%	0.21%	0.38%	0.45%	0.00%	0.06%	0.06%	0.06%	0.01%	3.03%	0.22%	0.38%
2400	4.34%	0.32%	0.39%	0.76%	0.00%	0.09%	0.06%	0.05%	0.07%	4.41%	0.34%	0.40%
2500	5.84%	0.26%	0.24%	1.46%	0.00%	0.08%	0.06%	0.05%	0.05%	6.02%	0.27%	0.26%

4 Measurements at BNM-INM

4.1 Primary scale realisation

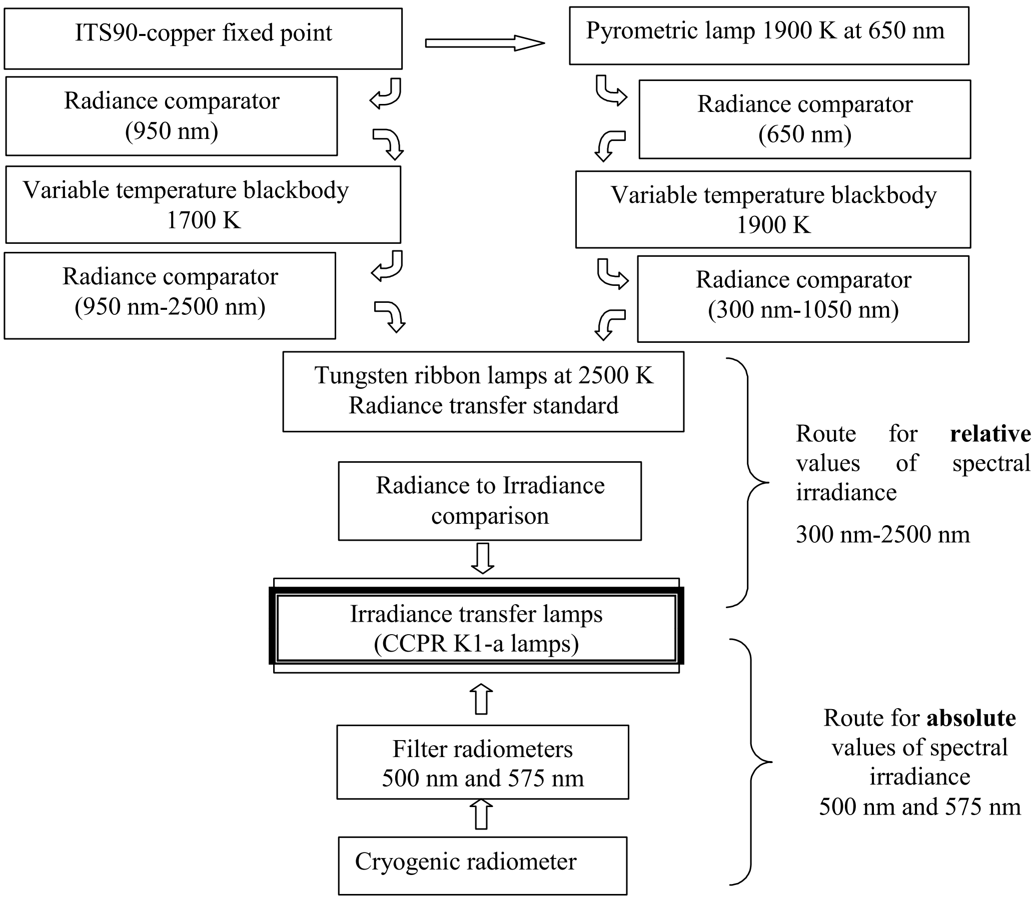

Figure 4-1 Traceability chain for the spectral irradiance calibration at BNM-INM

The measurement is performed in two completely separate operations. First we measure the relative spectral irradiance with our radiance scale as a reference, through a specific optical device. Secondly, we measure the irradiance value at two wavelengths with a radiometer calibrated against our detector responsivity reference. Then we calculate the irradiance over the whole spectral range.

4.1.1 Radiance reference

The radiance references used in the radiance to irradiance comparison are tungsten ribbon lamps operating at 2500 K. The primary standard of radiance is a variable temperature blackbody whose temperature is measured by comparison to a fixed-point blackbody (ITS90 temperature of copper point). Radiance measurement in the whole spectral range is performed with an infrared radiance comparator and a [UV-visible] radiance comparator. In the [UV-visible] range the blackbody temperature measurement (1900 K) is done by using an intermediate pyrometric lamp calibrated against our fixed-point blackbody. The radiance temperature of the pyrometric lamp is 1900 K at 650 nm.

4.1.2 Responsivity reference

The filter radiometers are calibrated against a silicon trap detector on our spectral responsivity bench.

The trap detector is calibrated with laser beams (488 nm to 633 nm) by comparison to a cryogenic radiometer.

4.2 Description of measurement facility

The spectrometer used is a grating spectrometer, 320 mm focal length, from the French manufacturers Jobin Yvon and is equipped with two gratings: one for the UV and visible range (1200 grooves/mm) and another for the IR range (300 grooves/mm).

The spectral radiance to irradiance comparison facility comprises an integrating sphere, a monochromator and a detector that measures the photocurrents due to the radiant flux coming from two optical devices. One is proportional to the radiance of a source considered as a reference radiance standard and a second one is proportional to the irradiance of the source to be measured. The two optical devices are designed so that the ratios between the two fluxes (radiance and irradiance respectively) do not depend on wavelength. These optical devices are an assembly of two spherical mirrors. They are similar in radiance and irradiance operation but they are placed in optically conjugate positions. In order to avoid a transmittance difference between the two sets of mirrors we make two measurements by exchanging the place of mirrors. This is shown in Figure 4-2.

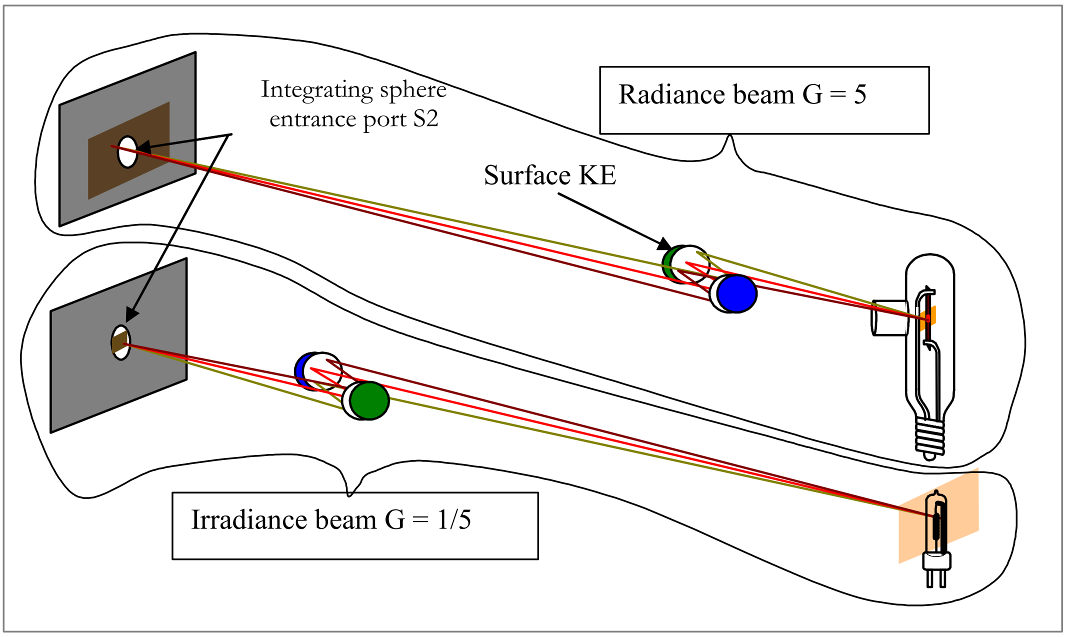

Figure 4-2 Radiance and Irradiance comparison set-up

For the absolute irradiance measurements, the calibrated broadband filter radiometer is placed at 50 cm from the reference plane of the lamp. The experimental set-up is shown in Figure 4-3.

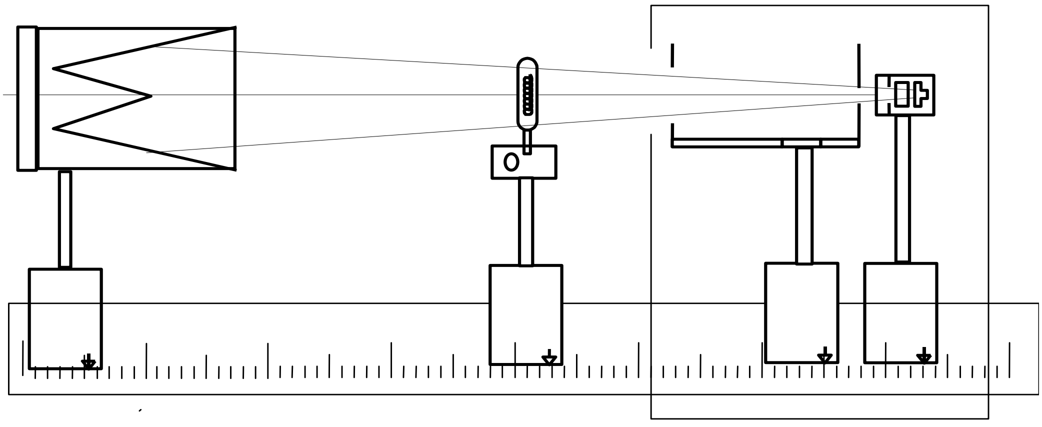

Figure 4-3 Experimental set-up for filter radiometer measurement

4.3 Laboratory conditions

Temperature controlled: 23 °C ± 2 °C. Humidity: 35 % to 60 %.

4.4 Laboratory standards

2 radiance transfer lamps: The ribbon temperatures are 2500 and 2550 K

A calibrated filter radiometer with two filters: 500 nm and 575 nm

4.5 Measurement procedure and analysis

First we measure the relative spectral irradiance using the radiance/irradiance comparison facility (Figure 4-2). We can compute the irradiance of the source by using the measured photocurrents and the calibrated standard radiance. As the dimensions of the aperture areas and the distance between them cannot be known with the expected accuracy we only compute the relative values of irradiance.

4.5.1 Details of radiance to irradiance computation

For each wavelength we measure the fluxes (photocurrents) with the first mirror configuration:

-Radiance beam flux $FL1(\lambda)$

-Irradiance beam flux $FE2(\lambda)$

The radiance and irradiance mirror assemblies are inverted and a measurement is performed with the second mirror configuration:

-Radiance beam $FL2(\lambda)$

-Irradiance beam $FE2(\lambda)$

We write:

$L(\lambda)$ Radiance of 'radiance standard source'

$E(\lambda)$ Irradiance of unknown source

$T1(\lambda)$ Reflectance of first assembly mirrors

$T2(\lambda)$ Reflectance of second assembly mirrors

$S(\lambda)$ Responsivity of the whole detector device

KL Geometrical extension for radiance measurement

KE Irradiance diaphragm surface

We have:

First mirror configuration	Second mirror configuration
$FL1(\lambda) = L(\lambda) \times T1(\lambda) \times KL \times S(\lambda)$	$FL2(\lambda) = L(\lambda) \times T2(\lambda) \times KL \times S(\lambda)$
$FE2(\lambda) = E(\lambda) \times T2(\lambda) \times KE \times S(\lambda)$	$FE1(\lambda) = E(\lambda) \times T1(\lambda) \times KE \times S(\lambda)$

$$R1(\lambda) = FL1(\lambda) / FE2(\lambda) = (L(\lambda)/E(\lambda)) \times (T1(\lambda)/T2(\lambda)) \times (KL/KE)$$

$$R2(\lambda) = FL2(\lambda) / FE1(\lambda) = (L(\lambda)/E(\lambda)) \times (T2(\lambda)/T1(\lambda)) \times (KL/KE)$$

We calculate: $\left(R1(\lambda) \times R2(\lambda)\right)^{1/2} = (L(\lambda)/E(\lambda)) \times (KL/KE)$

The response ratio is independent of the mirrors reflectivity:

$$E(\lambda) = \frac{L(\lambda)}{(R1(\lambda) \times R2(\lambda)) \times (KL/KE)} \qquad (4\text{-}1)$$

As the ratio (KL/KE) cannot be evaluated with the required uncertainty, it is considered as an unknown, but it does not vary with wavelength. So we can calculate the relative irradiance value from Equation (4-1).

$$E_{r\lambda_0} = E(\lambda)/E(\lambda_0) \qquad (4\text{-}2)$$

4.5.2 Absolute irradiance: broadband measurement

Following the relative measurement we measure the irradiance value at two wavelengths with a filter radiometer. The photocurrent *i* supplied by the radiometer is calculated as:

$$i = E(\lambda_0) \cdot \int_{\Delta\lambda} S_2 \cdot Se(\lambda) \cdot E_{r\lambda_0} \cdot d\lambda \qquad (4\text{-}3)$$

Where,

$Se(\lambda)$: Spectral responsivity of the radiometer.

$\Delta\lambda$: Spectral range with non-zero responsivity.

λ_0 : Arbitrary wavelength close to the centre of the spectral responsivity of the radiometer.

$E(\lambda) = E(\lambda_0) \times E_{r\lambda_0}(\lambda)$, with

$E_{r\lambda_0}(\lambda)$:Relative spectral irradiance, equals 1 at $\lambda = \lambda_0$.

Since every term of the integral is the result of a calibration, we numerically calculate the value of the integral. The irradiance $E(\lambda_0)$ is determined from this value and from the measured photocurrent.

We have two filters centred at 500 nm and 575 nm. Their half height widths are 60 nm and 35 nm respectively.The final irradiance $E(\lambda)$ is calculated as the average of the two calibrations obtained with radiometer at 500 nm and 575 nm.

4.6 Uncertainty determination

4.6.1 Primary Scale uncertainty

4.6.1.1 Radiance primary scale

Radiance transfer lamps were calibrated in 2000 and the calibration was confirmed in 2003. Table 4-1 shows the uncertainty breakdown of radiance transfer lamps. In the uncertainty table (Table 4-3) this is "Scale: *relative values*".

Table 4-1 Uncertainty values for primary radiance scale

Description of uncertainty parameter and its value		**300**	**325**	**500**	**850**	**1050**	**1050**	**1550**	**2200**	**2500**
VTBB temperature 300-1050 nm	0.39 K	0.52%	0.48%	0.31%	0.18%	0.15%	-	-	-	-
VTBB temperature 950-2500 nm	0.14 K	-	-	-	-	-	0.07%	0.05%	0.04%	0.03%
Photocurrent		1.50%	0.60%	0.18%	0.09%	0.09%	0.37%	0.13%	0.34%	0.34%
Blocking	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wavelength 300-1050 nm	0.2 nm	0.34%	0.29%	0.12%	0.04%	0.03%	-	-	-	-
Wavelength 950-2500 nm	0.025 nm	-	-	-	-	-	0.01%	0.00%	0.00%	0.00%
Size of source effect	0.30%	-	-	-	-	-	0.30%	0.30%	0.30%	0.30%
Non linearity		0.01%	0.01%	0.01%	0.01%	0.01%	0.20%	0.20%	0.20%	0.20%
Lamp alignment	0.10%	0.22%	0.20%	0.13%	0.08%	0.06%	0.06%	0.04%	0.03%	0.03%
Combined standard uncertainty (*k*=1)		1.64%	0.84%	0.40%	0.22%	0.19%	0.53%	0.39%	0.50%	0.50%

4.6.1.2 Responsivity primary scale

The filter radiometer was calibrated in February 2001 with the two filters centred at 500 nm and 575 nm. The traceability is described in section 4.1.2 and the lamp measurement method is described in section 4.5.2. Table 4-2 shows the uncertainty breakdown applied to the responsivity measurement of radiometers. In the uncertainty table (Table 4-3) this is "Scale : *absolute values*".

Table 4-2 Uncertainty values for absolute measurement with the filter radiometer

Description of uncertainty parameter and its value		500 nm	575 nm
Wavelength	0.054 nm	0.05%	0.03%
Reference	0.2%	0.2%	0.2%
Stray light	0.02%	0.02%	0.02%
Detector homogeneity	0.05%	0.05%	0.05%
Band pass width	0.04%	0.04%	0.04%
Filter temperature	0.4°C	0.02%	0.17%
Combined standard uncertainty (*k* = 1)		0.22%	0.27%

4.6.2 Calibration uncertainty and correlation

The uncertainty budget for spectral irradiance calibration is given in Table 4-3. The following terms are given:

Current Absolute irradiance measurement: We observed a global variation of our own standards for the year 2000, the year of the CCPR K1 first round. The resistor used for current measurement had been calibrated a month after the CCPR K1 measurements. Although this calibration seemed to be correct, the drift (0.1%) of its value was the sign of a possible problem. After this date we made a systematic control with an additional resistor. This control roughly confirmed the calibrated value but a problem appeared a few months later when this resistor became quite unstable. The CCPR K1 results had been obtained by using this resistor. We adopted the last calibrated value to calculate the lamp current and we added an extra uncertainty to this measurement. An additional row has been added to the uncertainty budget to account for the resistor drift. This uncertainty value agrees with the observed variations of our irradiance standards.

This uncertainty is estimated by a Type B method but it could be considered as uncorrelated uncertainty between the two sets of measurements as well as between lamps. The difference between first and second round could be due to the drift or instability of the resistor.

Optical dissymmetry: Term due to our optical arrangement: difference between the reflectivity of mirrors in first and second configuration (see section 4.5)

Spectroradiometer blocking: Effect of the out-of-band transmission of the spectro-radiometer

Combined standard uncertainty ($k = 1$) 2nd round: Because the rules of the comparison prevent participants from reducing their uncertainties after the publication of the pre-draft A report, these values are not used in the results. Nevertheless this is the best estimate of the uncertainties of the 2nd round and thus can be used to understand results of the comparison.

Correlation: N: values Not correlated; C: values Correlated between lamps and between the two rounds, R: values correlated between lamps but not correlated between rounds.

Correlated uncertainties: This is a combination of those effects marked C in the correlation column. As explained above, the large value of the current measurement uncertainty must be considered as uncorrelated since we are not sure the resistor value was the same from one measurement to another one.

Correlated between lamps in a round: Wavelength, non-linearity and optical dissymmetry uncertainties are correlated between lamps in the same round.

Table 4-3 Uncertainty budget for spectral irradiance measurement. For notes on this table, see above

	Spectral range (nm)	Correlation	Units	300-320	330-390	400-500	500-800	850-1000	1050-1300	1500-1700	1800-2200	2300-2500
Type A	Repeatability of reference *Relative values*	N	%	0.16%	0.29%	0.11%	0.10%	0.20%	0.20%	0.09%	0.19%	0.27%
Type A	Repeatability of reference *Absolute values*	N	%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%
Type B	Scale: *Relative values*	C	%	1.64%	0.84%	0.51%	0.40%	0.24%	0.53%	0.53%	0.50%	0.50%
Type B	Scale: *Absolute values*	C	%	0.27%	0.27%	0.27%	0.27%	0.27%	0.27%	0.27%	0.27%	0.27%
Type B	Distance		mm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Type B	Distance	N	%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%
Type B	Current *(usual)*		mA	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Type B	Current	N	%	0.11%	0.10%	0.08%	0.06%	0.04%	0.03%	0.02%	0.02%	0.01%
Type B	Current *1st round Absolute irradiance measurement*		mA	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7
Type B	Current	N	%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%
Type B	Wavelength		nm	0.2	0.2	0.2	0.2	0.2	0.2	0.025	0.025	0.025
Type B	Wavelength	R	%	0.34%	0.28%	0.19%	0.10%	0.04%	0.03%	0.00%	0.00%	0.00%
Type B	Non linearity	R	%	0.10%	0.10%	0.10%	0.20%	0.02%	0.02%	1.00%	0.10%	0.10%
Type B	Optical dissymmetry	R	%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
Type B	Spectro radiometer Blocking	C	%	0.04%	0.04%	0.02%	0.02%	0.02%	0.02%	0.50%	0.20%	0.20%
	RMS Type A		%	0.26%	0.35%	0.23%	0.23%	0.29%	0.28%	0.22%	0.28%	0.33%
	RMS Type B		%	1.85%	1.18%	0.95%	0.89%	0.80%	0.93%	1.45%	0.94%	0.94%
	Combined standard uncertainty (k=1)		%	1.86%	1.23%	0.97%	0.92%	0.85%	0.97%	1.47%	0.98%	0.99%
	Correlated uncertainties		%	1.66%	0.89%	0.58%	0.49%	0.36%	0.59%	0.77%	0.60%	0.60%
	Uncorrelated uncertainties		%	0.76%	0.79%	0.74%	0.74%	0.76%	0.76%	0.74%	0.76%	0.78%
	Correlated between lamps in a round		%	0.37%	0.32%	0.24%	0.25%	0.11%	0.11%	1.00%	0.14%	0.14%
	Values not used in Table A1:											
	Combined standard uncertainty (k=1) 2nd round		%	1.73%	1.01%	0.67%	0.59%	0.48%	0.67%	1.29%	0.68%	0.70%

4.7 BNM-INM Results

BNM-INM measured two lamps. The results for FEL BN 9101 197 are given in Table 4-4 and the results for FEL BN 9101 246 are given in Table 4-5.

Table 4-4 BNM-INM Results for FEL BN 9101 197. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

*NOTE: * 1100 nm, BNM-INM asked for their first round data to be excluded at this wavelength.*

FEL 197	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.188E-03	0.76%	0.37%	1.68%	1.88%	1.171E-03	0.76%	0.37%	1.68%	1.88%
310	1.759E-03	0.76%	0.37%	1.68%	1.88%	1.717E-03	0.76%	0.37%	1.68%	1.88%
320	2.474E-03	0.76%	0.37%	1.68%	1.88%	2.412E-03	0.76%	0.37%	1.68%	1.88%
330	3.337E-03	0.79%	0.32%	0.90%	1.24%	3.276E-03	0.79%	0.32%	0.90%	1.24%
340	4.419E-03	0.79%	0.32%	0.90%	1.24%	4.345E-03	0.79%	0.32%	0.90%	1.24%
350	5.670E-03	0.79%	0.32%	0.90%	1.24%	5.549E-03	0.79%	0.32%	0.90%	1.24%
360	7.235E-03	0.79%	0.32%	0.90%	1.24%	7.104E-03	0.79%	0.32%	0.90%	1.24%
370	8.997E-03	0.79%	0.32%	0.90%	1.24%	8.863E-03	0.79%	0.32%	0.90%	1.24%
380	1.106E-02	0.79%	0.32%	0.90%	1.24%	1.091E-02	0.79%	0.32%	0.90%	1.24%
390	1.338E-02	0.79%	0.32%	0.90%	1.24%	1.320E-02	0.79%	0.32%	0.90%	1.24%
400	1.599E-02	0.74%	0.24%	0.59%	0.98%	1.576E-02	0.74%	0.24%	0.59%	0.98%
450	3.351E-02	0.74%	0.24%	0.59%	0.98%	3.299E-02	0.74%	0.24%	0.59%	0.98%
500	5.628E-02	0.74%	0.24%	0.51%	0.93%	5.552E-02	0.74%	0.24%	0.51%	0.93%
550	8.165E-02	0.74%	0.25%	0.50%	0.93%	8.142E-02	0.74%	0.25%	0.50%	0.93%
555	8.578E-02	0.74%	0.25%	0.50%	0.93%	8.407E-02	0.74%	0.25%	0.50%	0.93%
600	1.086E-01	0.74%	0.25%	0.50%	0.93%	1.073E-01	0.74%	0.25%	0.50%	0.93%
650	1.326E-01	0.74%	0.25%	0.50%	0.93%	1.312E-01	0.74%	0.25%	0.50%	0.93%
700	1.534E-01	0.74%	0.25%	0.50%	0.93%	1.519E-01	0.74%	0.25%	0.50%	0.93%
750	1.690E-01	0.74%	0.25%	0.50%	0.93%	1.688E-01	0.74%	0.25%	0.50%	0.93%
800	1.800E-01	0.74%	0.25%	0.50%	0.93%	1.784E-01	0.74%	0.25%	0.50%	0.93%
850	1.876E-01	0.76%	0.11%	0.37%	0.85%	1.859E-01	0.76%	0.11%	0.37%	0.85%
900	1.918E-01	0.76%	0.11%	0.37%	0.85%	1.895E-01	0.76%	0.11%	0.37%	0.85%
950	1.924E-01	0.76%	0.11%	0.37%	0.85%	1.897E-01	0.76%	0.11%	0.37%	0.85%
1000	1.900E-01	0.76%	0.11%	0.37%	0.85%	1.876E-01	0.76%	0.11%	0.37%	0.85%
1100*						1.776E-01	0.76%	0.60%	0.00%	0.97%
1200	1.648E-01	0.76%	0.11%	0.59%	0.97%	1.637E-01	0.76%	0.11%	0.59%	0.97%
1300	1.480E-01	0.76%	0.11%	0.59%	0.97%	1.468E-01	0.76%	0.11%	0.59%	0.97%
1400	1.308E-01	0.76%	0.11%	0.59%	0.97%	1.301E-01	0.76%	0.11%	0.59%	0.97%
1500	1.154E-01	0.74%	1.00%	0.76%	1.46%	1.146E-01	0.74%	1.00%	0.76%	1.46%
1600	1.012E-01	0.74%	1.00%	0.76%	1.46%	1.007E-01	0.74%	1.00%	0.76%	1.46%
1700	8.843E-02	0.74%	1.00%	0.76%	1.46%	8.838E-02	0.74%	1.00%	0.76%	1.46%
1800	7.738E-02	0.76%	0.14%	1.23%	1.46%	7.698E-02	0.76%	0.14%	1.23%	1.46%
1900	6.735E-02	0.76%	0.14%	1.23%	1.46%	6.710E-02	0.76%	0.14%	1.23%	1.46%
2000	5.907E-02	0.76%	0.14%	0.59%	0.97%	5.878E-02	0.76%	0.14%	0.59%	0.97%
2100	5.124E-02	0.76%	0.14%	0.59%	0.97%	5.114E-02	0.76%	0.14%	0.59%	0.97%
2200	4.529E-02	0.76%	0.14%	0.59%	0.97%	4.516E-02	0.76%	0.14%	0.59%	0.97%
2300	3.994E-02	0.78%	0.14%	0.59%	0.99%	3.945E-02	0.78%	0.14%	0.59%	0.99%
2400	3.493E-02	0.78%	0.14%	0.59%	0.99%	3.468E-02	0.78%	0.14%	0.59%	0.99%
2500	3.104E-02	0.78%	0.14%	0.62%	1.01%	3.084E-02	0.78%	0.14%	0.62%	1.01%

Table 4-5 BNM-INM Results for FEL BN 9101 246. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

*NOTE: * 1100 nm, BNM-INM asked for their first round data to be excluded at this wavelength.*

FEL 246	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.327E-03	0.76%	0.37%	1.68%	1.88%	1.302E-03	0.76%	0.37%	1.68%	1.88%
310	1.970E-03	0.76%	0.37%	1.68%	1.88%	1.913E-03	0.76%	0.37%	1.68%	1.88%
320	2.751E-03	0.76%	0.37%	1.68%	1.88%	2.670E-03	0.76%	0.37%	1.68%	1.88%
330	3.705E-03	0.79%	0.32%	0.90%	1.24%	3.614E-03	0.79%	0.32%	0.90%	1.24%
340	4.899E-03	0.79%	0.32%	0.90%	1.24%	4.783E-03	0.79%	0.32%	0.90%	1.24%
350	6.271E-03	0.79%	0.32%	0.90%	1.24%	6.096E-03	0.79%	0.32%	0.90%	1.24%
360	7.990E-03	0.79%	0.32%	0.90%	1.24%	7.792E-03	0.79%	0.32%	0.90%	1.24%
370	9.919E-03	0.79%	0.32%	0.90%	1.24%	9.700E-03	0.79%	0.32%	0.90%	1.24%
380	1.216E-02	0.79%	0.32%	0.90%	1.24%	1.192E-02	0.79%	0.32%	0.90%	1.24%
390	1.471E-02	0.79%	0.32%	0.90%	1.24%	1.439E-02	0.79%	0.32%	0.90%	1.24%
400	1.756E-02	0.74%	0.24%	0.59%	0.98%	1.716E-02	0.74%	0.24%	0.59%	0.98%
450	3.651E-02	0.74%	0.24%	0.59%	0.98%	3.564E-02	0.74%	0.24%	0.59%	0.98%
500	6.092E-02	0.74%	0.24%	0.51%	0.93%	5.964E-02	0.74%	0.24%	0.51%	0.93%
550	8.890E-02	0.74%	0.25%	0.50%	0.93%	8.699E-02	0.74%	0.25%	0.50%	0.93%
555	9.181E-02	0.74%	0.25%	0.50%	0.93%	8.978E-02	0.74%	0.25%	0.50%	0.93%
600	1.165E-01	0.74%	0.25%	0.50%	0.93%	1.141E-01	0.74%	0.25%	0.50%	0.93%
650	1.417E-01	0.74%	0.25%	0.50%	0.93%	1.391E-01	0.74%	0.25%	0.50%	0.93%
700	1.634E-01	0.74%	0.25%	0.50%	0.93%	1.605E-01	0.74%	0.25%	0.50%	0.93%
750	1.794E-01	0.74%	0.25%	0.50%	0.93%	1.778E-01	0.74%	0.25%	0.50%	0.93%
800	1.907E-01	0.74%	0.25%	0.50%	0.93%	1.873E-01	0.74%	0.25%	0.50%	0.93%
850	1.983E-01	0.76%	0.11%	0.37%	0.85%	1.949E-01	0.76%	0.11%	0.37%	0.85%
900	2.022E-01	0.76%	0.11%	0.37%	0.85%	1.981E-01	0.76%	0.11%	0.37%	0.85%
950	2.025E-01	0.76%	0.11%	0.37%	0.85%	1.980E-01	0.76%	0.11%	0.37%	0.85%
1000	1.997E-01	0.76%	0.11%	0.37%	0.85%	1.954E-01	0.76%	0.11%	0.37%	0.85%
1100*						1.846E-01	0.76%	0.60%	0.00%	0.97%
1200	1.720E-01	0.76%	0.11%	0.59%	0.97%	1.700E-01	0.76%	0.11%	0.59%	0.97%
1300	1.541E-01	0.76%	0.11%	0.59%	0.97%	1.522E-01	0.76%	0.11%	0.59%	0.97%
1400	1.359E-01	0.76%	0.11%	0.59%	0.97%	1.347E-01	0.76%	0.11%	0.59%	0.97%
1500	1.197E-01	0.74%	1.00%	0.76%	1.46%	1.184E-01	0.74%	1.00%	0.76%	1.46%
1600	1.048E-01	0.74%	1.00%	0.76%	1.46%	1.039E-01	0.74%	1.00%	0.76%	1.46%
1700	9.149E-02	0.74%	1.00%	0.76%	1.46%	9.109E-02	0.74%	1.00%	0.76%	1.46%
1800	7.988E-02	0.76%	0.14%	1.23%	1.46%	7.924E-02	0.76%	0.14%	1.23%	1.46%
1900	6.955E-02	0.76%	0.14%	1.23%	1.46%	6.902E-02	0.76%	0.14%	1.23%	1.46%
2000	6.083E-02	0.76%	0.14%	0.59%	0.97%	6.036E-02	0.76%	0.14%	0.59%	0.97%
2100	5.288E-02	0.76%	0.14%	0.59%	0.97%	5.246E-02	0.76%	0.14%	0.59%	0.97%
2200	4.661E-02	0.76%	0.14%	0.59%	0.97%	4.628E-02	0.76%	0.14%	0.59%	0.97%
2300	4.111E-02	0.78%	0.14%	0.59%	0.99%	4.041E-02	0.78%	0.14%	0.59%	0.99%
2400	3.608E-02	0.78%	0.14%	0.59%	0.99%	3.548E-02	0.78%	0.14%	0.59%	0.99%
2500	3.193E-02	0.78%	0.14%	0.62%	1.01%	3.154E-02	0.78%	0.14%	0.62%	1.01%

4.8 Pilot Results

NPL's measurements of lamp BN 9101 197 are given in Table 4-6 and NPL's measurements of lamp BN 9101 246 are given in Table 4-7.

Table 4-6 NPL Results for FEL BN 9101 197. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 197	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.230E-03	0.18%	0.40%	0.25%	0.51%	1.214E-03	0.25%	0.37%	0.25%	0.51%
310	1.759E-03	0.17%	0.39%	0.28%	0.51%	1.737E-03	0.23%	0.36%	0.28%	0.51%
320	2.444E-03	0.16%	0.37%	0.25%	0.48%	2.413E-03	0.21%	0.35%	0.25%	0.48%
330	3.309E-03	0.15%	0.36%	0.28%	0.48%	3.268E-03	0.20%	0.34%	0.28%	0.48%
340	4.375E-03	0.15%	0.35%	0.33%	0.50%	4.323E-03	0.19%	0.33%	0.33%	0.50%
350	5.665E-03	0.14%	0.34%	0.36%	0.52%	5.599E-03	0.18%	0.32%	0.36%	0.51%
360	7.197E-03	0.13%	0.33%	0.43%	0.56%	7.113E-03	0.17%	0.31%	0.43%	0.56%
370	8.984E-03	0.13%	0.32%	0.46%	0.58%	8.882E-03	0.17%	0.30%	0.46%	0.57%
380	1.104E-02	0.13%	0.31%	0.52%	0.62%	1.092E-02	0.16%	0.29%	0.52%	0.62%
390	1.337E-02	0.13%	0.31%	0.50%	0.60%	1.323E-02	0.16%	0.29%	0.50%	0.60%
400	1.598E-02	0.12%	0.30%	0.46%	0.56%	1.581E-02	0.16%	0.28%	0.46%	0.56%
450	3.311E-02	0.12%	0.27%	0.10%	0.31%	3.280E-02	0.16%	0.25%	0.10%	0.31%
500	5.591E-02	0.11%	0.24%	0.01%	0.26%	5.546E-02	0.15%	0.22%	0.01%	0.27%
550	8.192E-02	0.10%	0.22%	0.00%	0.24%	8.135E-02	0.13%	0.20%	0.00%	0.24%
555	8.459E-02	0.10%	0.22%	0.00%	0.24%	8.401E-02	0.13%	0.20%	0.00%	0.24%
600	1.084E-01	0.09%	0.20%	0.00%	0.22%	1.077E-01	0.12%	0.19%	0.00%	0.22%
650	1.330E-01	0.09%	0.18%	0.00%	0.20%	1.322E-01	0.12%	0.17%	0.00%	0.21%
700	1.540E-01	0.09%	0.17%	0.00%	0.19%	1.531E-01	0.11%	0.16%	0.00%	0.19%
750	1.705E-01	0.08%	0.16%	0.01%	0.18%	1.696E-01	0.11%	0.15%	0.01%	0.18%
800	1.823E-01	0.08%	0.15%	0.00%	0.17%	1.814E-01	0.10%	0.14%	0.00%	0.17%
850	1.897E-01	0.07%	0.14%	0.00%	0.16%	1.888E-01	0.10%	0.13%	0.00%	0.17%
900	1.931E-01	0.07%	0.13%	0.00%	0.15%	1.923E-01	0.10%	0.12%	0.00%	0.16%
950	1.932E-01	0.07%	0.13%	0.01%	0.14%	1.926E-01	0.10%	0.12%	0.01%	0.15%
1000	1.907E-01	0.07%	0.12%	0.01%	0.14%	1.902E-01	0.10%	0.11%	0.01%	0.15%
1100*	1.802E-01	0.07%	0.11%	0.01%	0.13%	1.800E-01	0.12%	0.10%	0.01%	0.16%
1200	1.655E-01	0.09%	0.10%	0.02%	0.14%	1.655E-01	0.14%	0.09%	0.02%	0.17%
1300	1.490E-01	0.10%	0.09%	0.00%	0.14%	1.491E-01	0.14%	0.09%	0.00%	0.17%
1400	1.324E-01	0.12%	0.09%	0.01%	0.15%	1.324E-01	0.14%	0.08%	0.01%	0.16%
1500	1.167E-01	0.11%	0.08%	0.01%	0.14%	1.166E-01	0.13%	0.08%	0.01%	0.15%
1600	1.025E-01	0.10%	0.08%	0.01%	0.13%	1.021E-01	0.12%	0.07%	0.01%	0.14%
1700	8.980E-02	0.12%	0.07%	0.01%	0.14%	8.922E-02	0.14%	0.07%	0.01%	0.16%
1800	7.864E-02	0.14%	0.07%	0.02%	0.16%	7.794E-02	0.18%	0.07%	0.02%	0.19%
1900	6.880E-02	0.16%	0.07%	0.02%	0.17%	6.810E-02	0.20%	0.06%	0.02%	0.21%
2000	6.013E-02	0.18%	0.07%	0.05%	0.20%	5.954E-02	0.22%	0.06%	0.05%	0.23%
2100	5.259E-02	0.18%	0.06%	0.02%	0.19%	5.214E-02	0.20%	0.06%	0.02%	0.21%
2200	4.614E-02	0.19%	0.06%	0.00%	0.20%	4.579E-02	0.19%	0.06%	0.00%	0.19%
2300	4.069E-02	0.21%	0.06%	0.01%	0.22%	4.032E-02	0.25%	0.06%	0.01%	0.25%
2400	3.597E-02	0.32%	0.06%	0.07%	0.34%	3.547E-02	0.27%	0.05%	0.07%	0.28%
2500	3.171E-02	0.26%	0.06%	0.05%	0.27%	3.128E-02	0.16%	0.05%	0.05%	0.18%

Table 4-7 NPL Results for FEL 246. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 246	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.353E-03	0.23%	0.40%	0.25%	0.52%	1.359E-03	0.34%	0.37%	0.25%	0.56%
310	1.929E-03	0.21%	0.39%	0.28%	0.52%	1.936E-03	0.30%	0.36%	0.28%	0.55%
320	2.674E-03	0.19%	0.37%	0.25%	0.49%	2.679E-03	0.28%	0.35%	0.25%	0.51%
330	3.612E-03	0.18%	0.36%	0.28%	0.49%	3.614E-03	0.26%	0.34%	0.28%	0.51%
340	4.766E-03	0.17%	0.35%	0.33%	0.51%	4.764E-03	0.24%	0.33%	0.33%	0.52%
350	6.159E-03	0.16%	0.34%	0.36%	0.52%	6.150E-03	0.23%	0.32%	0.36%	0.53%
360	7.808E-03	0.15%	0.33%	0.43%	0.56%	7.792E-03	0.21%	0.31%	0.43%	0.57%
370	9.730E-03	0.15%	0.32%	0.46%	0.58%	9.704E-03	0.20%	0.30%	0.46%	0.59%
380	1.193E-02	0.15%	0.31%	0.52%	0.62%	1.190E-02	0.20%	0.29%	0.52%	0.63%
390	1.443E-02	0.14%	0.31%	0.50%	0.60%	1.438E-02	0.19%	0.29%	0.50%	0.61%
400	1.722E-02	0.14%	0.30%	0.46%	0.57%	1.716E-02	0.19%	0.28%	0.46%	0.57%
450	3.544E-02	0.15%	0.27%	0.10%	0.32%	3.531E-02	0.19%	0.25%	0.10%	0.33%
500	5.952E-02	0.14%	0.24%	0.01%	0.27%	5.933E-02	0.17%	0.22%	0.01%	0.28%
550	8.681E-02	0.12%	0.22%	0.00%	0.25%	8.658E-02	0.15%	0.20%	0.00%	0.25%
555	8.960E-02	0.12%	0.22%	0.00%	0.25%	8.937E-02	0.14%	0.20%	0.00%	0.25%
600	1.144E-01	0.11%	0.20%	0.00%	0.23%	1.142E-01	0.13%	0.19%	0.00%	0.23%
650	1.398E-01	0.11%	0.18%	0.00%	0.21%	1.395E-01	0.13%	0.17%	0.00%	0.22%
700	1.613E-01	0.11%	0.17%	0.00%	0.20%	1.611E-01	0.13%	0.16%	0.00%	0.20%
750	1.780E-01	0.10%	0.16%	0.01%	0.19%	1.779E-01	0.12%	0.15%	0.01%	0.19%
800	1.898E-01	0.10%	0.15%	0.00%	0.18%	1.898E-01	0.12%	0.14%	0.00%	0.18%
850	1.969E-01	0.09%	0.14%	0.00%	0.17%	1.970E-01	0.12%	0.13%	0.00%	0.17%
900	1.999E-01	0.09%	0.13%	0.00%	0.16%	2.002E-01	0.11%	0.12%	0.00%	0.17%
950	1.996E-01	0.08%	0.13%	0.01%	0.15%	2.001E-01	0.12%	0.12%	0.01%	0.17%
1000	1.966E-01	0.08%	0.12%	0.01%	0.15%	1.973E-01	0.12%	0.11%	0.01%	0.17%
1100*	1.851E-01	0.10%	0.11%	0.01%	0.15%	1.859E-01	0.15%	0.10%	0.01%	0.18%
1200	1.694E-01	0.12%	0.10%	0.02%	0.16%	1.702E-01	0.18%	0.09%	0.02%	0.20%
1300	1.522E-01	0.15%	0.09%	0.00%	0.18%	1.528E-01	0.18%	0.09%	0.00%	0.20%
1400	1.349E-01	0.17%	0.09%	0.01%	0.19%	1.354E-01	0.18%	0.08%	0.01%	0.20%
1500	1.187E-01	0.16%	0.08%	0.01%	0.18%	1.192E-01	0.17%	0.08%	0.01%	0.19%
1600	1.041E-01	0.16%	0.08%	0.01%	0.18%	1.046E-01	0.16%	0.07%	0.01%	0.17%
1700	9.118E-02	0.21%	0.07%	0.01%	0.22%	9.174E-02	0.18%	0.07%	0.01%	0.20%
1800	7.981E-02	0.26%	0.07%	0.02%	0.27%	8.032E-02	0.23%	0.07%	0.02%	0.24%
1900	6.975E-02	0.30%	0.07%	0.02%	0.31%	7.018E-02	0.27%	0.06%	0.02%	0.27%
2000	6.085E-02	0.33%	0.07%	0.05%	0.34%	6.124E-02	0.31%	0.06%	0.05%	0.32%
2100	5.310E-02	0.33%	0.06%	0.02%	0.34%	5.352E-02	0.29%	0.06%	0.02%	0.30%
2200	4.650E-02	0.36%	0.06%	0.00%	0.37%	4.699E-02	0.28%	0.06%	0.00%	0.28%
2300	4.097E-02	0.40%	0.06%	0.01%	0.41%	4.142E-02	0.36%	0.06%	0.01%	0.37%
2400	3.618E-02	0.59%	0.06%	0.07%	0.60%	3.642E-02	0.40%	0.05%	0.07%	0.41%
2500	3.188E-02	0.50%	0.06%	0.05%	0.51%	3.230E-02	0.25%	0.05%	0.05%	0.26%

4.9 Lamp Behaviour

4.9.1 BNM-INM Lamps

The following lamps were supplied to BNM-INM by NPL:

FEL BN 9101 233 FEL BN 9101 197 FEL BN 9101 246

FEL BN 9101 233 was damaged at BNM-INM on the first measurement, and has therefore been removed from the comparison.

Measurements were made in the sequence: BNM – NPL – BNM – NPL. There was an initial measurement of the lamps at NPL prior to this sequence, however the decision was made to ignore those results, as discussed in Section 2.7.3.

BNM-INM measured all intercomparison wavelengths from 300 nm to 2500 nm.

4.9.2 Lamp electrical stability

The lamp was operated at 8.100 A at both laboratories, the lamp voltage measured was:

Table 4-8 Electrical Potential across lamp as measured by both laboratories

Lamp	Potential first BNM measurement	Potential first NPL measurement	Potential second BNM measurement	Potential second NPL measurement
FEL BN 9101 197	100.92 to 101.16 V	101.05 V	100.92 to 101.16 V	101.07 V
FEL BN 9101 246	105.64 to 105.91 V	105.74 V	105.64 to 105.91 V	105.77 V

4.9.3 Lamp history

Table 4-9 Lamp history for FEL BN 9101 197

Date period	Activity	Burn hours:minutes
July – August 2000	0th round measurements at NPL (not used)	6:47
September 2000	Hand-carried to BNM-INM	
Sept. – Oct. 2000	1st round measurements at BNM-INM	15:30
November 2000	Hand-carried to NPL	
February – July 2002	1st round measurements at NPL	12:34
September 2002	Hand-carried to BNM-INM	
Oct. 2002 – March 2003	2nd round measurements at BNM-INM	8:30
April 2003	Hand-carried to NPL	
June – August 2003	2nd round measurements at NPL	17:59
November 2003	Hand-carried to BNM-INM	

Table 4-10 Lamp history for FEL BN 9101 246

Date period	Activity	Burn hours:minutes
July – August 2000	0th round measurements at NPL (not used)	7:12
September 2000	Hand-carried to BNM-INM	
Sept. – Oct. 2000	1st round measurements at BNM-INM	16:00
November 2000	Hand-carried to NPL	
February – July 2002	1st round measurements at NPL	13:54
September 2002	Hand-carried to BNM-INM	
Oct. 2002 – March 2003	2nd round measurements at BNM-INM	8:30
April 2003	Hand-carried to NPL	
June – August 2003	2nd round measurements at NPL	13:54
November 2003	Hand-carried to BNM-INM	

4.9.4 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the BNM lamps. The difference between the first and second measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

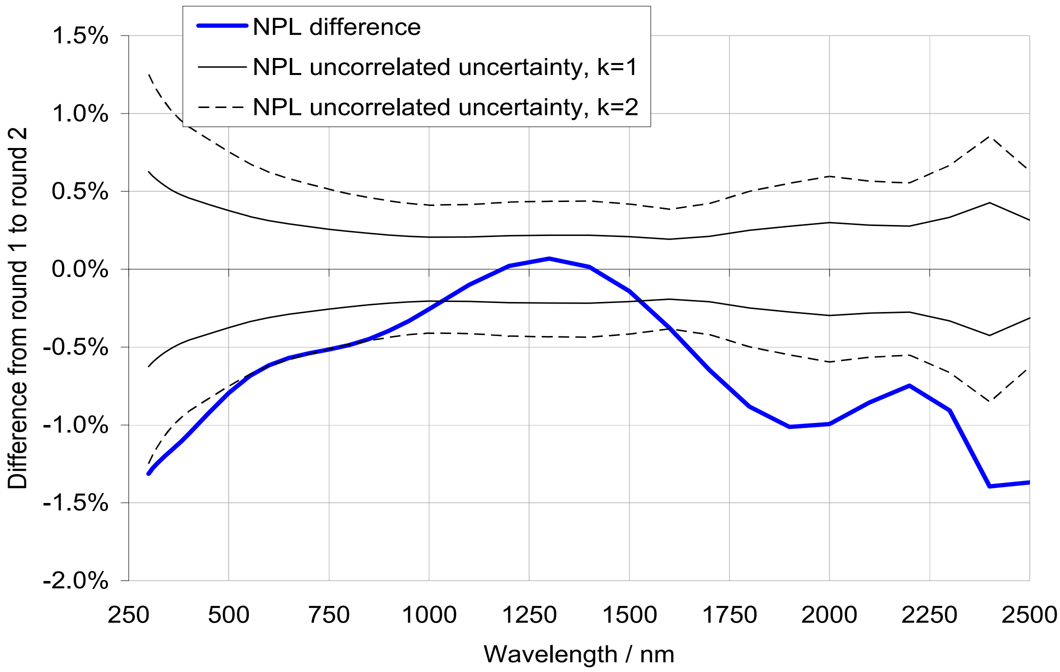

Figure 4-4 Difference between first and second round measurements of FEL BN 9101 197 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

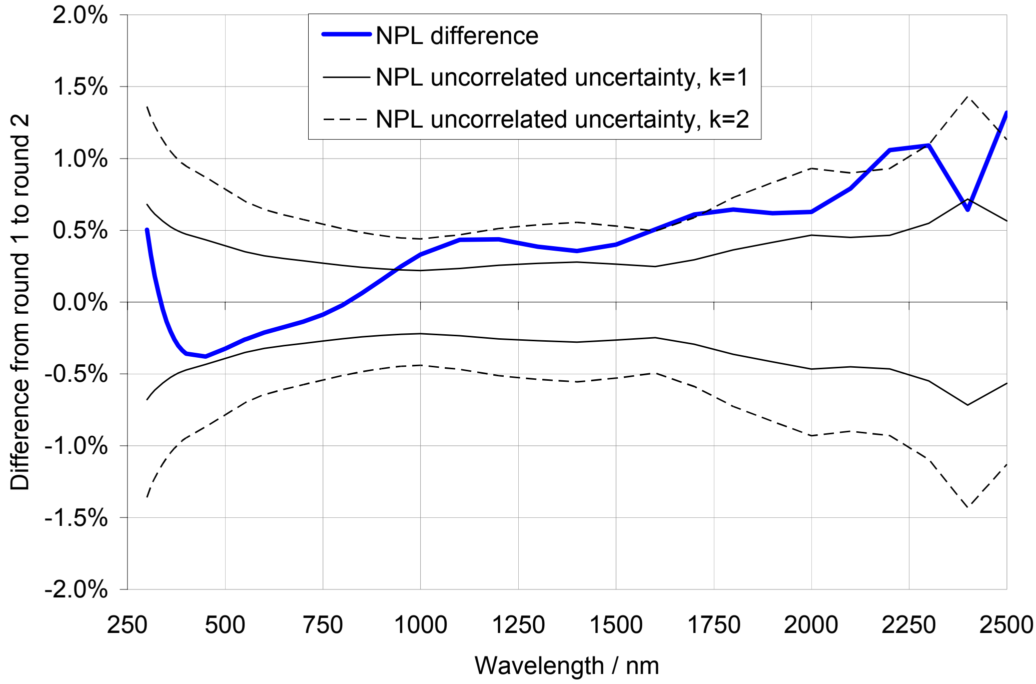

Figure 4-5 Difference between first and second round measurements of FEL BN 9101 246 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

4.9.5 Lamp stability from BNM-INM measurements

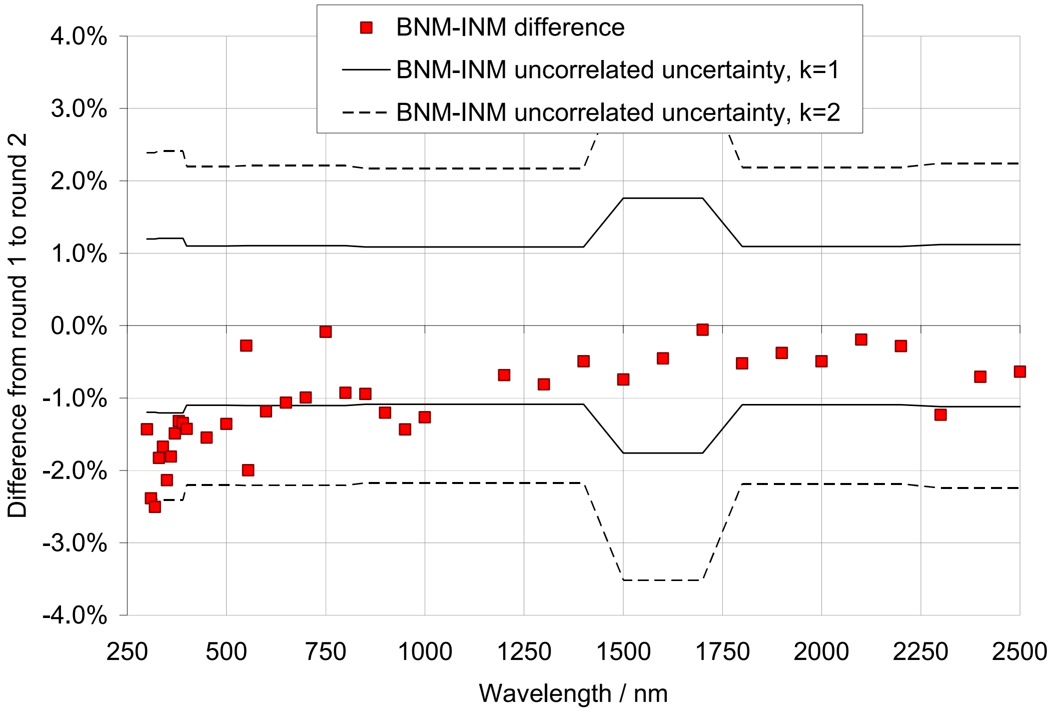

Figure 4-6 Difference between first and second round measurements of FEL BN 9101 197 by BNM-INM. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the BNM-INM measurements

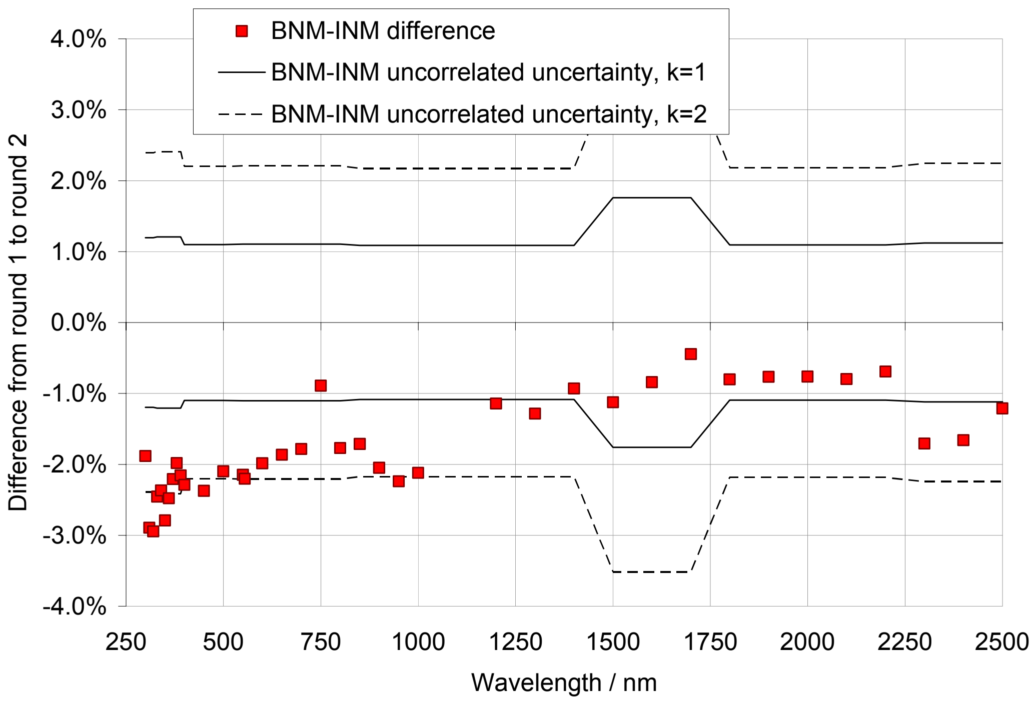

Figure 4-7 Difference between first and second round measurements of FEL BN 9101 246 by BNM-INM. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the BNM-INM measurements

4.9.6 Bilateral comparison between BNM-INM and the comparison scale

This graph shows the difference between the BNM-INM and NPL measurements of the BNM-INM lamps. A version of this graph normalised to show the relative difference between the lamps, but not the absolute difference between the measurements was used to assist in choosing which lamp measurements to use.

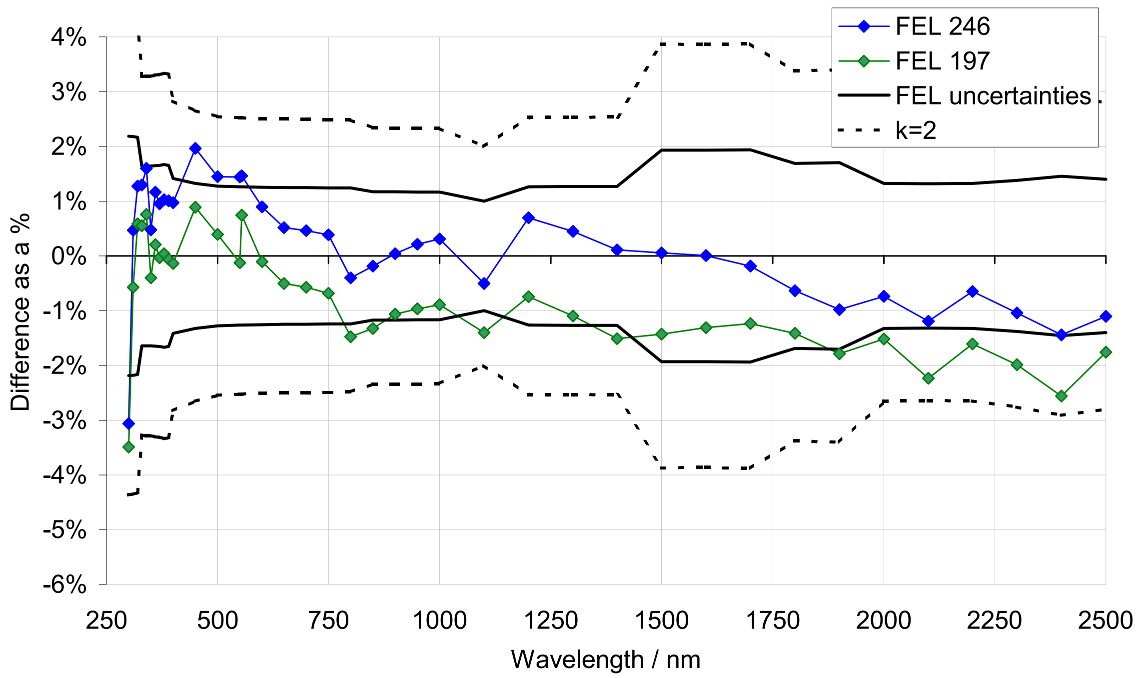

Figure 4-8 Bilateral comparisons of the BNM-INM lamps to the comparison scale

4.10 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to BNM-INM the information in the graphs Figure 4-4 to Figure 4-8. It was decided that both participant measurements and both pilot measurements would be used both for FEL BN 9101 197 and for FEL BN 9101 246.

5 Measurements at CENAM

5.1 Primary scale realisation

Traceability is to PTB. The last calibration was on 25/01/2000, with the calibration certificate number: S121-4.11-PTB00. The uncertainty in this calibration at the k = 2 level, is given in Table 5-1.

Table 5-1 Uncertainty of PTB calibration

Uncertainty	Start wavelength	End wavelength
± 0.001 μW cm^{-2} nm^{-1}	250 nm	260 nm
± 3%	270 nm	400 nm
± 1.6%	400 nm	800 nm
± 3%	800 nm	2000 nm
± 5%	2000 nm	2500 nm

5.2 Description of measurement facility

The spectrometer used was the Optronics Laboratories, Inc. OL 750D Basic Spectroradiometer-Double Monochromator in additive mode.

The facility set-up is shown in Figure 5-1 and the detectors used are listed in Table 5-2. The integrating sphere is a model OL IS-430, 6 inch diameter, and 1 inch aperture, PTFE coated sphere.

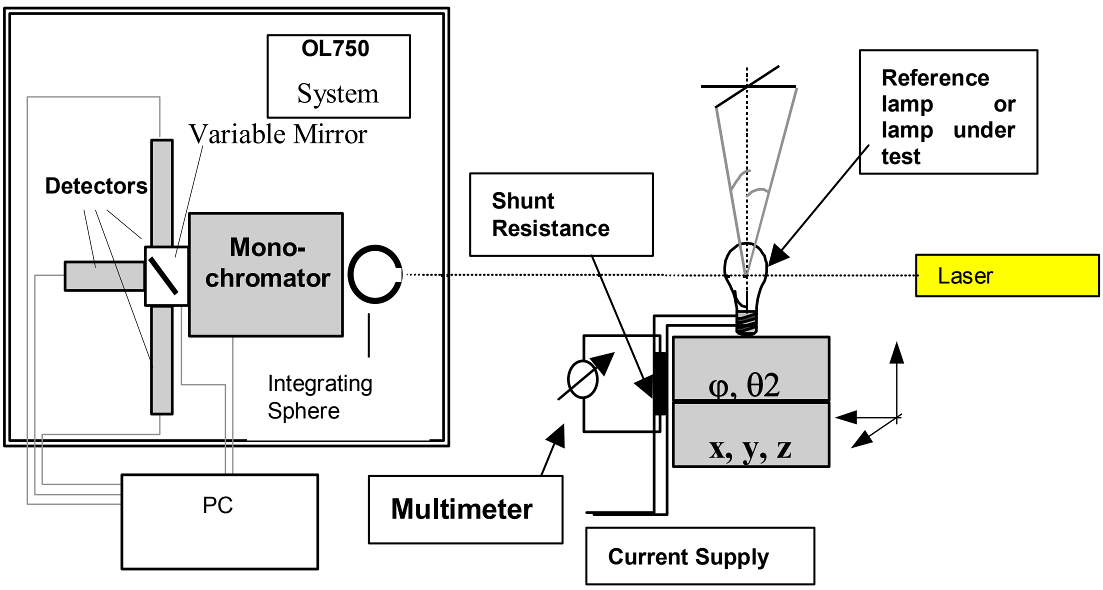

Figure 5-1 Set-up for spectral irradiance measurements

Table 5-2 Detectors used on spectroradiometer facility

Detector	Model	Start wavelength	End wavelength
PMT, (Photo Multiplier Tube)	OL 750-HSD-310 PMT (S-20)	250 nm	499 nm
Silicon Photodiode	OL 750-HSD-300 Silicon	500 nm	999 nm
PbS Photoconductive detector	OL 750-HSD-340 PbS	1000 nm	2400 nm

5.3 Laboratory conditions

The range for the temperature in the laboratory was from 20.9 ºC to 22.3 ºC; but during the measurement periods, the temperature was kept in the range of ±1 ºC. Throughout the measurement periods, the humidity was under 50%.

5.4 Laboratory standards

Reference standard: Tungsten Halogen Lamp, by Omtec, type LDU 1000H, serial no. SN00012.

5.5 Measurement procedure

The measuring technique is shown in the flow diagram, Figure 5-2.

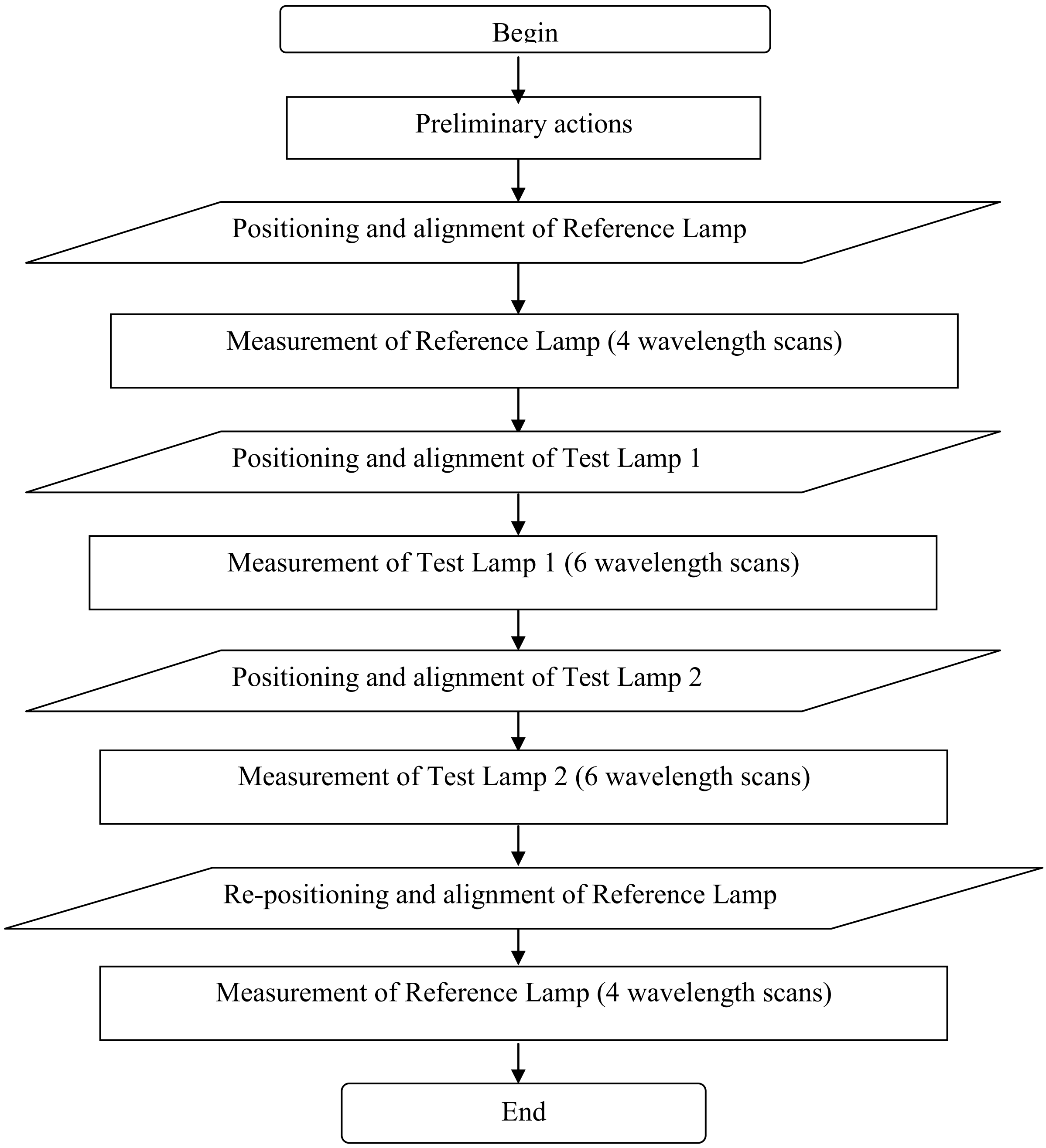

Figure 5-2 Flow diagram of measurement technique

5.6 Uncertainty determination

The uncertainty of the measurements was estimated according to the "ISO Guide to the Expression of Uncertainty in Measurement". The expanded uncertainty is declared with a confidence level of approximately 95%. Table 5-3 shows the sources of uncertainty in the measurement of spectral irradiance and Table 5-4 shows the contributions to the standard uncertainty at the interpolated wavelengths.

Table 5-3 Contributions to the standard uncertainty of the measurand, in percent

Spectral range / nm	**250 - 259**	**260 – 269**	**270 – 399**	**400 – 499**	**500 – 799**	**800 - 999**	**1000 - 1999**	**2000 - 2500**
Standard lamp (detector stabilised lamp)								
Calibration Certificate	5.5	3.0	1.5	0.8	0.8	1.5	1.5	2.5
Ageing	0.4	0.4	0.4	0.4	0.2	0.2	0.4	0.4
Type A (repeatability)	1.2	0.9	0.6	0.22	0.2	0.13	0.41	0.51
Stray light	1.0	0.8	0.20	0.20	0.20	0.50	0.8	0.5
Distance (at 70 cm)	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Alignment (tilt)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Wavelength	0.32	0.32	0.32	0.09	0.05	0.006	0.03	0.03
Test lamp (FEL, without detector stabilisation)								
Type A (repeatability)	0.6	0.5	0.48	0.25	0.1	0.13	0.15	0.13
Stray light	0.6	0.4	0.40	0.10	0.10	0.20	0.2	0.4
Distance (at 50 cm)	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
Alignment (tilt, off-axis)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Lamp Current	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Wavelength	0.32	0.32	0.32	0.09	0.05	0.006	0.03	0.03
Measuring system stability	0.5	0.5	0.5	0.5	0.2	0.2	0.2	0.2
Combined uncertainty / %	**5.9**	**3.4**	**2.0**	**1.2**	**1.1**	**1.7**	**1.9**	**2.7**
Expanded uncertainty (*k* = 2) / %	**11.8**	**6.8**	**4.0**	**2.4**	**2.2**	**3.4**	**3.8**	**5.4**

Table 5-4 Contributions to the standard uncertainty at interpolation wavelengths, in percent

Wavelength / nm	**310**	**330**	**350**	**370**	**390**	**450**	**550**	**555**	**650**	**750**
Combined uncertainty of the interpolation process	2.0	2.0	2.0	2.1	1.6	1.2	1.1	1.1	1.1	1.1
Interpolation error	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Combined uncertainty / %	**2.0**	**2.0**	**2.0**	**2.1**	**1.6**	**1.2**	**1.1**	**1.1**	**1.1**	**1.1**

5.6.1 Contributions related to the measurement of the standard lamp

Calibration of the standard lamp: The traceability is to PTB. This is clearly the dominant contribution.

Ageing: Though the standard lamp is detector-stabilised, a possible ageing effect is considered, with a similar range that could occur with a "conventional" FEL-lamp. This can be considered as a "conservative" uncertainty estimation.

5.6.2 Contributions related both to the measurement of the standard and the test lamp

These contributions are considered twice: in the measurements realised with the standard and with the test lamp.

Repeatability: Run to run repeatability without lamp realignment.

Stray light: The stray is measured individually for the standard and the test lamp and the resulting correction factors are applied to the measurement results. The estimated uncertainties of these correction factors are considered in the uncertainty budget. Due to the different positions of the standard and test lamp (distance of 70 cm and 50 cm), the uncertainties of the corrections are considered as (approximately) uncorrelated.

Distance error: For the standard lamp, the reference plane is defined by a lamp mounting plate. The measurement of the distance to the reference plane of the radiometer is realised by a calibrated rule with a standard uncertainty of 0.58 mm. For the test lamp, the distance from the reference plane of the radiometer to the centre of the lamp filament* is measured using a telescope mounted on a ruled rail and a standard uncertainty of 1.2 mm is considered (mainly due to the dimensions of the filament).

Alignment errors of the lamps (tilt, off-axis): The uncertainty was estimated experimentally in previous tests.

Wavelength error: The reproducibility of the selected wavelength of the monochromator in subsequent wavelength scans was taken into account.

5.6.3 Contributions related exclusively to the measurement of the test lamp

Lamp current†: The combined uncertainty due to the resolution and stability of the current source and due to the measurement (standard resistor, voltmeter) is considered. A sensitivity coefficient of 6 is considered to relate the uncertainty of the lamp current to the corresponding uncertainty in irradiance.

5.6.4 Stability of the measurement system

This contribution considers the possible drift of the complete measurement system during a complete measuring period (standard – test lamp 1 – test lamp 2 – standard), which was estimated experimentally. This contribution might be correlated with several of the contributions mentioned above (wavelength error, repeatability, lamp current); nevertheless, an analysis of the correlation would be difficult and is not justified due to the relatively small contribution of this term (compared to the uncertainty of the standard lamp).

5.6.5 Correlation between lamp measurements

Since the lamps were only measured once at CENAM, there is no "round correlation". The test lamp repeatability and the system stability are considered uncorrelated. All other effects are considered between the lamps.

5.7 Correction for current and distance

CENAM measured the lamps on only one occasion and for these measurements strictly followed the original protocol, both in terms of the wrong current and the wrong distance. Unfortunately this was not realised until after the completion of the comparison and the publication of pre-draft A. At this point it was too late to perform any additional experimentation. CENAM developed a model to correct the data both for current and for distance. The corrected results are presented here, but because of the uncertainty on the correction, CENAM's results will not be used for the calculation of the KCRV.

The correction for current was made by making measuring the colour temperature of the lamps at both operating currents and then calculating the expected change in spectral irradiance from the difference between Planck's law at the two obtained temperatures. The uncertainty in this correction was determined from the variability of the colour temperature measurements. This correction is shown in Figure 5-3, along with its uncertainty. The uncertainty is considered correlated between all the lamps.

The correction for distance was made using the inverse square law and assuming a distance of 23.2 mm from the filament to the correct measurement plane. This gives a correction factor of 0.9094.

* The distance measurement was made to the centre of the filament. A correction was applied afterwards, this is discussed in Section 5.7

† The lamps were measured with a current of 8.3 A. This uncertainty corresponds to that measurement. The results were corrected to match an 8.1 A operational current. This is discussed in Section 5.7.

No additional uncertainty has been included for this term, because the original uncertainty budget already includes a term for distance error (see section 5.6.2).

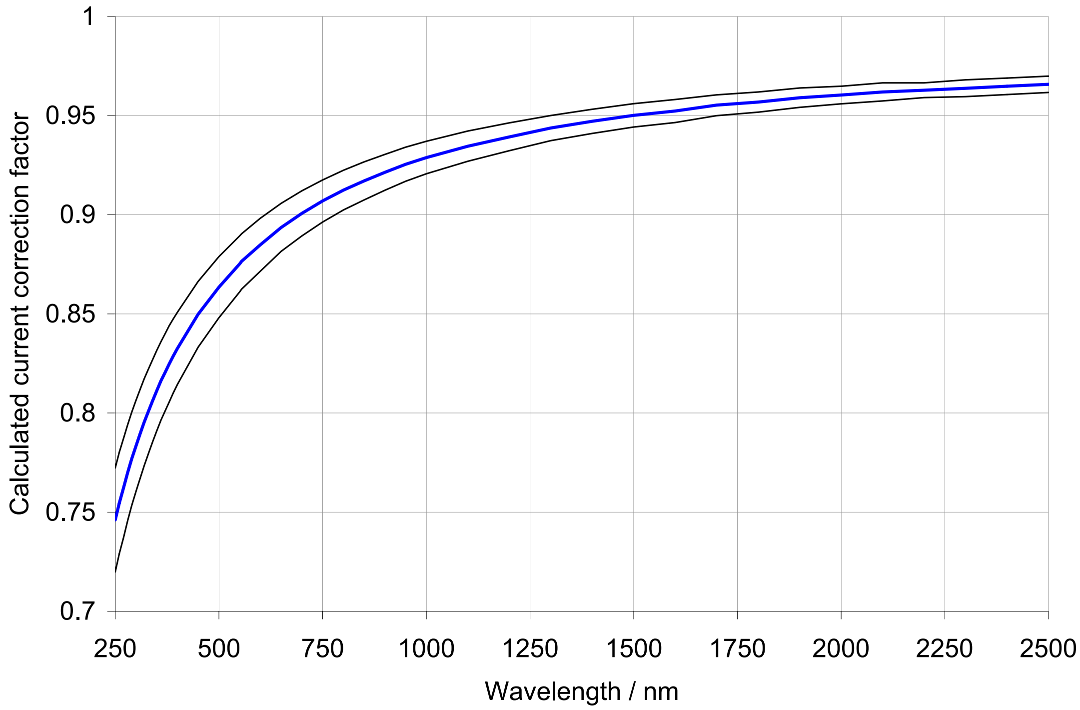

Figure 5-3 Current correction factor to correct the calibration at 8.3 A. Thin lines represent uncertainty

5.8 CENAM Results

CENAM measured three lamps on one occasion. Table 5-5 gives the results for FEL BN 9101 211, Table 5-6 gives the results for FEL BN 9101 255 and Table 5-5 gives the results for FEL BN 9101 259.

Table 5-5 CENAM Results for FEL BN 9101 211. Uncertainties have been split according to correlation between lamp and are at k = 1.

FEL 211	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.567E-04	0.78%	6.82%	0.00%	6.87%					
260	2.725E-04	0.71%	4.75%	0.00%	4.80%					
270	4.543E-04	0.69%	3.78%	0.00%	3.84%					
280	7.149E-04	0.69%	3.66%	0.00%	3.72%					
290	1.073E-03	0.69%	3.56%	0.00%	3.63%					
300	1.562E-03	0.69%	3.48%	0.00%	3.55%					
310	2.214E-03	0.69%	3.40%	0.00%	3.47%					
320	3.047E-03	0.69%	3.33%	0.00%	3.40%					
330	4.078E-03	0.69%	3.26%	0.00%	3.33%					
340	5.333E-03	0.69%	3.19%	0.00%	3.26%					
350	6.846E-03	0.69%	3.13%	0.00%	3.21%					
360	8.625E-03	0.69%	3.06%	0.00%	3.14%					
370	1.067E-02	0.69%	3.09%	0.00%	3.17%					
380	1.301E-02	0.69%	2.99%	0.00%	3.07%					
390	1.567E-02	0.69%	2.68%	0.00%	2.77%					
400	1.861E-02	0.56%	2.43%	0.00%	2.50%					
450	3.761E-02	0.56%	2.22%	0.00%	2.29%					
500	6.202E-02	0.22%	2.09%	0.00%	2.10%					
550	8.922E-02	0.22%	1.94%	0.00%	1.95%					
555	9.205E-02	0.22%	1.93%	0.00%	1.94%					
600	1.162E-01	0.22%	1.85%	0.00%	1.87%					
650	1.405E-01	0.22%	1.73%	0.00%	1.75%					
700	1.606E-01	0.22%	1.66%	0.00%	1.68%					
750	1.761E-01	0.22%	1.59%	0.00%	1.60%					
800	1.866E-01	0.24%	2.01%	0.00%	2.02%					
850	1.910E-01	0.24%	1.98%	0.00%	2.00%					
900	1.918E-01	0.24%	1.95%	0.00%	1.96%					
950	1.901E-01	0.24%	1.92%	0.00%	1.94%					
1000	1.855E-01	0.25%	2.08%	0.00%	2.10%					
1100	1.726E-01	0.25%	2.05%	0.00%	2.07%					
1200	1.573E-01	0.25%	2.03%	0.00%	2.04%					
1300	1.406E-01	0.25%	2.00%	0.00%	2.02%					
1400	1.252E-01	0.25%	1.99%	0.00%	2.01%					
1500	1.107E-01	0.25%	1.98%	0.00%	2.00%					
1600	9.794E-02	0.25%	1.98%	0.00%	1.99%					
1700	8.586E-02	0.25%	1.96%	0.00%	1.98%					
1800	7.515E-02	0.25%	1.96%	0.00%	1.97%					
1900	6.590E-02	0.25%	1.95%	0.00%	1.97%					
2000	5.758E-02	0.24%	2.73%	0.00%	2.74%					
2100	5.010E-02	0.24%	2.73%	0.00%	2.74%					
2200	4.369E-02	0.24%	2.72%	0.00%	2.73%					
2300	3.861E-02	0.24%	2.72%	0.00%	2.74%					
2400	3.395E-02	0.24%	2.72%	0.00%	2.73%					
2500	3.004E-02	0.24%	2.72%	0.00%	2.73%					

Table 5-6 CENAM Results for FEL BN 9101 255. Uncertainties have been split according to correlation between lamps and are at k = 1.

FEL 255	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.263E-04	0.78%	6.82%	0.00%	6.87%					
260	2.229E-04	0.71%	4.75%	0.00%	4.80%					
270	3.740E-04	0.69%	3.78%	0.00%	3.84%					
280	5.875E-04	0.69%	3.66%	0.00%	3.72%					
290	9.035E-04	0.69%	3.56%	0.00%	3.63%					
300	1.320E-03	0.69%	3.48%	0.00%	3.55%					
310	1.887E-03	0.69%	3.40%	0.00%	3.47%					
320	2.619E-03	0.69%	3.33%	0.00%	3.40%					
330	3.529E-03	0.69%	3.26%	0.00%	3.33%					
340	4.648E-03	0.69%	3.19%	0.00%	3.26%					
350	6.012E-03	0.69%	3.13%	0.00%	3.21%					
360	7.628E-03	0.69%	3.06%	0.00%	3.14%					
370	9.496E-03	0.69%	3.09%	0.00%	3.17%					
380	1.165E-02	0.69%	2.99%	0.00%	3.07%					
390	1.410E-02	0.69%	2.68%	0.00%	2.77%					
400	1.682E-02	0.56%	2.43%	0.00%	2.50%					
450	3.485E-02	0.56%	2.22%	0.00%	2.29%					
500	5.842E-02	0.22%	2.09%	0.00%	2.10%					
550	8.532E-02	0.22%	1.94%	0.00%	1.95%					
555	8.810E-02	0.22%	1.93%	0.00%	1.94%					
600	1.126E-01	0.22%	1.85%	0.00%	1.87%					
650	1.375E-01	0.22%	1.73%	0.00%	1.75%					
700	1.586E-01	0.22%	1.66%	0.00%	1.68%					
750	1.753E-01	0.22%	1.59%	0.00%	1.60%					
800	1.869E-01	0.24%	2.01%	0.00%	2.02%					
850	1.924E-01	0.24%	1.98%	0.00%	2.00%					
900	1.941E-01	0.24%	1.95%	0.00%	1.96%					
950	1.932E-01	0.24%	1.92%	0.00%	1.94%					
1000	1.897E-01	0.25%	2.08%	0.00%	2.10%					
1100	1.773E-01	0.25%	2.05%	0.00%	2.07%					
1200	1.624E-01	0.25%	2.03%	0.00%	2.04%					
1300	1.455E-01	0.25%	2.00%	0.00%	2.02%					
1400	1.303E-01	0.25%	1.99%	0.00%	2.01%					
1500	1.154E-01	0.25%	1.98%	0.00%	2.00%					
1600	1.022E-01	0.25%	1.98%	0.00%	1.99%					
1700	8.975E-02	0.25%	1.96%	0.00%	1.98%					
1800	7.865E-02	0.25%	1.96%	0.00%	1.97%					
1900	6.912E-02	0.25%	1.95%	0.00%	1.97%					
2000	6.036E-02	0.24%	2.73%	0.00%	2.74%					
2100	5.263E-02	0.24%	2.73%	0.00%	2.74%					
2200	4.594E-02	0.24%	2.72%	0.00%	2.73%					
2300	4.056E-02	0.24%	2.72%	0.00%	2.74%					
2400	3.572E-02	0.24%	2.72%	0.00%	2.73%					
2500	3.159E-02	0.24%	2.72%	0.00%	2.73%					

Table 5-7 CENAM Results for FEL BN 9101 259. Uncertainties have been split according to correlation between lamps and are at k = 1.

FEL 259	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.481E-04	0.78%	6.82%	0.00%	6.87%					
260	2.583E-04	0.71%	4.75%	0.00%	4.80%					
270	4.325E-04	0.69%	3.78%	0.00%	3.84%					
280	6.628E-04	0.69%	3.66%	0.00%	3.72%					
290	1.028E-03	0.69%	3.56%	0.00%	3.63%					
300	1.491E-03	0.69%	3.48%	0.00%	3.55%					
310	2.122E-03	0.69%	3.40%	0.00%	3.47%					
320	2.935E-03	0.69%	3.33%	0.00%	3.40%					
330	3.939E-03	0.69%	3.26%	0.00%	3.33%					
340	5.163E-03	0.69%	3.19%	0.00%	3.26%					
350	6.645E-03	0.69%	3.13%	0.00%	3.21%					
360	8.393E-03	0.69%	3.06%	0.00%	3.14%					
370	1.041E-02	0.69%	3.09%	0.00%	3.17%					
380	1.273E-02	0.69%	2.99%	0.00%	3.07%					
390	1.535E-02	0.69%	2.68%	0.00%	2.77%					
400	1.827E-02	0.56%	2.43%	0.00%	2.50%					
450	3.727E-02	0.56%	2.22%	0.00%	2.29%					
500	6.181E-02	0.22%	2.09%	0.00%	2.10%					
550	8.948E-02	0.22%	1.94%	0.00%	1.95%					
555	9.232E-02	0.22%	1.93%	0.00%	1.94%					
600	1.171E-01	0.22%	1.85%	0.00%	1.87%					
650	1.421E-01	0.22%	1.73%	0.00%	1.75%					
700	1.629E-01	0.22%	1.66%	0.00%	1.68%					
750	1.791E-01	0.22%	1.59%	0.00%	1.60%					
800	1.901E-01	0.24%	2.01%	0.00%	2.02%					
850	1.949E-01	0.24%	1.98%	0.00%	2.00%					
900	1.961E-01	0.24%	1.95%	0.00%	1.96%					
950	1.947E-01	0.24%	1.92%	0.00%	1.94%					
1000	1.904E-01	0.25%	2.08%	0.00%	2.10%					
1100	1.773E-01	0.25%	2.05%	0.00%	2.07%					
1200	1.616E-01	0.25%	2.03%	0.00%	2.04%					
1300	1.446E-01	0.25%	2.00%	0.00%	2.02%					
1400	1.289E-01	0.25%	1.99%	0.00%	2.01%					
1500	1.140E-01	0.25%	1.98%	0.00%	2.00%					
1600	1.008E-01	0.25%	1.98%	0.00%	1.99%					
1700	8.834E-02	0.25%	1.96%	0.00%	1.98%					
1800	7.729E-02	0.25%	1.96%	0.00%	1.97%					
1900	6.792E-02	0.25%	1.95%	0.00%	1.97%					
2000	5.930E-02	0.24%	2.73%	0.00%	2.74%					
2100	5.166E-02	0.24%	2.73%	0.00%	2.74%					
2200	4.504E-02	0.24%	2.72%	0.00%	2.73%					
2300	3.970E-02	0.24%	2.72%	0.00%	2.74%					
2400	3.494E-02	0.24%	2.72%	0.00%	2.73%					
2500	3.099E-02	0.24%	2.72%	0.00%	2.73%					

5.9 Pilot Results

NPL's measurements of lamp BN 9101 211 are given in Table 5-8, NPL's measurements of lamp BN 9101 255 are given in Table 5-9 and NPL's measurements of lamp BN 9101 259 are given in Table 5-10.

Table 5-8 NPL Results for FEL BN 9101 211. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 211	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.611E-04	1.14%	0.32%	2.06%	2.37%	1.621E-04	1.53%	0.00%	2.06%	2.56%
260	2.784E-04	0.86%	0.32%	2.05%	2.25%	2.806E-04	1.14%	0.00%	2.05%	2.35%
270	4.575E-04	0.65%	0.31%	2.05%	2.17%	4.615E-04	0.85%	0.00%	2.05%	2.22%
280	7.191E-04	0.50%	0.29%	1.56%	1.66%	7.259E-04	0.64%	0.00%	1.56%	1.69%
290	1.086E-03	0.40%	0.27%	1.08%	1.18%	1.097E-03	0.49%	0.00%	1.08%	1.19%
300	1.584E-03	0.33%	0.33%	0.45%	0.64%	1.601E-03	0.39%	0.15%	0.45%	0.61%
310	2.240E-03	0.28%	0.38%	0.43%	0.64%	2.265E-03	0.32%	0.20%	0.43%	0.58%
320	3.078E-03	0.25%	0.43%	0.37%	0.62%	3.114E-03	0.28%	0.25%	0.37%	0.53%
330	4.126E-03	0.22%	0.47%	0.36%	0.63%	4.176E-03	0.25%	0.28%	0.36%	0.52%
340	5.405E-03	0.17%	0.53%	0.35%	0.66%	5.473E-03	0.22%	0.33%	0.35%	0.53%
350	6.936E-03	0.21%	0.58%	0.34%	0.70%	7.026E-03	0.21%	0.36%	0.34%	0.54%
360	8.738E-03	0.20%	0.67%	0.33%	0.78%	8.854E-03	0.20%	0.43%	0.33%	0.58%
370	1.082E-02	0.19%	0.72%	0.32%	0.81%	1.097E-02	0.19%	0.46%	0.32%	0.59%
380	1.320E-02	0.18%	0.81%	0.31%	0.88%	1.338E-02	0.18%	0.52%	0.31%	0.64%
390	1.587E-02	0.17%	0.78%	0.31%	0.85%	1.610E-02	0.18%	0.50%	0.31%	0.61%
400	1.885E-02	0.17%	0.72%	0.30%	0.80%	1.912E-02	0.18%	0.46%	0.30%	0.58%
450	3.795E-02	0.15%	0.31%	0.27%	0.43%	3.852E-02	0.20%	0.10%	0.27%	0.35%
500	6.265E-02	0.14%	0.31%	0.24%	0.42%	6.358E-02	0.19%	0.00%	0.24%	0.30%
550	9.015E-02	0.13%	0.33%	0.22%	0.42%	9.141E-02	0.16%	0.00%	0.22%	0.27%
555	9.294E-02	0.13%	0.33%	0.22%	0.42%	9.422E-02	0.16%	0.00%	0.22%	0.27%
600	1.175E-01	0.13%	0.33%	0.20%	0.41%	1.190E-01	0.15%	0.00%	0.20%	0.25%
650	1.423E-01	0.06%	0.32%	0.18%	0.38%	1.440E-01	0.14%	0.00%	0.18%	0.23%
700	1.630E-01	0.14%	0.31%	0.17%	0.38%	1.648E-01	0.14%	0.00%	0.17%	0.22%
750	1.788E-01	0.12%	0.30%	0.16%	0.36%	1.807E-01	0.13%	0.00%	0.16%	0.20%
800	1.896E-01	0.11%	0.29%	0.15%	0.34%	1.916E-01	0.12%	0.00%	0.15%	0.19%
850	1.958E-01	0.10%	0.28%	0.14%	0.33%	1.979E-01	0.11%	0.00%	0.14%	0.18%
900	1.981E-01	0.09%	0.26%	0.13%	0.31%	2.001E-01	0.10%	0.00%	0.13%	0.17%
950	1.971E-01	0.09%	0.25%	0.13%	0.30%	1.991E-01	0.10%	0.00%	0.13%	0.16%
1000	1.936E-01	0.09%	0.25%	0.12%	0.29%	1.955E-01	0.10%	0.00%	0.12%	0.16%
1100	1.814E-01	0.09%	0.25%	0.11%	0.29%	1.831E-01	0.12%	0.00%	0.11%	0.16%
1200	1.653E-01	0.09%	0.28%	0.10%	0.32%	1.669E-01	0.16%	0.00%	0.10%	0.19%
1300	1.478E-01	0.10%	0.32%	0.09%	0.35%	1.493E-01	0.20%	0.00%	0.09%	0.22%
1400	1.307E-01	0.10%	0.33%	0.09%	0.36%	1.320E-01	0.23%	0.00%	0.09%	0.25%
1500	1.148E-01	0.10%	0.30%	0.08%	0.32%	1.159E-01	0.22%	0.00%	0.08%	0.24%
1600	1.004E-01	0.09%	0.26%	0.08%	0.28%	1.015E-01	0.22%	0.00%	0.08%	0.23%
1700	8.768E-02	0.12%	0.23%	0.08%	0.27%	8.862E-02	0.31%	0.00%	0.08%	0.31%
1800	7.649E-02	0.25%	0.21%	0.08%	0.34%	7.731E-02	0.44%	0.00%	0.08%	0.44%
1900	6.670E-02	0.42%	0.23%	0.07%	0.49%	6.737E-02	0.57%	0.00%	0.07%	0.58%
2000	5.818E-02	0.54%	0.29%	0.08%	0.62%	5.869E-02	0.68%	0.00%	0.08%	0.69%
2100	5.083E-02	0.61%	0.38%	0.07%	0.73%	5.124E-02	0.69%	0.00%	0.07%	0.69%
2200	4.455E-02	0.82%	0.45%	0.06%	0.94%	4.494E-02	0.73%	0.00%	0.06%	0.73%
2300	3.911E-02	0.96%	0.45%	0.06%	1.06%	3.959E-02	0.77%	0.00%	0.06%	0.77%
2400	3.418E-02	1.46%	0.76%	0.09%	1.65%	3.487E-02	1.13%	0.00%	0.09%	1.14%

2500	3.048E-02	1.94%	1.46%	0.08%	2.43%	3.088E-02	0.98%	0.00%	0.08%	0.99%

Table 5-9 NPL Results for FEL BN 9101 255. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 255	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.287E-04	1.37%	0.32%	2.06%	2.49%	1.277E-04	2.19%	0.00%	2.06%	3.01%
260	2.247E-04	1.02%	0.32%	2.05%	2.32%	2.234E-04	1.63%	0.00%	2.05%	2.62%
270	3.729E-04	0.77%	0.31%	2.05%	2.21%	3.713E-04	1.21%	0.00%	2.05%	2.38%
280	5.918E-04	0.58%	0.29%	1.56%	1.69%	5.898E-04	0.92%	0.00%	1.56%	1.81%
290	9.027E-04	0.45%	0.27%	1.08%	1.20%	8.999E-04	0.70%	0.00%	1.08%	1.29%
300	1.329E-03	0.37%	0.33%	0.45%	0.67%	1.325E-03	0.56%	0.15%	0.45%	0.73%
310	1.895E-03	0.31%	0.38%	0.43%	0.65%	1.890E-03	0.45%	0.20%	0.43%	0.66%
320	2.627E-03	0.27%	0.43%	0.37%	0.63%	2.619E-03	0.39%	0.25%	0.37%	0.59%
330	3.550E-03	0.24%	0.47%	0.36%	0.64%	3.538E-03	0.34%	0.28%	0.36%	0.57%
340	4.687E-03	0.19%	0.53%	0.35%	0.67%	4.670E-03	0.30%	0.33%	0.35%	0.57%
350	6.060E-03	0.23%	0.58%	0.34%	0.71%	6.036E-03	0.28%	0.36%	0.34%	0.57%
360	7.688E-03	0.22%	0.67%	0.33%	0.78%	7.656E-03	0.26%	0.43%	0.33%	0.60%
370	9.587E-03	0.21%	0.72%	0.32%	0.81%	9.544E-03	0.25%	0.46%	0.32%	0.62%
380	1.177E-02	0.20%	0.81%	0.31%	0.89%	1.171E-02	0.25%	0.52%	0.31%	0.66%
390	1.424E-02	0.19%	0.78%	0.31%	0.86%	1.417E-02	0.24%	0.50%	0.31%	0.64%
400	1.700E-02	0.18%	0.72%	0.30%	0.80%	1.691E-02	0.25%	0.46%	0.30%	0.60%
450	3.507E-02	0.16%	0.31%	0.27%	0.44%	3.487E-02	0.27%	0.10%	0.27%	0.39%
500	5.895E-02	0.15%	0.31%	0.24%	0.42%	5.862E-02	0.25%	0.00%	0.24%	0.34%
550	8.604E-02	0.14%	0.33%	0.22%	0.42%	8.556E-02	0.21%	0.00%	0.22%	0.30%
555	8.881E-02	0.14%	0.33%	0.22%	0.42%	8.832E-02	0.20%	0.00%	0.22%	0.30%
600	1.134E-01	0.13%	0.33%	0.20%	0.41%	1.128E-01	0.18%	0.00%	0.20%	0.27%
650	1.387E-01	0.08%	0.32%	0.18%	0.38%	1.379E-01	0.18%	0.00%	0.18%	0.26%
700	1.603E-01	0.15%	0.31%	0.17%	0.38%	1.593E-01	0.18%	0.00%	0.17%	0.25%
750	1.771E-01	0.13%	0.30%	0.16%	0.36%	1.760E-01	0.17%	0.00%	0.16%	0.23%
800	1.891E-01	0.12%	0.29%	0.15%	0.35%	1.879E-01	0.15%	0.00%	0.15%	0.21%
850	1.965E-01	0.10%	0.28%	0.14%	0.33%	1.951E-01	0.14%	0.00%	0.14%	0.20%
900	1.998E-01	0.10%	0.26%	0.13%	0.31%	1.984E-01	0.13%	0.00%	0.13%	0.19%
950	1.996E-01	0.09%	0.25%	0.13%	0.30%	1.983E-01	0.12%	0.00%	0.13%	0.18%
1000	1.967E-01	0.09%	0.25%	0.12%	0.29%	1.955E-01	0.12%	0.00%	0.12%	0.17%
1100	1.851E-01	0.10%	0.25%	0.11%	0.29%	1.843E-01	0.16%	0.00%	0.11%	0.20%
1200	1.693E-01	0.10%	0.28%	0.10%	0.32%	1.689E-01	0.22%	0.00%	0.10%	0.24%
1300	1.519E-01	0.11%	0.32%	0.09%	0.35%	1.518E-01	0.27%	0.00%	0.09%	0.29%
1400	1.348E-01	0.11%	0.33%	0.09%	0.36%	1.347E-01	0.31%	0.00%	0.09%	0.32%
1500	1.187E-01	0.11%	0.30%	0.08%	0.33%	1.185E-01	0.30%	0.00%	0.08%	0.31%
1600	1.040E-01	0.10%	0.26%	0.08%	0.29%	1.038E-01	0.30%	0.00%	0.08%	0.31%
1700	9.064E-02	0.14%	0.23%	0.08%	0.28%	9.072E-02	0.43%	0.00%	0.08%	0.44%
1800	7.886E-02	0.30%	0.21%	0.08%	0.37%	7.914E-02	0.60%	0.00%	0.08%	0.61%
1900	6.867E-02	0.50%	0.23%	0.07%	0.56%	6.898E-02	0.79%	0.00%	0.07%	0.80%
2000	6.003E-02	0.62%	0.29%	0.08%	0.69%	6.018E-02	0.95%	0.00%	0.08%	0.96%
2100	5.275E-02	0.64%	0.38%	0.07%	0.75%	5.267E-02	0.95%	0.00%	0.07%	0.95%
2200	4.651E-02	0.82%	0.45%	0.06%	0.94%	4.632E-02	0.97%	0.00%	0.06%	0.98%
2300	4.091E-02	0.97%	0.45%	0.06%	1.07%	4.086E-02	1.07%	0.00%	0.06%	1.07%
2400	3.564E-02	1.46%	0.76%	0.09%	1.64%	3.594E-02	1.62%	0.00%	0.09%	1.63%
2500	3.192E-02	1.93%	1.46%	0.08%	2.42%	3.169E-02	1.38%	0.00%	0.08%	1.39%

Table 5-10 NPL Results for FEL BN 9101 259. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 259	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.512E-04	0.74%	0.32%	2.06%	2.21%	1.502E-04	1.53%	0.00%	2.06%	2.56%
260	2.623E-04	0.56%	0.32%	2.05%	2.15%	2.611E-04	1.14%	0.00%	2.05%	2.35%
270	4.327E-04	0.43%	0.31%	2.05%	2.11%	4.312E-04	0.85%	0.00%	2.05%	2.22%
280	6.825E-04	0.34%	0.29%	1.56%	1.62%	6.808E-04	0.64%	0.00%	1.56%	1.69%
290	1.035E-03	0.28%	0.27%	1.08%	1.15%	1.033E-03	0.49%	0.00%	1.08%	1.19%
300	1.514E-03	0.24%	0.33%	0.45%	0.60%	1.512E-03	0.39%	0.15%	0.45%	0.61%
310	2.147E-03	0.21%	0.38%	0.43%	0.61%	2.146E-03	0.32%	0.20%	0.43%	0.58%
320	2.959E-03	0.19%	0.43%	0.37%	0.60%	2.960E-03	0.28%	0.25%	0.37%	0.53%
330	3.976E-03	0.17%	0.47%	0.36%	0.62%	3.980E-03	0.25%	0.28%	0.36%	0.52%
340	5.223E-03	0.11%	0.53%	0.35%	0.65%	5.230E-03	0.22%	0.33%	0.35%	0.53%
350	6.720E-03	0.18%	0.58%	0.34%	0.69%	6.732E-03	0.21%	0.36%	0.34%	0.54%
360	8.485E-03	0.17%	0.67%	0.33%	0.77%	8.505E-03	0.20%	0.43%	0.33%	0.58%
370	1.053E-02	0.16%	0.72%	0.32%	0.80%	1.056E-02	0.19%	0.46%	0.32%	0.59%
380	1.287E-02	0.15%	0.81%	0.31%	0.88%	1.292E-02	0.18%	0.52%	0.31%	0.64%
390	1.551E-02	0.15%	0.78%	0.31%	0.85%	1.557E-02	0.18%	0.50%	0.31%	0.61%
400	1.846E-02	0.14%	0.72%	0.30%	0.80%	1.853E-02	0.18%	0.46%	0.30%	0.58%
450	3.747E-02	0.13%	0.31%	0.27%	0.43%	3.766E-02	0.20%	0.10%	0.27%	0.35%
500	6.229E-02	0.13%	0.31%	0.24%	0.42%	6.260E-02	0.19%	0.00%	0.24%	0.30%
550	9.013E-02	0.12%	0.33%	0.22%	0.42%	9.052E-02	0.16%	0.00%	0.22%	0.27%
555	9.296E-02	0.12%	0.33%	0.22%	0.42%	9.335E-02	0.16%	0.00%	0.22%	0.27%
600	1.180E-01	0.12%	0.33%	0.20%	0.40%	1.184E-01	0.15%	0.00%	0.20%	0.25%
650	1.434E-01	0.04%	0.32%	0.18%	0.37%	1.438E-01	0.14%	0.00%	0.18%	0.23%
700	1.648E-01	0.13%	0.31%	0.17%	0.38%	1.651E-01	0.14%	0.00%	0.17%	0.22%
750	1.811E-01	0.12%	0.30%	0.16%	0.36%	1.814E-01	0.13%	0.00%	0.16%	0.20%
800	1.924E-01	0.11%	0.29%	0.15%	0.34%	1.927E-01	0.12%	0.00%	0.15%	0.19%
850	1.990E-01	0.10%	0.28%	0.14%	0.33%	1.993E-01	0.11%	0.00%	0.14%	0.18%
900	2.015E-01	0.09%	0.26%	0.13%	0.31%	2.019E-01	0.10%	0.00%	0.13%	0.17%
950	2.007E-01	0.09%	0.25%	0.13%	0.30%	2.010E-01	0.10%	0.00%	0.13%	0.16%
1000	1.972E-01	0.08%	0.25%	0.12%	0.29%	1.976E-01	0.10%	0.00%	0.12%	0.16%
1100	1.849E-01	0.08%	0.25%	0.11%	0.29%	1.853E-01	0.12%	0.00%	0.11%	0.16%
1200	1.687E-01	0.08%	0.28%	0.10%	0.31%	1.690E-01	0.16%	0.00%	0.10%	0.19%
1300	1.510E-01	0.08%	0.32%	0.09%	0.34%	1.513E-01	0.20%	0.00%	0.09%	0.22%
1400	1.336E-01	0.08%	0.33%	0.09%	0.35%	1.339E-01	0.23%	0.00%	0.09%	0.25%
1500	1.173E-01	0.08%	0.30%	0.08%	0.32%	1.176E-01	0.22%	0.00%	0.08%	0.24%
1600	1.026E-01	0.08%	0.26%	0.08%	0.28%	1.029E-01	0.22%	0.00%	0.08%	0.23%
1700	8.962E-02	0.11%	0.23%	0.08%	0.26%	8.986E-02	0.31%	0.00%	0.08%	0.31%
1800	7.825E-02	0.19%	0.21%	0.08%	0.30%	7.847E-02	0.44%	0.00%	0.08%	0.44%
1900	6.839E-02	0.31%	0.23%	0.07%	0.39%	6.850E-02	0.57%	0.00%	0.07%	0.58%
2000	5.983E-02	0.38%	0.29%	0.08%	0.49%	5.983E-02	0.68%	0.00%	0.08%	0.69%
2100	5.243E-02	0.40%	0.38%	0.07%	0.56%	5.235E-02	0.69%	0.00%	0.07%	0.69%
2200	4.608E-02	0.52%	0.45%	0.06%	0.69%	4.592E-02	0.73%	0.00%	0.06%	0.73%
2300	4.059E-02	0.60%	0.45%	0.06%	0.76%	4.033E-02	0.77%	0.00%	0.06%	0.77%
2400	3.563E-02	0.91%	0.76%	0.09%	1.19%	3.535E-02	1.13%	0.00%	0.09%	1.14%
2500	3.170E-02	1.22%	1.46%	0.08%	1.91%	3.138E-02	0.98%	0.00%	0.08%	0.99%

5.10 Lamp Behaviour

The following lamps were supplied to CENAM by NPL:

FEL BN 9101 211 FEL BN 9101 259 FEL BN 9101 255

Measurements were made in the sequence: NPL – CENAM – NPL.

CENAM measured all intercomparison wavelengths. CENAM did not make a second measurement of the lamps.

5.10.1 CENAM lamps

5.10.2 Lamp electrical stability

The lamp was operated at 8.100 A at NPL and 8.3 A at CENAM, the lamp voltage measured was:

Lamp	Potential first NPL measurement	Potential first CENAM measurement	Potential second NPL measurement
FEL BN 9101 211	105.5 V	110.1-110.9 V	105.5 V
FEL BN 9101 259	109.1 V	114.1-114.2 V	109.3 V
FEL BN 9101 255	104.1 V	108.8-109.3 V	104.2 V

5.10.3 Lamp history

Table 5-11 Lamp history for FEL BN 9101 211

Date period	Activity	Burn hours:minutes
March – April 2001	1st round measurements at NPL	6:50
May 2001	Hand-carried to CENAM	
November 2001	1st round measurements at CENAM	8:34
January 2002	Hand-carried to NPL	
February – April 2002	2nd round measurements at NPL	9:54
April 2002	Hand-carried to CENAM	

Table 5-12 Lamp history for FEL BN 9101 259

Date period	Activity	Burn hours:minutes
March – April 2001	1st round measurements at NPL	8:02
May 2001	Hand-carried to CENAM	
November 2001	1st round measurements at CENAM	9:23
January 2002	Hand-carried to NPL	
February – April 2002	2nd round measurements at NPL	7:11
April 2002	Hand-carried to CENAM	

Table 5-13 Lamp history for FEL BN 9101 255

Date period	Activity	Burn hours:minutes
March – April 2001	1st round measurements at NPL	10:27
May 2001	Hand-carried to CENAM	
November 2001	1st round measurements at CENAM	8:15
January 2002	Hand-carried to NPL	
February – April 2002	2nd round measurements at NPL	8:31
April 2002	Hand-carried to CENAM	

5.10.4 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the CENAM lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

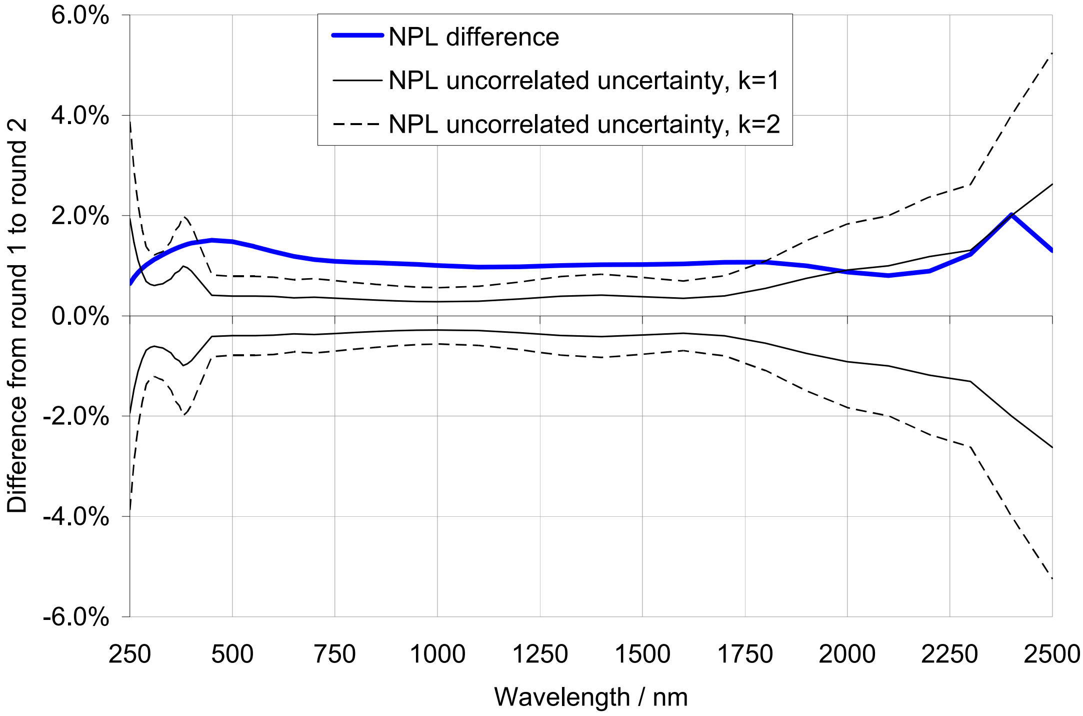

Figure 5-4 Difference between first and second round measurements of FEL BN 9101 211 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

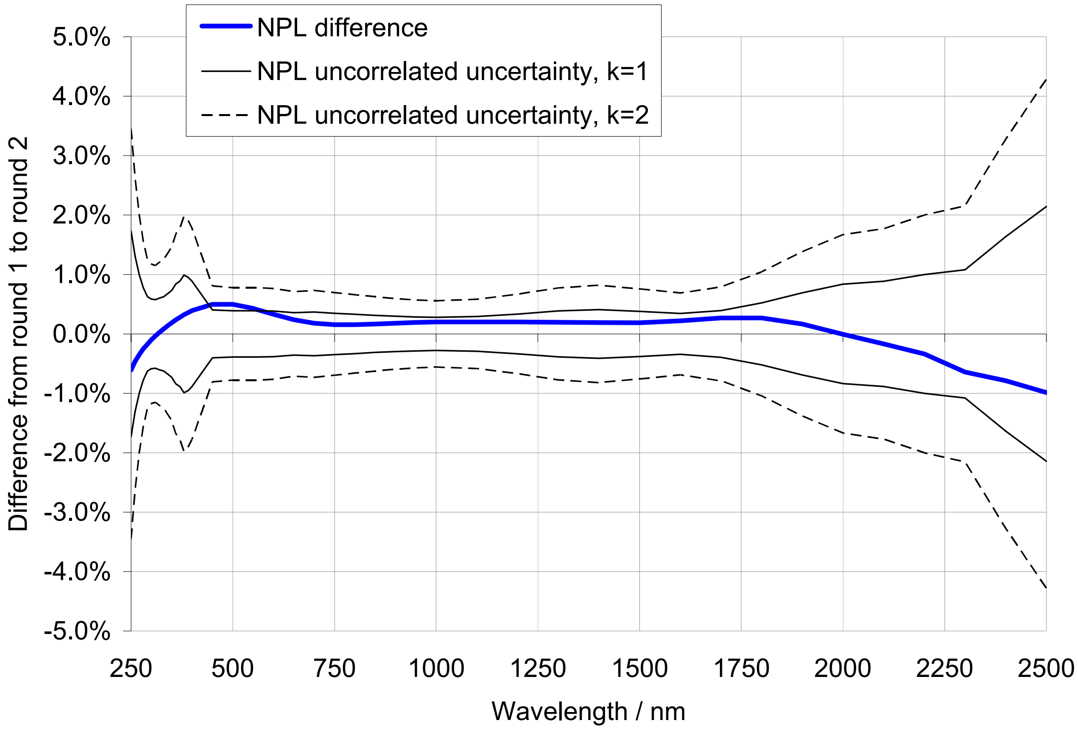

Figure 5-5 Difference between first and second round measurements of FEL BN 9101 259 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

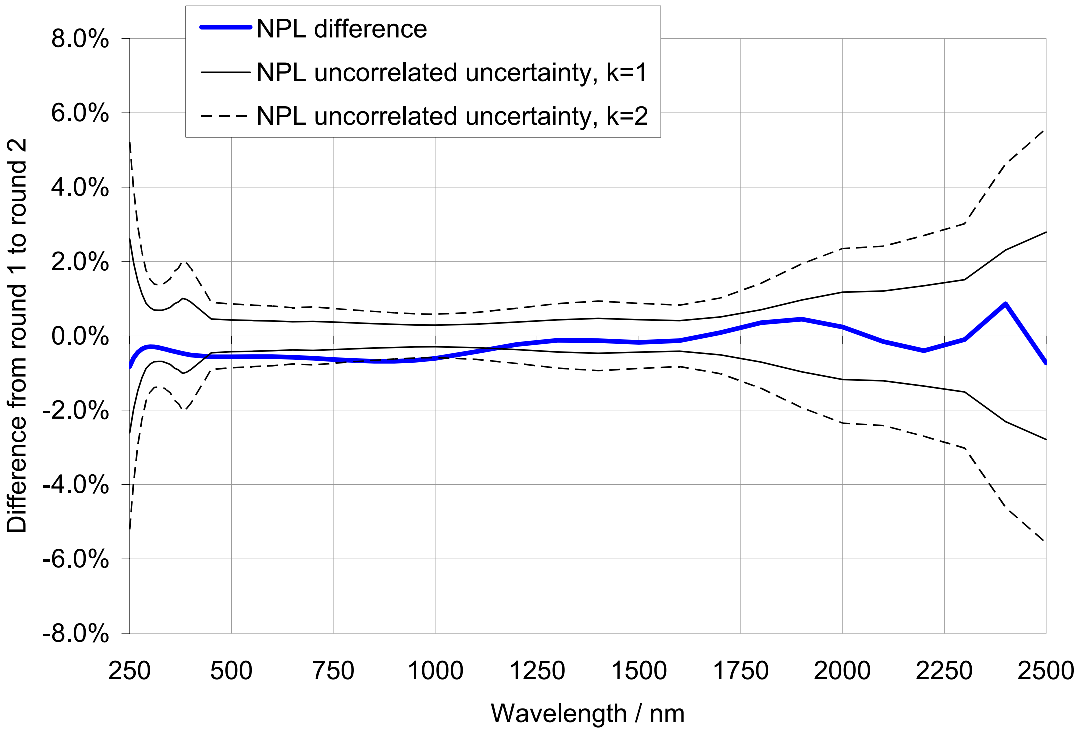

Figure 5-6 Difference between first and second round measurements of FEL BN 9101 255 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

5.10.5 Lamp stability from CENAM measurements

As there is only one set of CENAM measurements, there is no lamp stability data from CENAM.

5.10.6 Bilateral comparison between CENAM and the comparison scale

This graph shows the difference between the CENAM and NPL measurements of the CENAM lamps. A version of this graph normalised to show the relative difference between the lamps, but not the absolute difference between the measurements was used to assist in choosing which lamp measurements to use.

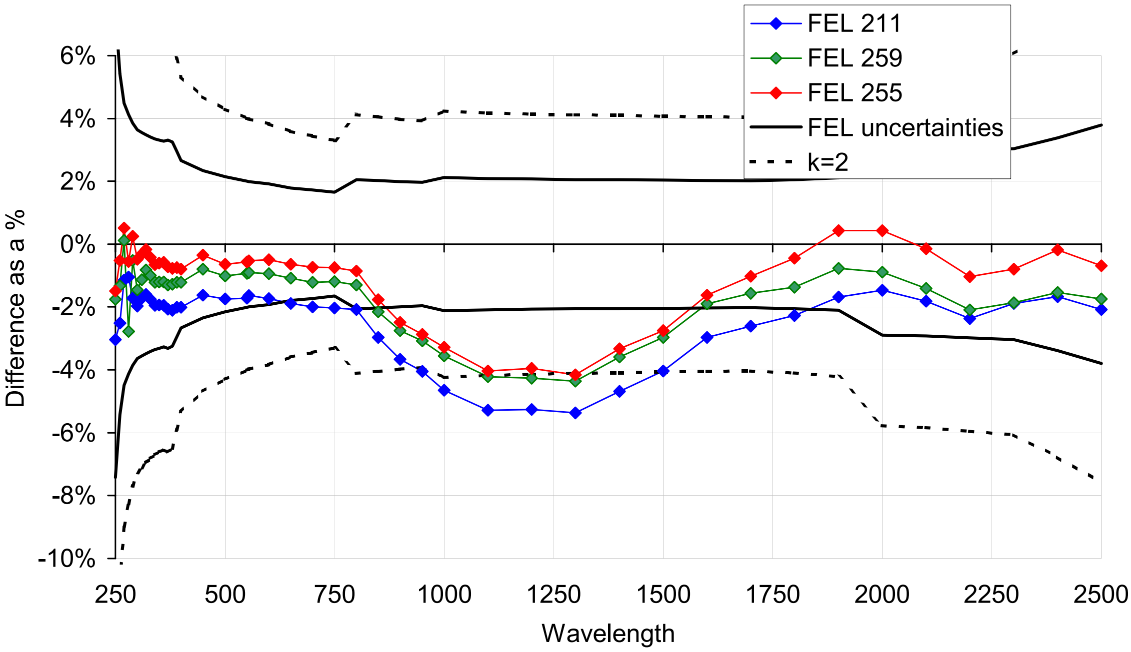

Figure 5-7 Difference between bilateral comparisons of the CENAM lamps

5.11 Decisions on which results to use

At the pre-draft A stage, the pilot submitted to CENAM the information in the graphs Figure 5-4 to Figure 5-7. It was decided all measurements would be used for both FEL BN 9101 259 and for FEL BN 9101 255, but that FEL BN 9101 211 would not be used for the comparison, because this lamp changed between the two NPL measurements by more than the NPL uncertainty.

6 Measurements at CSIRO*

6.1 Primary Scale Realisation

The spectral irradiance units are based on two inputs:

- the NML2003 scale of relative spectral irradiance [1], and
- the NML1997 unit of illuminance [2].

The measured values of relative spectral irradiance normalised at 550 nm are used together with illuminance measurements from the lamps at the required distance to normalise the relative values to SI spectral irradiance units. The independently established NML1997 illuminance unit is used for this.

6.1.1 Basis of the NML2003 relative spectral irradiance scale

Filter radiometers with spectral bandwidths of about 50 nm and peak wavelengths near 340, 450, 550, 700, 940, 1300 and 1540 nm have been built and fitted four at a time into an integrating sphere and calibrated in the sphere for spectral responsivity using the NML1998 scale of spectral responsivity [3]. Measurements of signal ratios from pairs of radiometers were made for flux entering the sphere from each of several types of tungsten halogen reference lamps operated at between 3000 and 3200 K distribution temperature.

The lamps were then compared spectrally with a high-temperature graphite blackbody [4,5] operated at a temperature between 2850 and 2950 K. A mirror optical system was constructed to allow comparison of irradiance from the whole lamp and from a part of the bottom of the cavity wall with a diameter of about 2 mm in such a way that the spectral reflection function of the system was common to both sources and therefore did not have to be measured. The mirror system is shown in Figure 6-1.

For each lamp, the measured relative spectral power ratios $\rho(\lambda)$ are used with the signal ratios S_1/S_2 from each pair of filter radiometers to find the blackbody temperature T that solves the following Equation (6-2):

$$E(\lambda) = L(\lambda, T)\rho(\lambda) \tag{6-1}$$

$$\begin{aligned} S_1 \big/ S_2 &= \int E(\lambda) R_1(\lambda)\, d\lambda \Big/ \int E(\lambda) R_2(\lambda)\, d\lambda \\ &= \int L(\lambda, T)\rho(\lambda) R_1(\lambda)\, d\lambda \Big/ \int L(\lambda, T)\rho(\lambda) R_2(\lambda)\, d\lambda \end{aligned} \tag{6-2}$$

where $E(\lambda)$ is the lamp relative spectral irradiance, $L(\lambda,T)$ is the blackbody relative spectral radiance at temperature T, and $R_1(\lambda)$ and $R_2(\lambda)$ are the radiometer spectral responses. All distributions are normalised to unity at the same wavelength. The lamp spectral power distribution is then given by Equation (6-1).

Each comparison of the lamp and blackbody spanned wavelength ranges sufficient to determine blackbody temperatures based on pairs of filter radiometers with peak response wavelengths between 340 and 700 nm or between 700 and 1540 nm.

The uncertainty in the response of each filter radiometer, spectrally integrated with a lamp spectral power distribution approximating that of the reference lamps, was calculated using the NML1998 spectral response scale and transfer uncertainties. Standard uncertainties are:

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* The CSIRO National Measurement Laboratory (CSIRO in this comparison) was recently combined with the Australian Government Analytical Laboratories and the National Standards Commission and placed within the Australian Government Department of Industry, Tourism and Resources to form the National Measurement Institute of Australia, and will in future be known internationally as NMIA

- for peak wavelengths: 700, 940 nm – 0.10%, for 550 nm – 0.15%,
- for 340 nm – 0.34%, 450 nm – 0.18%, for 1300 nm – 0.39%, for 1540 nm – 0.17%.

Combining these uncertainties for pairs of radiometers for ratio measurements and using their effective wavelengths, the uncertainty in the measurement of a temperature of a blackbody near 2900 K can be obtained from combined uncertainties. For example, for the pair with peak wavelengths of 450 nm and 700 nm, the combined uncertainty is 0.26%, which results in a temperature uncertainty of about 2.1 K.

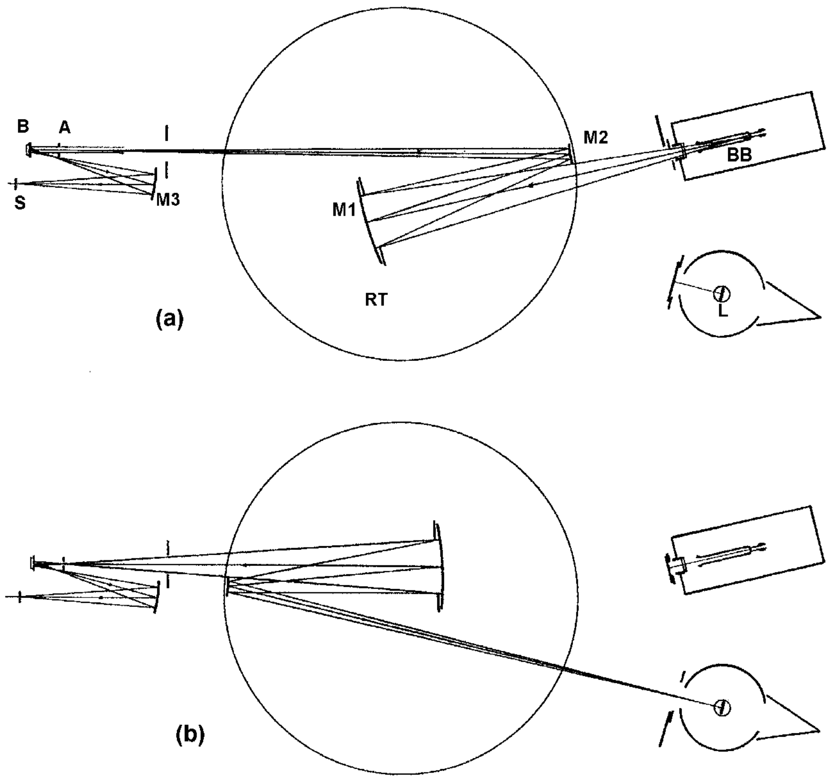

Figure 6-1 Concentric mirror system M1 and M2 in position (a) images the blackbody with a linear magnification of × 8, or in conjugate position (b) images the lamp with a magnification of × 1/8 onto an aperture A in front of a plane Halon target plate B. A small area of the plate is imaged onto the monochromator entrance slit by mirror M3.

Temperature results obtained using the radiometer with peak response near 340 nm were significantly different from those obtained with responses at longer wavelengths and were rejected on the basis of probable under-estimation of filter long-wavelength out-of band transmission. Temperatures and their uncertainties obtained from the ratios 450/700 nm and 700/940 nm were use to obtain weighted average temperatures and their uncertainties for lamp-blackbody comparisons in the range 250 – 1300 nm. The radiometer with peak response near 940 nm could not be paired with any other of the shorter-wavelength radiometers.

For the IR comparisons, "ratio temperatures" were measured using the ratios 700/1300 nm and 940/1540 nm. These were also combined to obtaine weighted mean temperatures and their uncertainties. For the temperatures measured for the 250 – 1300 nm comparisons the assessed standard uncertainty in the blackbody temperatures was 2.0 K. For the comparisons covering the range 650 – 2500 nm, the temperature uncertainty from the filter radiometers was 3.5 K.

6.2 Description of measurement facility

For the measurements of illuminance, the transfer lamps were set up at the required distance of 500.0 mm from the photometer on an optical bench with suitable black curtains, screens and shutter and with a 200 mm-diameter gloss black-painted light-trap behind the lamp to eliminate background reflections.

The system used for the relative spectral irradiance measurements consisted of a **McPherson model 285 grating monochromator fitted with a model 608M1 quartz prism pre-disperser**. The monochromator was used with **either single or double gratings** for different wavelength ranges, as indicated in Table 6-1. For infra-red wavelength measurements an additional RG780 filter or a silicon filter was used as an order-sorter and to reduce the level of stray-light.

Table 6-1 Monochromators and detectors used for comparing spectral irradiance lamps

Wavelength range /nm	Mono-chromator	Blaze wavelength /nm	Spectral bandwidth /nm	Detector	Amplifier, gain
240 – 900	Double	300	2	Hamamatsu R562 PMT #SA4965	AD515KH op amp 1 MΩ
400 – 750	Double	500	2	Hamamatsu Si S1337-1010BQ	AD515KH op amp 1 GΩ
800 – 1700	Single (round 1)	1000	8	Telcom Devices InGaAs # TD1	AD515KH op amp 100 MΩ
	Double (round 2)	1000	4		
1700 - 2500	Single	1850	8	NEP 10×5 mm 2 stage cooled PbS	NEP DMC7 + Ithaco 3 Dynatrac lockin PSD

The configuration of the lamps and input optics to the monochromator is shown in Figure 6-2.

The reference and comparison lamps were each operated in a cylinder of diameter 310 mm, height 420 mm, open at the top and with a 50 mm gap between the bottom of the cylinder and the top of the table to allow natural circulation of room air. The cylinder is painted matt black and has a 90 mm-diameter viewing aperture opposite the lamp and a 200 mm-diameter aperture behind the lamp that is covered by a conical gloss-black light-trap. The measurement system could not see any of the cylinder wall.

The two lamps, housed in this way, irradiate in turn at normal incidence a plane 50×50 mm $BaSO_4$ plate (Karl Lüers). Lamp – plate distances are from 500 to 600 mm (for measurement of relative spectral irradiances only). The plate is rotated through 90° to face either lamp and flux reflected by the plate on an axis approx. 45° from the normal is collected by a small concave spherical mirror M1 and directed over the plate to a second spherical mirror M2 which images the first mirror onto the monochromator entrance slit via a plane mirror, M3. The effective target area of the plate viewed by the monochromator is oval, approx 40×30 mm. The system is symmetric about the vertical plane containing the monochromator entrance beam axis. Lamp positions are swapped to check and correct for any small level of spectral bias between the two positions.

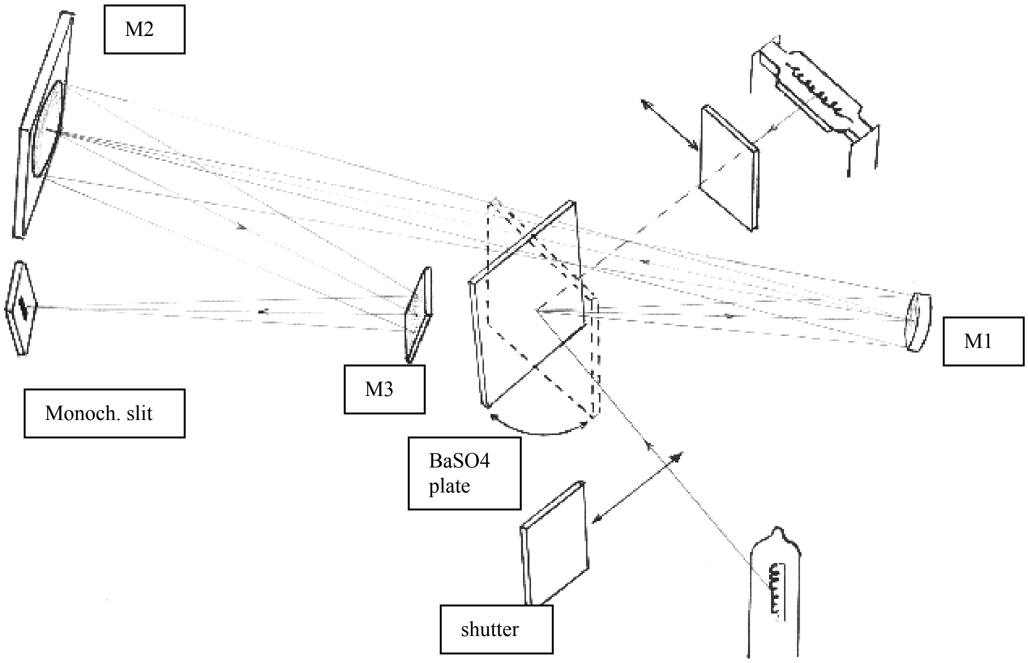

Figure 6-2 Spectral irradiance target optics used at CSIRO

6.2.1.1 Detectors and amplifiers

Four types of detectors and circuits were used for the lamp comparisons. Details of these are given in Table 6-1.

6.3 Laboratory conditions

The measurements reported here have been performed in laboratories having ambient temperatures of 21.0 °C ± 0.5 °C and relative humidity 50 % ± 10 %.

6.4 Laboratory standards

All lamps used are of the tungsten halogen type — the standard lamps used to provide the NML2003 scale of relative spectral irradiance were:

- one Ushio Electric 100 V 500 W (as used in the 1975 CCPR key comparison),
- one GEC 14 A 750 W (transfer lamp in 1990 intercomparison)
- one GE FEL 120 V 1000 W (transfer lamp in 1990)
- three Sylvania FEL 120 V 1000 W.

These lamps are operated at distribution temperatures between 3100 and 3200 K. They therefore have similar distribution temperatures and power levels to those of the comparison lamps. Therefore, the low levels of uncertainty assessed for stray-light and wavelength effects result from the common influences these have on both reference and test lamps.

The illuminance standards used to provide the NML1997 illuminance unit were

- Philips type 6369 24 V 250 W

which were operated at a distribution temperature of 2856 K.

6.5 Measurement procedure

6.5.1 Scan method

Spectral ranges were chosen (as given in Table 6-1) for each detector, and each range was broken up into blocks which were scanned in turn for each lamp. A reference wavelength was adopted at which signals were also recorded for each lamp at the beginning and end of each block scan. The ratios of the two lamp spectral power distributions normalised at the reference wavelength were thereby obtained.

The reference wavelength for measurements in the range 250 – 1000 nm was 555 nm. For the infrared scans it was 1000 nm or 1500 nm. These wavelengths were chosen to tie in the ratios of the lamp relative spectral power distributions to normalise all values to the wavelength 555 nm. The ratios were then multiplied by the reference lamp relative spectral irradiances to obtain those of the test lamp. Finally, these values were multiplied by the spectral irradiance at the normalising wavelength, 555 nm, obtained from the illuminance measurement.

6.5.2 Correlations and degrees of freedom

The uncertainties that have been assessed for each lamp for each round of the tests have been divided into their categories of correlation and are given in the Tables 1-6 to 1-8.

6.5.2.1 Round 1

The three sets of spectral irradiances submitted in **round 1** for each of the three lamps all share **common relative spectral irradiances**, measured with only one set-up, but their absolute values have scaling factors obtained from measurements of illuminance made using different set-ups on three different occasions. Therefore, the relative spectral irradiances will be found to be 100 % correlated, whereas the absolute components will only be partially correlated by the common type B component of the NML illuminance scale uncertainty.

The “uncorrelated” uncertainties given in Tables 6-6 to 6-8 are for round 1 uncorrelated between the three lamps. However, only a component of 0.11 % of these uncertainties is uncorrelated between the three measurements reported for each lamp. The rest of each of these uncertainties is correlated.

Each of these measurements involves taking mean values of large numbers of readings, resulting in large degrees of freedom. The generation of the three sets of spectral irradiances is outlined in Figure 6-3.

6.5.2.2 Round 2

Three sets of relative spectral irradiances of each lamp were measured in **round 2** using three separate reference standards of relative spectral irradiance. Their spectral irradiances have been measured by comparison with blackbody radiation and their calibrations together form the NML2003 scale of relative spectral irradiance. Their calibration values are almost wholly uncorrelated, so the three transfers to these key comparison transfer lamps are themselves virtually uncorrelated. The “uncorrelated” components given in Tables 6-6 to 6-8 thus refer to both the three sets of measurements for each lamp and between the three lamps themselves.

For round 2 only, one set of spectral comparisons was made between each reference and transfer lamp. By examining the results from the three reference lamps across about eight lamps that were calibrated it was possible to compare the differences at each wavelength. The spread of these was also used as a measure of the transfer uncertainties and these were consistent with those calculated on the basis of the standard deviations of the 50 readings taken at each measurement point in the comparisons.

For the illuminance measurements a set of four lamp standards of illuminance was used to calibrate a photometer that was then used to measure the transfer lamp illuminances. This whole procedure was done on three occasions.

After correcting the measured illuminances for differences between the spectra of the illuminance standards (at Ill A) and the spectral irradiance lamps (at DT about 3000 K) and the mismatch of the photometer spectral response with V(λ), one illuminance value was combined with one of the measured sets of relative spectral irradiances to obtain three independent sets of absolute spectral irradiances. The degree of correlation of these is assessed as <10 %.

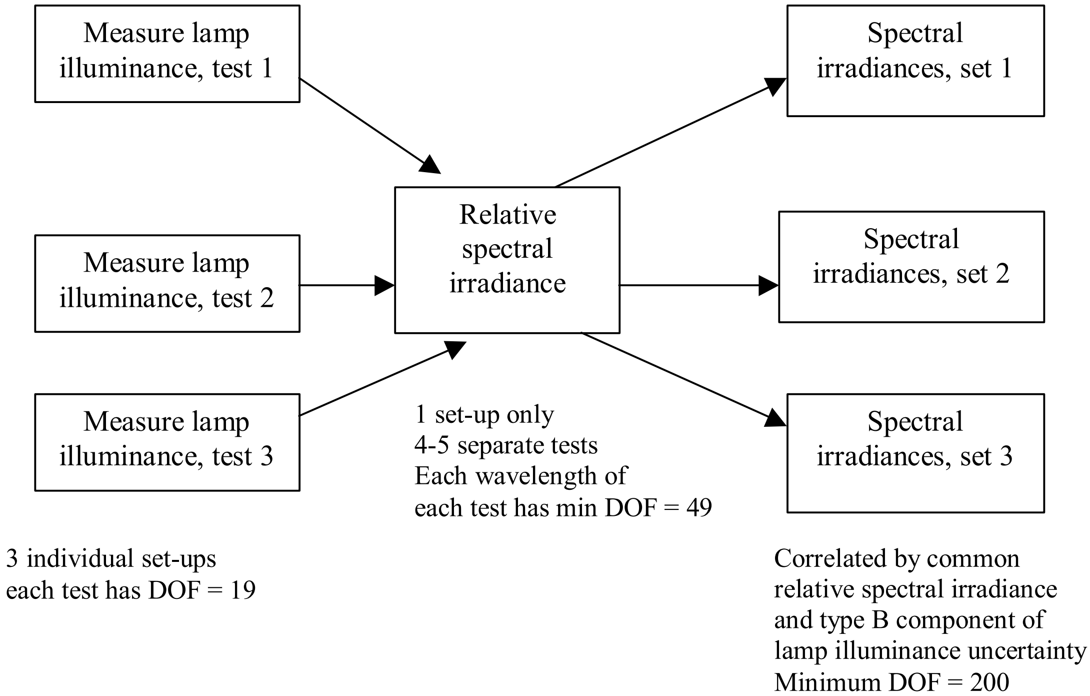

Figure 6-3 Relationship of inputs to 3 sets of results of spectral irradiances submitted for round 1 of K1-a key comparison by CSIRO

6.6 Uncertainty determination

Uncertainty budgets for each round are given in Table 6-2 and Table 6-3. They are slightly different for the two rounds due to the use of different reference lamps and slightly different equipment configuration. The uncertainties for round 2 are combined into type A and type B components in a summary Table 6-5.

Some details of the uncertainties assessed for the blackbody temperatures have been discussed in section 6.1.1 above. When the spectra of lamps calibrated directly from the blackbody were compared (via common comparisons with many other test lamps), differences that appeared to be explained by relative discrepancies in their temperatures amounting to 1 – 3.5 K were found. These were larger than expected from random transfer uncertainties. The lamps were deliberately selected to represent different filament and envelope geometries in order to reveal systematic errors in the lamp and blackbody imaging system. It has been assumed that this source of systematic error may be present and Type B uncertainties have been included for it (component 13, Table 6-2 and Table 6-3).

In the comparison of the lamps with the blackbody, Type A transfer uncertainties were obtained that have been converted to Type B uncertainties in the scale as represented by these lamps (component 14, Table 6-2 and Table 6-3).

It has been stated before that the results from CSIRO are obtained by normalising measured relative spectral irradiances by measuring the lamp illuminance and then calculating the absolute spectral irradiance at the wavelength (555 nm) where the relative distributions are normalised. The uncertainties at 555 nm should be due only to uncertainties associated with the illuminance measurements.

In combining the three sets for each lamp for the two rounds, it has been noticed that the standard deviations of the values at 555 nm considerably exceed the sums of the random uncertainty components previously estimated for the illuminance measurement. The illuminances vary quite randomly over the 6 sets of measurements, with standard deviations between 0.05 % and 0.16 % and a mean of 0.09 %. These are not explainable by lamp current uncertainties or positioning uncertainties when a distance uncertainty of 0.05 mm in 500 mm is used between the reference plane on the lamp base and the photometer plane.

We now consider that it is possible that the large filaments in this type of lamp may well move about randomly with heating, cooling and handling, with effective planes shifting by as much as 0.2 mm. A shift by this amount, treated as a standard deviation, results in a variation in spectral irradiances with a standard deviation of 0.08 %.

We have, so far, no solid evidence for such shifts but in order to explain our observed changes in illuminance we are postulating possible changes in filament planes of 0.2 mm (SD) with accompanying uncertainties in irradiances of 0.08 %. This Type A uncertainty has been added to the uncertainty budgets previously submitted.

The uncertainties and combined uncertainty in the lamp illuminance measurements that were used to obtain the normalisation factor for the relative spectral irradiances to obtain the absolute spectral irradiances are given in Table 6-4.

Table 6-2 Round 1 uncertainties. All values are standard uncertainties in %

Key
1 - NML1997 illuminance scale
2 - Reference lamp transfers to photometer
3 - agreement between illuminance standards
4 - Transfers photometer to test lamps
5 - lamp current for illuminance tests
6 - distance
7 - photometer non-linearity
8 - angular setting and illuminance field non-uniformity
9 - illuminance stray light
10 - photometer colour correction and spectral integration
11 - Uncertainty in blackbody temperature
12 - uncertainty in blackbody window transmittances
13 - Blackbody to lamp transfer optical effects
14 - Transfers blackbody to reference lamps
15 - Transfers reference to CCPR transfer lamps
16 - lamp current for spectral tests
17 - wavelength error and reproducibility

	Illuminance measurements to normalise relative spectral irradiances										Relative spectral irradiance measurements							Total uncertainties		
Type:	B	A	B	A	B	A	B	B	B	B	B	B	B	B	A	B	B	Type A	Type B	Type A + B
Key:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	A	B	A + B
250	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	1.3	0.04	0.754	0.8	0.508	0.12	0.01	0.515	1.79	1.863
260	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.692	0.04	0.701	0.5	0.215	0.111	0.01	0.229	1.235	1.256
270	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.643	0.04	0.652	0.45	0.133	0.103	0.01	0.156	1.16	1.17
280	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.598	0.04	0.607	0.4	0.109	0.096	0.01	0.135	1.09	1.098
290	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.557	0.04	0.564	0.3	0.09	0.09	0.01	0.121	1.009	1.017
300	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.518	0.04	0.525	0.2	0.078	0.083	0.01	0.112	0.94	0.946
310	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.481	0.04	0.488	0.15	0.065	0.077	0.01	0.103	0.889	0.895
320	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.447	0.04	0.453	0.15	0.054	0.072	0.01	0.097	0.852	0.857
330	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.415	0.04	0.421	0.15	0.05	0.067	0.01	0.095	0.818	0.823
340	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.385	0.04	0.39	0.15	0.044	0.062	0.01	0.092	0.787	0.792
350	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.356	0.04	0.361	0.15	0.04	0.057	0.01	0.09	0.759	0.764
360	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.33	0.04	0.334	0.15	0.036	0.053	0.01	0.088	0.733	0.739
370	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.304	0.04	0.308	0.15	0.036	0.049	0.01	0.088	0.711	0.716
380	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.28	0.04	0.284	0.15	0.03	0.045	0.01	0.086	0.69	0.695
390	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.257	0.04	0.261	0.15	0.03	0.041	0.01	0.086	0.671	0.677
400	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.236	0.04	0.239	0.1	0.027	0.038	0.01	0.085	0.645	0.651
450	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.142	0.04	0.144	0.1	0.027	0.023	0.01	0.085	0.586	0.592
500	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.067	0.04	0.068	0.1	0.027	0.011	0.01	0.085	0.558	0.565
550	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.006	0.04	0.006	0.1	0.027	0.001	0.01	0.085	0.55	0.556
555	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0	0	0	0	0	0	0	0.08	0.539	0.545
600	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.045	0.04	0.046	0.1	0.027	0.007	0.01	0.085	0.554	0.56

Key
1 - NML1997 illuminance scale
2 - Reference lamp transfers to photometer
3 - agreement between illuminance standards
4 - Transfers photometer to test lamps
5 - lamp current for illuminance tests
6 - distance
7 - photometer non-linearity
8 - angular setting and illuminance field non-uniformity
9 - illuminance stray light
10 - photometer colour correction and spectral integration
11 - Uncertainty in blackbody temperature
12 - uncertainty in blackbody window transmittances
13 - Blackbody to lamp transfer optical effects
14 - Transfers blackbody to reference lamps
15 - Transfers reference to CCPR transfer lamps
16 - lamp current for spectral tests
17 - wavelength error and reproducibility

	Illuminance measurements to normalise relative spectral irradiances										Relative spectral irradiance measurements							Total uncertainties		
Type:	B	A	B	A	B	A	B	B	B	B	B	B	B	B	A	B	B	Type A	Type B	Type A + B
Key:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17			
650	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.089	0.04	0.09	0.1	0.027	0.014	0.01	0.085	0.564	0.571
700	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.125	0.04	0.178	0.1	0.04	0.02	0.01	0.09	0.592	0.599
750	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.184	0.04	0.266	0.1	0.04	0.025	0.01	0.09	0.639	0.645
800	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.235	0.04	0.252	0.1	0.05	0.03	0.01	0.095	0.65	0.656
850	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.28	0.15	0.212	0.1	0.05	0.034	0.01	0.095	0.669	0.676
900	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.32	0.15	0.234	0.1	0.05	0.038	0.01	0.095	0.694	0.701
950	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.355	0.15	0.254	0.1	0.05	0.041	0.01	0.095	0.718	0.724
1000	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.387	0.15	0.271	0.1	0.05	0.044	0.01	0.095	0.741	0.747
1100	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.441	0.15	0.301	0.3	0.078	0.049	0.01	0.112	0.831	0.839
1200	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.486	0.15	0.338	0.3	0.078	0.053	0.01	0.112	0.87	0.877
1300	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.523	0.15	0.369	0.3	0.078	0.056	0.01	0.112	0.903	0.91
1400	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.554	0.15	0.395	0.35	0.172	0.059	0.01	0.19	0.95	0.969
1500	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.581	0.15	0.418	0.4	0.078	0.062	0.01	0.112	0.995	1.001
1600	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.819	0.15	0.437	0.4	0.078	0.064	0.01	0.112	1.157	1.163
1700	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	0.908	0.15	0.453	0.4	0.206	0.066	0.01	0.221	1.228	1.248
1800	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	1.325	0.15	0.468	0.4	0.251	0.068	0.01	0.264	1.566	1.588
1900	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	1.164	0.15	0.481	0.4	0.125	0.069	0.01	0.149	1.437	1.444
2000	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	1.279	0.15	0.492	0.4	0.148	0.071	0.01	0.169	1.535	1.545
2100	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	1.278	0.2	0.503	0.5	0.202	0.072	0.01	0.218	1.572	1.587
2200	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	1.229	0.2	0.512	0.5	0.297	0.073	0.01	0.307	1.536	1.566
2300	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	1.406	0.2	0.52	0.5	0.339	0.074	0.01	0.349	1.684	1.719
2400	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	1.738	0.2	0.528	0.5	0.317	0.075	0.01	0.327	1.971	1.998
2500	0.17	0.002	0.054	0.006	0.063	0.08	0.031	0.05	0.5	0.04	1.594	0.2	0.534	0.5	0.317	0.076	0.01	0.327	1.848	1.876

Table 6-3 Round 2 uncertainties. All values are standard uncertainties in %

Key
1 - NML1997 illuminance scale
2 - Reference lamp transfers to photometer
3 - agreement between illuminance standards
4 - Transfers photometer to test lamps
5 - lamp current for illuminance tests
6 - distance
7 - photometer non-linearity
8 - angular setting and illuminance field non-uniformity
9 - illuminance stray light
10 - photometer colour correction and spectral integration
11 - Uncertainty in blackbody temperature
12 - uncertainty in blackbody window transmittances
13 - Blackbody to lamp transfer optical effects
14 - Transfers blackbody to reference lamps
15 - Transfers reference to CCPR transfer lamps
16 - lamp current for spectral tests
17 - wavelength error and reproducibility

	Illuminance measurements to normalise relative spectral irradiances										Relative spectral irradiance measurements							Total uncertainties		
Type:	B	A	B	A	B	A	B	B	B	B	B	B	B	B	A	B	B	Type	Type	Type
Key:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	A	B	A + B
250	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	1.300	0.040	0.754	0.800	0.842	0.120	0.01	0.846	1.722	1.918
260	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.692	0.040	0.701	0.500	0.386	0.111	0.01	0.394	1.133	1.199
270	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.643	0.040	0.652	0.450	0.327	0.103	0.01	0.337	1.050	1.103
280	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.598	0.040	0.607	0.400	0.269	0.096	0.01	0.281	0.973	1.012
290	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.557	0.040	0.564	0.300	0.095	0.090	0.01	0.124	0.882	0.890
300	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.518	0.040	0.525	0.200	0.059	0.083	0.01	0.100	0.801	0.807
310	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.481	0.040	0.488	0.150	0.075	0.077	0.01	0.110	0.741	0.749
320	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.447	0.040	0.453	0.150	0.072	0.072	0.01	0.108	0.696	0.704
330	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.415	0.040	0.421	0.150	0.036	0.067	0.01	0.088	0.653	0.659
340	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.385	0.040	0.390	0.150	0.072	0.062	0.01	0.108	0.614	0.624
350	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.356	0.040	0.361	0.150	0.076	0.057	0.01	0.110	0.578	0.589
360	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.330	0.040	0.334	0.150	0.063	0.053	0.01	0.102	0.544	0.554
370	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.304	0.040	0.308	0.150	0.057	0.049	0.01	0.099	0.513	0.523
380	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.280	0.040	0.284	0.150	0.044	0.045	0.01	0.092	0.484	0.493
390	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.257	0.040	0.261	0.150	0.027	0.041	0.01	0.085	0.458	0.465
400	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.236	0.040	0.239	0.100	0.050	0.038	0.01	0.095	0.418	0.429
450	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.142	0.040	0.144	0.100	0.032	0.023	0.01	0.087	0.320	0.331
500	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.067	0.040	0.068	0.100	0.042	0.011	0.01	0.091	0.265	0.280
550	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.006	0.040	0.006	0.100	0.014	0.001	0.01	0.082	0.247	0.260
555	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.000	0.000	0	0	0	0	0	0.080	0.222	0.236
600	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.045	0.040	0.046	0.100	0.012	0.007	0.01	0.081	0.255	0.268
650	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.089	0.040	0.090	0.100	0.042	0.014	0.01	0.091	0.277	0.292

Key
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3 - agreement between illuminance standards
4 - Transfers photometer to test lamps
5 - lamp current for illuminance tests
6 - distance
7 - photometer non-linearity
8 - angular setting and illuminance field non-uniformity
9 - illuminance stray light
10 - photometer colour correction and spectral integration
11 - Uncertainty in blackbody temperature
12 - uncertainty in blackbody window transmittances
13 - Blackbody to lamp transfer optical effects
14 - Transfers blackbody to reference lamps
15 - Transfers reference to CCPR transfer lamps
16 - lamp current for spectral tests
17 - wavelength error and reproducibility

	Illuminance measurements to normalise relative spectral irradiances										Relative spectral irradiance measurements							Total uncertainties		
Type:	B	A	B	A	B	A	B	B	B	B	B	B	B	B	A	B	B	Type A	Type B	Type A + B
Key:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17			
700	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.125	0.040	0.178	0.100	0.020	0.020	0.01	0.083	0.330	0.340
750	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.184	0.040	0.266	0.100	0.029	0.025	0.01	0.085	0.408	0.417
800	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.235	0.040	0.252	0.100	0.035	0.030	0.01	0.088	0.425	0.434
850	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.280	0.150	0.212	0.100	0.027	0.034	0.01	0.085	0.454	0.462
900	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.320	0.150	0.234	0.100	0.043	0.038	0.01	0.091	0.490	0.499
950	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.355	0.150	0.254	0.100	0.039	0.041	0.01	0.089	0.523	0.531
1000	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.387	0.150	0.271	0.100	0.012	0.044	0.01	0.081	0.554	0.560
1100	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.441	0.150	0.301	0.300	0.028	0.049	0.01	0.085	0.670	0.676
1200	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.486	0.150	0.338	0.300	0.112	0.053	0.01	0.138	0.718	0.731
1300	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.523	0.150	0.369	0.300	0.102	0.056	0.01	0.130	0.758	0.769
1400	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.554	0.150	0.395	0.350	0.134	0.059	0.01	0.157	0.813	0.828
1500	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.581	0.150	0.418	0.400	0.168	0.062	0.01	0.186	0.865	0.885
1600	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.819	0.150	0.437	0.400	0.126	0.064	0.01	0.149	1.048	1.058
1700	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	0.908	0.150	0.453	0.400	0.108	0.066	0.01	0.135	1.125	1.133
1800	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	1.325	0.150	0.468	0.400	0.090	0.068	0.01	0.121	1.487	1.492
1900	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	1.164	0.150	0.481	0.400	0.138	0.069	0.01	0.160	1.350	1.359
2000	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	1.279	0.150	0.492	0.400	0.170	0.071	0.01	0.188	1.455	1.467
2100	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	1.278	0.200	0.503	0.500	0.154	0.072	0.01	0.174	1.493	1.503
2200	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	1.229	0.200	0.512	0.500	0.273	0.073	0.01	0.285	1.455	1.482
2300	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	1.406	0.200	0.520	0.500	0.324	0.074	0.01	0.334	1.610	1.644
2400	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	1.738	0.200	0.528	0.500	0.237	0.075	0.01	0.251	1.909	1.925
2500	0.17	0.002	0.054	0.008	0.063	0.080	0.031	0.05	0.002	0.1	1.594	0.200	0.534	0.500	0.495	0.076	0.01	0.501	1.781	1.850

Table 6-4 Estimated uncertainties in the illuminance measurements of transfer lamps BN-9101-196, -206, -247 used to calculate the factors for normalising the relative spectral irradiances to SI spectral irradiance units for CIPM key comparison K1-a in December 2003. Notes follow the table

Standard uncertainties in the measurement of illuminance for uncertainty in:	Note	Type	%
1997 scale of illuminance		B	0.170
Transfers to photometer		A	0.002
Agreement between reference lamps	1	B	0.054
Transfers to sp irradiance lamps		A	0.008
Lamp current uncertainty for illuminance tests	2	B	0.063
Distance for illuminance (absolute) tests	3	B	0.023
Photometer non-linearity	4	B	0.031
Angular setting / field non-uniformity	5	B	0.050
Illuminance test straylight		B	0.100
Calculated photometer colour correction factor	6	B	0.040
Total type A	7		0.008
Total standard uncertainty	7		0.227

Notes on contents of Table 6-4

1. ESDM of set of 4 responsivity values transferred from illuminance standards.
2. Uncertainty in current estimated to be 0.01 %. Sensitivity coefficient = 6.25.
3. Distance uncertainty estimated to be 0.1 mm in 500 mm (rect. semi-range).
4. Upper limit in non-linearity for each 5:1 range estimated to be 0.01 %.
5. Field uniformities measured. Value is for angular uncertainty of 0.1 degrees.
6. Correction for $V(\lambda)$ mismatch is 0.16 %; uncertainty in calc. est. 25 % of value.
7. Uncertainties are added in quadrature.

Table 6-5 Estimated uncertainties for lamps BN-9101-196, -206, -247 due to contributing factors in the relative spectral irradiance measurements combined with the total uncertainties in the normalising factor from the illuminance measurements giving the total uncertainties in the spectral irradiances for round 2 of CIPM K1-a key comparison in December 2003. Notes follow the table

Wave-length (nm)	Illuminance uncertainties (%)		Relative spectral irradiance uncertainties (%) for uncertainties in				Spectral irradiance	
	Transfers	Systematic	NML2003 scale	Sp irrad transfer	Lamp current	Wavelength uncert	total	Total standard
Type:	A	B	B	A	B	B	type A	uncertainty
Note:	1	1	2	3	4	5	%	%
250	0.08	0.22	1.70	0.842	0.120	0.010	0.846	1.918
260	0.08	0.22	1.11	0.386	0.111	0.010	0.394	1.199
270	0.08	0.22	1.02	0.327	0.103	0.010	0.337	1.103
280	0.08	0.22	0.94	0.269	0.096	0.010	0.489	1.012
290	0.08	0.22	0.85	0.095	0.090	0.010	0.281	0.890
300	0.08	0.22	0.76	0.059	0.083	0.010	0.124	0.807
310	0.08	0.22	0.70	0.075	0.077	0.010	0.100	0.749
320	0.08	0.22	0.66	0.072	0.072	0.010	0.108	0.704
330	0.08	0.22	0.61	0.036	0.067	0.010	0.088	0.659
340	0.08	0.22	0.57	0.072	0.062	0.010	0.108	0.624
350	0.08	0.22	0.53	0.076	0.057	0.010	0.110	0.589
360	0.08	0.22	0.49	0.063	0.053	0.010	0.102	0.554
370	0.08	0.22	0.46	0.057	0.049	0.010	0.099	0.523
380	0.08	0.22	0.43	0.044	0.045	0.010	0.092	0.493
390	0.08	0.22	0.40	0.027	0.041	0.010	0.085	0.465
400	0.08	0.22	0.35	0.050	0.038	0.010	0.095	0.429
450	0.08	0.22	0.23	0.032	0.023	0.010	0.087	0.331
500	0.08	0.22	0.14	0.042	0.011	0.010	0.091	0.280
550	0.08	0.22	0.11	0.014	0.001	0.010	0.082	0.260
555	0.08	0.22	0.00	0.000	0.000	0.000	0.080	0.236
600	0.08	0.22	0.13	0.012	0.007	0.010	0.081	0.268
650	0.08	0.22	0.17	0.042	0.014	0.010	0.091	0.292
700	0.08	0.22	0.24	0.020	0.020	0.010	0.083	0.340
750	0.08	0.22	0.34	0.029	0.025	0.010	0.085	0.417
800	0.08	0.22	0.36	0.035	0.030	0.010	0.088	0.434
850	0.08	0.22	0.39	0.027	0.034	0.010	0.085	0.462
900	0.08	0.22	0.44	0.043	0.038	0.010	0.091	0.499
950	0.08	0.22	0.47	0.039	0.041	0.010	0.089	0.531
1000	0.08	0.22	0.51	0.012	0.044	0.010	0.081	0.560
1100	0.08	0.22	0.63	0.028	0.049	0.010	0.085	0.676
1200	0.08	0.22	0.68	0.112	0.053	0.010	0.138	0.731
1300	0.08	0.22	0.72	0.120	0.056	0.010	0.130	0.769
1400	0.08	0.22	0.78	0.134	0.059	0.010	0.157	0.828
1500	0.08	0.22	0.83	0.168	0.062	0.010	0.186	0.885
1600	0.08	0.22	1.02	0.126	0.064	0.010	0.149	1.058
1700	0.08	0.22	1.10	0.108	0.066	0.010	0.135	1.133
1800	0.08	0.22	1.47	0.090	0.068	0.010	0.121	1.492
1900	0.08	0.22	1.33	0.138	0.069	0.010	0.160	1.359

Wave-length (nm)	Illuminance uncertainties (%)		Relative spectral irradiance uncertainties (%) for uncertainties in				Spectral irradiance	
	Transfers	Systematic	NML2003 scale	Sp irrad transfer	Lamp current	Wavelength uncert	total	Total standard
Type:	A	B	B	A	B	B	type A	uncertainty
Note:	1	1	2	3	4	5	%	%
2000	0.08	0.22	1.44	0.170	0.071	0.010	0.188	1.467
2100	0.08	0.22	1.47	0.154	0.072	0.010	0.174	1.503
2200	0.08	0.22	1.44	0.273	0.073	0.010	0.285	1.482
2300	0.08	0.22	1.59	0.324	0.074	0.010	0.334	1.644
2400	0.08	0.22	1.89	0.237	0.075	0.010	0.251	1.925
2500	0.08	0.22	1.77	0.495	0.076	0.010	0.501	1.850

Notes on contents of Table 6-5

1. These values are given in Table 6-4 above.
2. This scale has recently been established and details of its origin and uncertainties are to be published [1]. These uncertainties include transfers to the laboratory scale reference standard lamps. There is some discussion of these above.
3. Transfer uncertainties are for transfers from laboratory standard lamps to CCPR transfer lamps. They have been calculated from internal propagated uncertainties using estimates of typical system noise, where the resulting degrees of freedom are large due to the large number of readings taken at each wavelength.
4. Combined uncertainty in both reference and transfer lamp currents is estimated to be 0.017 %. Uncertainty in spectral irradiance has sensitivity coefficient estimated to be = 8 × 400/(wavelength in nm).
5. Wavelength uncertainty is estimated to be 0.1 nm for spectral range 250-800 nm and 0.2 nm for IR wavelengths. Wavelength reproducibility is about 0.03 nm. The lamp temperatures and therefore their spectra are very similar.

6.7 CSIRO Results

CSIRO measured three lamps. The results for FEL BN 9101 196 are given in Table 6-6 and the results for FEL BN 9101 206 are given in Table 6-7 and the results for FEL BN 9101 247 are given in Table 6-8.

Table 6-6 CSIRO Results for FEL BN 9101 196. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 196	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.214E-04	0.53 %	1.21 %	1.31 %	1.86 %	1.199E-04	0.50 %	1.11 %	1.31 %	1.79 %
260	2.131E-04	0.27 %	1.00 %	0.71 %	1.26 %	2.140E-04	0.24 %	0.87 %	0.71 %	1.15 %
270	3.571E-04	0.20 %	0.94 %	0.67 %	1.17 %	3.582E-04	0.21 %	0.80 %	0.67 %	1.06 %
280	5.764E-04	0.18 %	0.89 %	0.62 %	1.10 %	5.744E-04	0.18 %	0.74 %	0.62 %	0.98 %
290	8.689E-04	0.17 %	0.81 %	0.58 %	1.02 %	8.722E-04	0.10 %	0.65 %	0.58 %	0.88 %
300	1.281E-03	0.16 %	0.76 %	0.55 %	0.95 %	1.281E-03	0.09 %	0.57 %	0.55 %	0.80 %
310	1.818E-03	0.15 %	0.72 %	0.51 %	0.89 %	1.822E-03	0.09 %	0.52 %	0.51 %	0.74 %
320	2.526E-03	0.15 %	0.70 %	0.48 %	0.86 %	2.521E-03	0.09 %	0.49 %	0.48 %	0.69 %
330	3.408E-03	0.14 %	0.67 %	0.45 %	0.82 %	3.399E-03	0.08 %	0.46 %	0.45 %	0.65 %
340	4.511E-03	0.14 %	0.66 %	0.42 %	0.79 %	4.491E-03	0.09 %	0.43 %	0.42 %	0.61 %
350	5.813E-03	0.13 %	0.64 %	0.40 %	0.76 %	5.800E-03	0.09 %	0.41 %	0.40 %	0.58 %
360	7.383E-03	0.13 %	0.62 %	0.37 %	0.74 %	7.356E-03	0.08 %	0.38 %	0.37 %	0.54 %
370	9.180E-03	0.13 %	0.61 %	0.35 %	0.72 %	9.171E-03	0.08 %	0.36 %	0.35 %	0.51 %
380	1.128E-02	0.13 %	0.60 %	0.33 %	0.70 %	1.126E-02	0.08 %	0.34 %	0.33 %	0.48 %
390	1.365E-02	0.12 %	0.59 %	0.31 %	0.68 %	1.362E-02	0.07 %	0.32 %	0.31 %	0.45 %
400	1.636E-02	0.12 %	0.57 %	0.29 %	0.65 %	1.628E-02	0.08 %	0.28 %	0.29 %	0.42 %
450	3.373E-02	0.12 %	0.53 %	0.22 %	0.59 %	3.365E-02	0.07 %	0.21 %	0.22 %	0.32 %
500	5.712E-02	0.12 %	0.52 %	0.19 %	0.57 %	5.679E-02	0.07 %	0.17 %	0.19 %	0.26 %
550	8.352E-02	0.12 %	0.52 %	0.17 %	0.56 %	8.309E-02	0.07 %	0.15 %	0.17 %	0.24 %
555	8.611E-02	0.11 %	0.51 %	0.17 %	0.54 %	8.575E-02	0.07 %	0.12 %	0.17 %	0.22 %
600	1.102E-01	0.12 %	0.52 %	0.18 %	0.56 %	1.097E-01	0.07 %	0.16 %	0.18 %	0.25 %
650	1.347E-01	0.12 %	0.52 %	0.20 %	0.57 %	1.342E-01	0.07 %	0.18 %	0.20 %	0.27 %
700	1.553E-01	0.12 %	0.55 %	0.22 %	0.60 %	1.552E-01	0.07 %	0.24 %	0.22 %	0.33 %
750	1.716E-01	0.12 %	0.58 %	0.25 %	0.64 %	1.715E-01	0.07 %	0.31 %	0.25 %	0.40 %
800	1.835E-01	0.13 %	0.57 %	0.29 %	0.66 %	1.832E-01	0.07 %	0.30 %	0.29 %	0.42 %
850	1.907E-01	0.13 %	0.56 %	0.36 %	0.68 %	1.904E-01	0.09 %	0.26 %	0.36 %	0.45 %
900	1.937E-01	0.13 %	0.57 %	0.39 %	0.70 %	1.938E-01	0.09 %	0.28 %	0.39 %	0.49 %
950	1.937E-01	0.13 %	0.57 %	0.42 %	0.72 %	1.939E-01	0.09 %	0.30 %	0.42 %	0.52 %
1000	1.912E-01	0.13 %	0.58 %	0.45 %	0.75 %	1.912E-01	0.09 %	0.31 %	0.45 %	0.55 %
1100	1.803E-01	0.15 %	0.66 %	0.50 %	0.84 %	1.797E-01	0.07 %	0.44 %	0.50 %	0.67 %
1200	1.651E-01	0.15 %	0.68 %	0.54 %	0.88 %	1.648E-01	0.10 %	0.47 %	0.54 %	0.72 %
1300	1.487E-01	0.15 %	0.69 %	0.57 %	0.91 %	1.482E-01	0.09 %	0.49 %	0.57 %	0.76 %
1400	1.315E-01	0.21 %	0.73 %	0.60 %	0.97 %	1.311E-01	0.11 %	0.54 %	0.60 %	0.81 %
1500	1.164E-01	0.15 %	0.77 %	0.62 %	1.00 %	1.158E-01	0.12 %	0.59 %	0.62 %	0.87 %
1600	1.023E-01	0.15 %	0.78 %	0.85 %	1.16 %	1.016E-01	0.10 %	0.60 %	0.85 %	1.05 %
1700	8.922E-02	0.24 %	0.79 %	0.94 %	1.25 %	8.853E-02	0.10 %	0.62 %	0.94 %	1.12 %
1800	7.787E-02	0.28 %	0.80 %	1.34 %	1.59 %	7.750E-02	0.09 %	0.63 %	1.34 %	1.49 %
1900	6.837E-02	0.18 %	0.80 %	1.19 %	1.44 %	6.814E-02	0.11 %	0.64 %	1.19 %	1.35 %
2000	6.008E-02	0.20 %	0.81 %	1.30 %	1.54 %	5.984E-02	0.12 %	0.65 %	1.30 %	1.46 %
2100	5.234E-02	0.24 %	0.87 %	1.30 %	1.59 %	5.242E-02	0.12 %	0.72 %	1.30 %	1.49 %
2200	4.565E-02	0.33 %	0.88 %	1.26 %	1.57 %	4.581E-02	0.18 %	0.73 %	1.26 %	1.46 %
2300	4.059E-02	0.37 %	0.88 %	1.43 %	1.72 %	4.022E-02	0.20 %	0.73 %	1.43 %	1.62 %

2400	3.534E-02	0.34 %	0.89 %	1.76 %	2.00 %	3.535E-02	0.16 %	0.74 %	1.76 %	1.91 %
2500	3.169E-02	0.34 %	0.89 %	1.62 %	1.88 %	3.124E-02	0.30 %	0.74 %	1.62 %	1.80 %

Table 6-7 CSIRO Results for FEL BN 9101 206. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 206	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.112E-04	0.53 %	1.21 %	1.31 %	1.86 %	1.102E-04	0.50 %	1.11 %	1.31 %	1.79 %
260	1.973E-04	0.27 %	1.00 %	0.71 %	1.26 %	1.970E-04	0.24 %	0.87 %	0.71 %	1.15 %
270	3.313E-04	0.20 %	0.94 %	0.67 %	1.17 %	3.333E-04	0.21 %	0.80 %	0.67 %	1.06 %
280	5.369E-04	0.18 %	0.89 %	0.62 %	1.10 %	5.350E-04	0.18 %	0.74 %	0.62 %	0.98 %
290	8.119E-04	0.17 %	0.81 %	0.58 %	1.02 %	8.161E-04	0.10 %	0.65 %	0.58 %	0.88 %
300	1.200E-03	0.16 %	0.76 %	0.55 %	0.95 %	1.202E-03	0.09 %	0.57 %	0.55 %	0.80 %
310	1.705E-03	0.15 %	0.72 %	0.51 %	0.89 %	1.716E-03	0.09 %	0.52 %	0.51 %	0.74 %
320	2.375E-03	0.15 %	0.70 %	0.48 %	0.86 %	2.382E-03	0.09 %	0.49 %	0.48 %	0.69 %
330	3.213E-03	0.14 %	0.67 %	0.45 %	0.82 %	3.219E-03	0.08 %	0.46 %	0.45 %	0.65 %
340	4.255E-03	0.14 %	0.66 %	0.42 %	0.79 %	4.261E-03	0.09 %	0.43 %	0.42 %	0.61 %
350	5.497E-03	0.13 %	0.64 %	0.40 %	0.76 %	5.510E-03	0.09 %	0.41 %	0.40 %	0.58 %
360	6.992E-03	0.13 %	0.62 %	0.37 %	0.74 %	7.004E-03	0.08 %	0.38 %	0.37 %	0.54 %
370	8.709E-03	0.13 %	0.61 %	0.35 %	0.72 %	8.738E-03	0.08 %	0.36 %	0.35 %	0.51 %
380	1.071E-02	0.13 %	0.60 %	0.33 %	0.70 %	1.074E-02	0.08 %	0.34 %	0.33 %	0.48 %
390	1.298E-02	0.12 %	0.59 %	0.31 %	0.68 %	1.301E-02	0.07 %	0.32 %	0.31 %	0.45 %
400	1.556E-02	0.12 %	0.57 %	0.29 %	0.65 %	1.556E-02	0.08 %	0.28 %	0.29 %	0.42 %
450	3.224E-02	0.12 %	0.53 %	0.22 %	0.59 %	3.229E-02	0.07 %	0.21 %	0.22 %	0.32 %
500	5.471E-02	0.12 %	0.52 %	0.19 %	0.57 %	5.459E-02	0.07 %	0.17 %	0.19 %	0.26 %
550	8.014E-02	0.12 %	0.52 %	0.17 %	0.56 %	7.993E-02	0.07 %	0.15 %	0.17 %	0.24 %
555	8.260E-02	0.11 %	0.51 %	0.17 %	0.54 %	8.249E-02	0.07 %	0.12 %	0.17 %	0.22 %
600	1.058E-01	0.12 %	0.52 %	0.18 %	0.56 %	1.055E-01	0.07 %	0.16 %	0.18 %	0.25 %
650	1.294E-01	0.12 %	0.52 %	0.20 %	0.57 %	1.292E-01	0.07 %	0.18 %	0.20 %	0.27 %
700	1.493E-01	0.12 %	0.55 %	0.22 %	0.60 %	1.493E-01	0.07 %	0.24 %	0.22 %	0.33 %
750	1.649E-01	0.12 %	0.58 %	0.25 %	0.64 %	1.650E-01	0.07 %	0.31 %	0.25 %	0.40 %
800	1.763E-01	0.13 %	0.57 %	0.29 %	0.66 %	1.762E-01	0.07 %	0.30 %	0.29 %	0.42 %
850	1.829E-01	0.13 %	0.56 %	0.36 %	0.68 %	1.831E-01	0.09 %	0.26 %	0.36 %	0.45 %
900	1.859E-01	0.13 %	0.57 %	0.39 %	0.70 %	1.863E-01	0.09 %	0.28 %	0.39 %	0.49 %
950	1.859E-01	0.13 %	0.57 %	0.42 %	0.72 %	1.863E-01	0.09 %	0.30 %	0.42 %	0.52 %
1000	1.835E-01	0.13 %	0.58 %	0.45 %	0.75 %	1.835E-01	0.09 %	0.31 %	0.45 %	0.55 %
1100	1.728E-01	0.15 %	0.66 %	0.50 %	0.84 %	1.723E-01	0.07 %	0.44 %	0.50 %	0.67 %
1200	1.582E-01	0.15 %	0.68 %	0.54 %	0.88 %	1.580E-01	0.10 %	0.47 %	0.54 %	0.72 %
1300	1.423E-01	0.15 %	0.69 %	0.57 %	0.91 %	1.419E-01	0.09 %	0.49 %	0.57 %	0.76 %
1400	1.258E-01	0.21 %	0.73 %	0.60 %	0.97 %	1.256E-01	0.11 %	0.54 %	0.60 %	0.81 %
1500	1.112E-01	0.15 %	0.77 %	0.62 %	1.00 %	1.106E-01	0.12 %	0.59 %	0.62 %	0.87 %
1600	9.776E-02	0.15 %	0.78 %	0.85 %	1.16 %	9.705E-02	0.10 %	0.60 %	0.85 %	1.05 %
1700	8.519E-02	0.24 %	0.79 %	0.94 %	1.25 %	8.475E-02	0.10 %	0.62 %	0.94 %	1.12 %
1800	7.438E-02	0.28 %	0.80 %	1.34 %	1.59 %	7.392E-02	0.09 %	0.63 %	1.34 %	1.49 %
1900	6.542E-02	0.18 %	0.80 %	1.19 %	1.44 %	6.500E-02	0.11 %	0.64 %	1.19 %	1.35 %
2000	5.715E-02	0.20 %	0.81 %	1.30 %	1.54 %	5.709E-02	0.12 %	0.65 %	1.30 %	1.46 %
2100	5.000E-02	0.24 %	0.87 %	1.30 %	1.59 %	4.996E-02	0.12 %	0.72 %	1.30 %	1.49 %
2200	4.366E-02	0.33 %	0.88 %	1.26 %	1.57 %	4.358E-02	0.18 %	0.73 %	1.26 %	1.46 %
2300	3.865E-02	0.37 %	0.88 %	1.43 %	1.72 %	3.832E-02	0.20 %	0.73 %	1.43 %	1.62 %
2400	3.391E-02	0.34 %	0.89 %	1.76 %	2.00 %	3.379E-02	0.16 %	0.74 %	1.76 %	1.91 %
2500	3.020E-02	0.34 %	0.89 %	1.62 %	1.88 %	2.981E-02	0.30 %	0.74 %	1.62 %	1.80 %

Table 6-8 CSIRO Results for FEL BN 9101 247. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

*Note *: This lamp was not measured at 2500 nm in the first round*

FEL 247	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.274E-04	0.53 %	1.21 %	1.31 %	1.86 %	1.251E-04	0.50 %	1.11 %	1.31 %	1.79 %
260	2.234E-04	0.27 %	1.00 %	0.71 %	1.26 %	2.210E-04	0.24 %	0.87 %	0.71 %	1.15 %
270	3.723E-04	0.20 %	0.94 %	0.67 %	1.17 %	3.712E-04	0.21 %	0.80 %	0.67 %	1.06 %
280	5.965E-04	0.18 %	0.89 %	0.62 %	1.10 %	5.904E-04	0.18 %	0.74 %	0.62 %	0.98 %
290	9.030E-04	0.17 %	0.81 %	0.58 %	1.02 %	9.001E-04	0.10 %	0.65 %	0.58 %	0.88 %
300	1.327E-03	0.16 %	0.76 %	0.55 %	0.95 %	1.319E-03	0.09 %	0.57 %	0.55 %	0.80 %
310	1.887E-03	0.15 %	0.72 %	0.51 %	0.89 %	1.882E-03	0.09 %	0.52 %	0.51 %	0.74 %
320	2.607E-03	0.15 %	0.70 %	0.48 %	0.86 %	2.594E-03	0.09 %	0.49 %	0.48 %	0.69 %
330	3.518E-03	0.14 %	0.67 %	0.45 %	0.82 %	3.496E-03	0.08 %	0.46 %	0.45 %	0.65 %
340	4.647E-03	0.14 %	0.66 %	0.42 %	0.79 %	4.618E-03	0.09 %	0.43 %	0.42 %	0.61 %
350	5.985E-03	0.13 %	0.64 %	0.40 %	0.76 %	5.962E-03	0.09 %	0.41 %	0.40 %	0.58 %
360	7.597E-03	0.13 %	0.62 %	0.37 %	0.74 %	7.558E-03	0.08 %	0.38 %	0.37 %	0.54 %
370	9.443E-03	0.13 %	0.61 %	0.35 %	0.72 %	9.416E-03	0.08 %	0.36 %	0.35 %	0.51 %
380	1.159E-02	0.13 %	0.60 %	0.33 %	0.70 %	1.156E-02	0.08 %	0.34 %	0.33 %	0.48 %
390	1.403E-02	0.12 %	0.59 %	0.31 %	0.68 %	1.398E-02	0.07 %	0.32 %	0.31 %	0.45 %
400	1.680E-02	0.12 %	0.57 %	0.29 %	0.65 %	1.670E-02	0.08 %	0.28 %	0.29 %	0.42 %
450	3.460E-02	0.12 %	0.53 %	0.22 %	0.59 %	3.449E-02	0.07 %	0.21 %	0.22 %	0.32 %
500	5.850E-02	0.12 %	0.52 %	0.19 %	0.57 %	5.815E-02	0.07 %	0.17 %	0.19 %	0.26 %
550	8.545E-02	0.12 %	0.52 %	0.17 %	0.56 %	8.496E-02	0.07 %	0.15 %	0.17 %	0.24 %
555	8.809E-02	0.11 %	0.51 %	0.17 %	0.54 %	8.767E-02	0.07 %	0.12 %	0.17 %	0.22 %
600	1.126E-01	0.12 %	0.52 %	0.18 %	0.56 %	1.120E-01	0.07 %	0.16 %	0.18 %	0.25 %
650	1.375E-01	0.12 %	0.52 %	0.20 %	0.57 %	1.369E-01	0.07 %	0.18 %	0.20 %	0.27 %
700	1.584E-01	0.12 %	0.55 %	0.22 %	0.60 %	1.581E-01	0.07 %	0.24 %	0.22 %	0.33 %
750	1.748E-01	0.12 %	0.58 %	0.25 %	0.64 %	1.744E-01	0.07 %	0.31 %	0.25 %	0.40 %
800	1.867E-01	0.13 %	0.57 %	0.29 %	0.66 %	1.862E-01	0.07 %	0.30 %	0.29 %	0.42 %
850	1.935E-01	0.13 %	0.56 %	0.36 %	0.68 %	1.932E-01	0.09 %	0.26 %	0.36 %	0.45 %
900	1.966E-01	0.13 %	0.57 %	0.39 %	0.70 %	1.964E-01	0.09 %	0.28 %	0.39 %	0.49 %
950	1.964E-01	0.13 %	0.57 %	0.42 %	0.72 %	1.963E-01	0.09 %	0.30 %	0.42 %	0.52 %
1000	1.937E-01	0.13 %	0.58 %	0.45 %	0.75 %	1.933E-01	0.09 %	0.31 %	0.45 %	0.55 %
1100	1.823E-01	0.15 %	0.66 %	0.50 %	0.84 %	1.817E-01	0.07 %	0.44 %	0.50 %	0.67 %
1200	1.668E-01	0.15 %	0.68 %	0.54 %	0.88 %	1.665E-01	0.10 %	0.47 %	0.54 %	0.72 %
1300	1.498E-01	0.15 %	0.69 %	0.57 %	0.91 %	1.493E-01	0.09 %	0.49 %	0.57 %	0.76 %
1400	1.324E-01	0.21 %	0.73 %	0.60 %	0.97 %	1.321E-01	0.11 %	0.54 %	0.60 %	0.81 %
1500	1.170E-01	0.15 %	0.77 %	0.62 %	1.00 %	1.164E-01	0.12 %	0.59 %	0.62 %	0.87 %
1600	1.028E-01	0.15 %	0.78 %	0.85 %	1.16 %	1.022E-01	0.10 %	0.60 %	0.85 %	1.05 %
1700	8.975E-02	0.24 %	0.79 %	0.94 %	1.25 %	8.905E-02	0.10 %	0.62 %	0.94 %	1.12 %
1800	7.841E-02	0.28 %	0.80 %	1.34 %	1.59 %	7.782E-02	0.09 %	0.63 %	1.34 %	1.49 %
1900	6.873E-02	0.18 %	0.80 %	1.19 %	1.44 %	6.835E-02	0.11 %	0.64 %	1.19 %	1.35 %
2000	6.042E-02	0.20 %	0.81 %	1.30 %	1.54 %	6.002E-02	0.12 %	0.65 %	1.30 %	1.46 %
2100	5.264E-02	0.24 %	0.87 %	1.30 %	1.59 %	5.250E-02	0.12 %	0.72 %	1.30 %	1.49 %
2200	4.569E-02	0.33 %	0.88 %	1.26 %	1.57 %	4.573E-02	0.18 %	0.73 %	1.26 %	1.46 %
2300	4.079E-02	0.37 %	0.88 %	1.43 %	1.72 %	4.024E-02	0.20 %	0.73 %	1.43 %	1.62 %
2400	3.572E-02	0.34 %	0.89 %	1.76 %	2.00 %	3.557E-02	0.16 %	0.74 %	1.76 %	1.91 %
2500*						3.125E-02	0.30 %	0.74 %	1.62 %	1.80 %

6.8 Pilot Results

NPL's results for FEL BN 9101 196 are given in Table 6-9, the results for FEL BN 9101 206 are given in Table 6-10 and the results for FEL BN 9101 247 are given in Table 6-10.

Table 6-9 NPL Results for FEL BN 9101 196. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 196	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.209E-04	1.53 %	0.32 %	2.06 %	2.58 %	1.197E-04	1.27 %	0.00 %	2.06 %	2.42 %
260	2.119E-04	1.14 %	0.32 %	2.05 %	2.37 %	2.105E-04	0.95 %	0.00 %	2.05 %	2.26 %
270	3.528E-04	0.86 %	0.31 %	2.05 %	2.24 %	3.513E-04	0.72 %	0.00 %	2.05 %	2.17 %
280	5.613E-04	0.66 %	0.29 %	1.56 %	1.72 %	5.599E-04	0.56 %	0.00 %	1.56 %	1.66 %
290	8.577E-04	0.51 %	0.27 %	1.08 %	1.23 %	8.566E-04	0.45 %	0.00 %	1.08 %	1.17 %
300	1.264E-03	0.42 %	0.33 %	0.45 %	0.70 %	1.264E-03	0.37 %	0.15 %	0.45 %	0.60 %
310	1.805E-03	0.35 %	0.38 %	0.43 %	0.68 %	1.806E-03	0.32 %	0.20 %	0.43 %	0.58 %
320	2.504E-03	0.31 %	0.43 %	0.37 %	0.65 %	2.506E-03	0.28 %	0.25 %	0.37 %	0.53 %
330	3.386E-03	0.28 %	0.47 %	0.36 %	0.66 %	3.389E-03	0.26 %	0.28 %	0.36 %	0.52 %
340	4.472E-03	0.23 %	0.53 %	0.35 %	0.68 %	4.478E-03	0.23 %	0.33 %	0.35 %	0.54 %
350	5.785E-03	0.25 %	0.58 %	0.34 %	0.72 %	5.793E-03	0.22 %	0.36 %	0.34 %	0.54 %
360	7.341E-03	0.24 %	0.67 %	0.33 %	0.79 %	7.352E-03	0.20 %	0.43 %	0.33 %	0.58 %
370	9.156E-03	0.23 %	0.72 %	0.32 %	0.82 %	9.170E-03	0.19 %	0.46 %	0.32 %	0.59 %
380	1.124E-02	0.21 %	0.81 %	0.31 %	0.89 %	1.126E-02	0.18 %	0.52 %	0.31 %	0.64 %
390	1.360E-02	0.20 %	0.78 %	0.31 %	0.86 %	1.363E-02	0.18 %	0.50 %	0.31 %	0.61 %
400	1.625E-02	0.19 %	0.72 %	0.30 %	0.81 %	1.628E-02	0.18 %	0.46 %	0.30 %	0.58 %
450	3.356E-02	0.17 %	0.31 %	0.27 %	0.44 %	3.364E-02	0.18 %	0.10 %	0.27 %	0.34 %
500	5.655E-02	0.16 %	0.31 %	0.24 %	0.43 %	5.670E-02	0.17 %	0.00 %	0.24 %	0.29 %
550	8.276E-02	0.14 %	0.33 %	0.22 %	0.42 %	8.299E-02	0.15 %	0.00 %	0.22 %	0.26 %
555	8.544E-02	0.14 %	0.33 %	0.22 %	0.42 %	8.569E-02	0.14 %	0.00 %	0.22 %	0.26 %
600	1.094E-01	0.14 %	0.33 %	0.20 %	0.41 %	1.097E-01	0.13 %	0.00 %	0.20 %	0.24 %
650	1.341E-01	0.09 %	0.32 %	0.18 %	0.38 %	1.345E-01	0.13 %	0.00 %	0.18 %	0.23 %
700	1.551E-01	0.15 %	0.31 %	0.17 %	0.39 %	1.556E-01	0.13 %	0.00 %	0.17 %	0.21 %
750	1.717E-01	0.14 %	0.30 %	0.16 %	0.37 %	1.722E-01	0.12 %	0.00 %	0.16 %	0.20 %
800	1.835E-01	0.12 %	0.29 %	0.15 %	0.35 %	1.840E-01	0.11 %	0.00 %	0.15 %	0.18 %
850	1.908E-01	0.11 %	0.28 %	0.14 %	0.33 %	1.912E-01	0.10 %	0.00 %	0.14 %	0.17 %
900	1.942E-01	0.10 %	0.26 %	0.13 %	0.31 %	1.945E-01	0.09 %	0.00 %	0.13 %	0.16 %
950	1.944E-01	0.10 %	0.25 %	0.13 %	0.30 %	1.945E-01	0.09 %	0.00 %	0.13 %	0.16 %
1000	1.918E-01	0.09 %	0.25 %	0.12 %	0.29 %	1.919E-01	0.10 %	0.00 %	0.12 %	0.16 %
1100	1.812E-01	0.10 %	0.25 %	0.11 %	0.30 %	1.813E-01	0.14 %	0.00 %	0.11 %	0.18 %
1200	1.662E-01	0.11 %	0.28 %	0.10 %	0.32 %	1.664E-01	0.17 %	0.00 %	0.10 %	0.20 %
1300	1.495E-01	0.12 %	0.32 %	0.09 %	0.36 %	1.498E-01	0.19 %	0.00 %	0.09 %	0.21 %
1400	1.328E-01	0.13 %	0.33 %	0.09 %	0.36 %	1.331E-01	0.21 %	0.00 %	0.09 %	0.23 %
1500	1.170E-01	0.12 %	0.30 %	0.08 %	0.33 %	1.173E-01	0.20 %	0.00 %	0.08 %	0.22 %
1600	1.027E-01	0.11 %	0.26 %	0.08 %	0.29 %	1.029E-01	0.19 %	0.00 %	0.08 %	0.21 %
1700	8.999E-02	0.17 %	0.23 %	0.08 %	0.29 %	9.009E-02	0.26 %	0.00 %	0.08 %	0.27 %
1800	7.883E-02	0.34 %	0.21 %	0.08 %	0.41 %	7.875E-02	0.34 %	0.00 %	0.08 %	0.35 %
1900	6.909E-02	0.57 %	0.23 %	0.07 %	0.62 %	6.875E-02	0.40 %	0.00 %	0.07 %	0.41 %
2000	6.059E-02	0.72 %	0.29 %	0.08 %	0.79 %	6.000E-02	0.46 %	0.00 %	0.08 %	0.47 %
2100	5.316E-02	0.86 %	0.38 %	0.07 %	0.94 %	5.247E-02	0.46 %	0.00 %	0.07 %	0.46 %
2200	4.667E-02	1.18 %	0.45 %	0.06 %	1.26 %	4.609E-02	0.45 %	0.00 %	0.06 %	0.45 %
2300	4.089E-02	1.32 %	0.45 %	0.06 %	1.40 %	4.063E-02	0.51 %	0.00 %	0.06 %	0.51 %
2400	3.566E-02	1.94 %	0.76 %	0.09 %	2.08 %	3.577E-02	0.73 %	0.00 %	0.09 %	0.74 %
2500	3.223E-02	2.59 %	1.46 %	0.08 %	2.98 %	3.161E-02	0.75 %	0.00 %	0.08 %	0.75 %

Table 6-10 NPL Results for FEL 206. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 206	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.101E-04	2.37 %	0.32 %	2.06 %	3.15 %	1.107E-04	0.40 %	0.00 %	2.06 %	2.09 %
260	1.941E-04	1.73 %	0.32 %	2.05 %	2.70 %	1.958E-04	0.31 %	0.00 %	2.05 %	2.08 %
270	3.246E-04	1.28 %	0.31 %	2.05 %	2.44 %	3.283E-04	0.25 %	0.00 %	2.05 %	2.06 %
280	5.185E-04	0.97 %	0.29 %	1.56 %	1.86 %	5.251E-04	0.21 %	0.00 %	1.56 %	1.57 %
290	7.952E-04	0.77 %	0.27 %	1.08 %	1.35 %	8.057E-04	0.19 %	0.00 %	1.08 %	1.10 %
300	1.176E-03	0.64 %	0.33 %	0.45 %	0.85 %	1.192E-03	0.18 %	0.15 %	0.45 %	0.50 %
310	1.684E-03	0.55 %	0.38 %	0.43 %	0.80 %	1.706E-03	0.17 %	0.20 %	0.43 %	0.51 %
320	2.343E-03	0.50 %	0.43 %	0.37 %	0.76 %	2.371E-03	0.16 %	0.25 %	0.37 %	0.48 %
330	3.176E-03	0.46 %	0.47 %	0.36 %	0.75 %	3.211E-03	0.15 %	0.28 %	0.36 %	0.48 %
340	4.205E-03	0.41 %	0.53 %	0.35 %	0.76 %	4.247E-03	0.14 %	0.33 %	0.35 %	0.50 %
350	5.450E-03	0.41 %	0.58 %	0.34 %	0.78 %	5.499E-03	0.13 %	0.36 %	0.34 %	0.51 %
360	6.929E-03	0.38 %	0.67 %	0.33 %	0.84 %	6.985E-03	0.13 %	0.43 %	0.33 %	0.56 %
370	8.657E-03	0.36 %	0.72 %	0.32 %	0.86 %	8.717E-03	0.13 %	0.46 %	0.32 %	0.58 %
380	1.064E-02	0.34 %	0.81 %	0.31 %	0.93 %	1.071E-02	0.12 %	0.52 %	0.31 %	0.62 %
390	1.290E-02	0.32 %	0.78 %	0.31 %	0.90 %	1.297E-02	0.12 %	0.50 %	0.31 %	0.60 %
400	1.543E-02	0.30 %	0.72 %	0.30 %	0.84 %	1.549E-02	0.12 %	0.46 %	0.30 %	0.56 %
450	3.202E-02	0.27 %	0.31 %	0.27 %	0.49 %	3.206E-02	0.13 %	0.10 %	0.27 %	0.31 %
500	5.411E-02	0.23 %	0.31 %	0.24 %	0.46 %	5.413E-02	0.12 %	0.00 %	0.24 %	0.27 %
550	7.932E-02	0.20 %	0.33 %	0.22 %	0.45 %	7.935E-02	0.11 %	0.00 %	0.22 %	0.25 %
555	8.191E-02	0.20 %	0.33 %	0.22 %	0.45 %	8.194E-02	0.11 %	0.00 %	0.22 %	0.24 %
600	1.050E-01	0.19 %	0.33 %	0.20 %	0.43 %	1.051E-01	0.11 %	0.00 %	0.20 %	0.23 %
650	1.287E-01	0.17 %	0.32 %	0.18 %	0.41 %	1.289E-01	0.11 %	0.00 %	0.18 %	0.21 %
700	1.491E-01	0.21 %	0.31 %	0.17 %	0.41 %	1.493E-01	0.10 %	0.00 %	0.17 %	0.20 %
750	1.650E-01	0.19 %	0.30 %	0.16 %	0.39 %	1.653E-01	0.09 %	0.00 %	0.16 %	0.18 %
800	1.764E-01	0.17 %	0.29 %	0.15 %	0.37 %	1.767E-01	0.08 %	0.00 %	0.15 %	0.17 %
850	1.835E-01	0.15 %	0.28 %	0.14 %	0.35 %	1.837E-01	0.08 %	0.00 %	0.14 %	0.16 %
900	1.868E-01	0.13 %	0.26 %	0.13 %	0.32 %	1.869E-01	0.07 %	0.00 %	0.13 %	0.15 %
950	1.869E-01	0.13 %	0.25 %	0.13 %	0.31 %	1.870E-01	0.07 %	0.00 %	0.13 %	0.14 %
1000	1.844E-01	0.13 %	0.25 %	0.12 %	0.30 %	1.845E-01	0.07 %	0.00 %	0.12 %	0.14 %
1100	1.740E-01	0.16 %	0.25 %	0.11 %	0.32 %	1.742E-01	0.08 %	0.00 %	0.11 %	0.13 %
1200	1.595E-01	0.19 %	0.28 %	0.10 %	0.36 %	1.597E-01	0.10 %	0.00 %	0.10 %	0.14 %
1300	1.434E-01	0.22 %	0.32 %	0.09 %	0.40 %	1.434E-01	0.11 %	0.00 %	0.09 %	0.15 %
1400	1.273E-01	0.23 %	0.33 %	0.09 %	0.41 %	1.271E-01	0.12 %	0.00 %	0.09 %	0.15 %
1500	1.121E-01	0.21 %	0.30 %	0.08 %	0.38 %	1.119E-01	0.11 %	0.00 %	0.08 %	0.14 %
1600	9.837E-02	0.19 %	0.26 %	0.08 %	0.33 %	9.828E-02	0.11 %	0.00 %	0.08 %	0.14 %
1700	8.617E-02	0.31 %	0.23 %	0.08 %	0.39 %	8.633E-02	0.15 %	0.00 %	0.08 %	0.17 %
1800	7.552E-02	0.78 %	0.21 %	0.08 %	0.81 %	7.577E-02	0.19 %	0.00 %	0.08 %	0.20 %
1900	6.625E-02	1.39 %	0.23 %	0.07 %	1.41 %	6.633E-02	0.23 %	0.00 %	0.07 %	0.24 %
2000	5.818E-02	1.81 %	0.29 %	0.08 %	1.84 %	5.790E-02	0.26 %	0.00 %	0.08 %	0.27 %
2100	5.112E-02	2.09 %	0.38 %	0.07 %	2.13 %	5.056E-02	0.25 %	0.00 %	0.07 %	0.26 %
2200	4.497E-02	2.68 %	0.45 %	0.06 %	2.72 %	4.435E-02	0.27 %	0.00 %	0.06 %	0.28 %
2300	3.957E-02	3.00 %	0.45 %	0.06 %	3.03 %	3.907E-02	0.31 %	0.00 %	0.06 %	0.31 %
2400	3.458E-02	4.34 %	0.76 %	0.09 %	4.41 %	3.425E-02	0.46 %	0.00 %	0.09 %	0.47 %
2500	3.016E-02	5.84 %	1.46 %	0.08 %	6.02 %	3.013E-02	0.42 %	0.00 %	0.08 %	0.42 %

Table 6-11 NPL Results for FEL 247. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 247	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.278E-04	2.31 %	0.32 %	2.06 %	3.11 %	1.261E-04	0.44 %	0.00 %	2.06 %	2.10 %
260	2.232E-04	1.72 %	0.32 %	2.05 %	2.69 %	2.203E-04	0.34 %	0.00 %	2.05 %	2.08 %
270	3.704E-04	1.29 %	0.31 %	2.05 %	2.44 %	3.657E-04	0.27 %	0.00 %	2.05 %	2.07 %
280	5.878E-04	0.98 %	0.29 %	1.56 %	1.86 %	5.806E-04	0.23 %	0.00 %	1.56 %	1.58 %
290	8.963E-04	0.76 %	0.27 %	1.08 %	1.35 %	8.855E-04	0.21 %	0.00 %	1.08 %	1.10 %
300	1.319E-03	0.62 %	0.33 %	0.45 %	0.83 %	1.303E-03	0.19 %	0.15 %	0.45 %	0.51 %
310	1.881E-03	0.52 %	0.38 %	0.43 %	0.78 %	1.859E-03	0.18 %	0.20 %	0.43 %	0.51 %
320	2.607E-03	0.46 %	0.43 %	0.37 %	0.73 %	2.576E-03	0.17 %	0.25 %	0.37 %	0.48 %
330	3.521E-03	0.41 %	0.47 %	0.36 %	0.72 %	3.480E-03	0.16 %	0.28 %	0.36 %	0.49 %
340	4.648E-03	0.36 %	0.53 %	0.35 %	0.73 %	4.595E-03	0.15 %	0.33 %	0.35 %	0.51 %
350	6.009E-03	0.36 %	0.58 %	0.34 %	0.76 %	5.940E-03	0.15 %	0.36 %	0.34 %	0.52 %
360	7.622E-03	0.34 %	0.67 %	0.33 %	0.82 %	7.537E-03	0.14 %	0.43 %	0.33 %	0.56 %
370	9.503E-03	0.32 %	0.72 %	0.32 %	0.85 %	9.398E-03	0.14 %	0.46 %	0.32 %	0.58 %
380	1.166E-02	0.30 %	0.81 %	0.31 %	0.91 %	1.154E-02	0.13 %	0.52 %	0.31 %	0.62 %
390	1.411E-02	0.28 %	0.78 %	0.31 %	0.88 %	1.396E-02	0.13 %	0.50 %	0.31 %	0.60 %
400	1.685E-02	0.27 %	0.72 %	0.30 %	0.83 %	1.668E-02	0.13 %	0.46 %	0.30 %	0.56 %
450	3.478E-02	0.24 %	0.31 %	0.27 %	0.47 %	3.446E-02	0.13 %	0.10 %	0.27 %	0.31 %
500	5.854E-02	0.21 %	0.31 %	0.24 %	0.45 %	5.807E-02	0.12 %	0.00 %	0.24 %	0.27 %
550	8.554E-02	0.19 %	0.33 %	0.22 %	0.44 %	8.491E-02	0.11 %	0.00 %	0.22 %	0.24 %
555	8.830E-02	0.18 %	0.33 %	0.22 %	0.44 %	8.766E-02	0.11 %	0.00 %	0.22 %	0.24 %
600	1.129E-01	0.18 %	0.33 %	0.20 %	0.43 %	1.121E-01	0.10 %	0.00 %	0.20 %	0.22 %
650	1.381E-01	0.15 %	0.32 %	0.18 %	0.40 %	1.372E-01	0.10 %	0.00 %	0.18 %	0.21 %
700	1.595E-01	0.19 %	0.31 %	0.17 %	0.40 %	1.586E-01	0.09 %	0.00 %	0.17 %	0.20 %
750	1.763E-01	0.17 %	0.30 %	0.16 %	0.38 %	1.754E-01	0.09 %	0.00 %	0.16 %	0.18 %
800	1.881E-01	0.15 %	0.29 %	0.15 %	0.36 %	1.873E-01	0.09 %	0.00 %	0.15 %	0.17 %
850	1.954E-01	0.13 %	0.28 %	0.14 %	0.34 %	1.946E-01	0.08 %	0.00 %	0.14 %	0.16 %
900	1.986E-01	0.12 %	0.26 %	0.13 %	0.32 %	1.979E-01	0.08 %	0.00 %	0.13 %	0.15 %
950	1.985E-01	0.12 %	0.25 %	0.13 %	0.31 %	1.978E-01	0.07 %	0.00 %	0.13 %	0.15 %
1000	1.957E-01	0.12 %	0.25 %	0.12 %	0.30 %	1.950E-01	0.08 %	0.00 %	0.12 %	0.14 %
1100	1.843E-01	0.14 %	0.25 %	0.11 %	0.31 %	1.837E-01	0.09 %	0.00 %	0.11 %	0.14 %
1200	1.687E-01	0.17 %	0.28 %	0.10 %	0.35 %	1.681E-01	0.10 %	0.00 %	0.10 %	0.14 %
1300	1.515E-01	0.19 %	0.32 %	0.09 %	0.39 %	1.510E-01	0.10 %	0.00 %	0.09 %	0.14 %
1400	1.344E-01	0.21 %	0.33 %	0.09 %	0.40 %	1.339E-01	0.11 %	0.00 %	0.09 %	0.15 %
1500	1.185E-01	0.20 %	0.30 %	0.08 %	0.37 %	1.180E-01	0.11 %	0.00 %	0.08 %	0.14 %
1600	1.040E-01	0.20 %	0.26 %	0.08 %	0.33 %	1.035E-01	0.11 %	0.00 %	0.08 %	0.14 %
1700	9.101E-02	0.32 %	0.23 %	0.08 %	0.40 %	9.037E-02	0.15 %	0.00 %	0.08 %	0.17 %
1800	7.952E-02	0.70 %	0.21 %	0.08 %	0.73 %	7.868E-02	0.21 %	0.00 %	0.08 %	0.23 %
1900	6.943E-02	1.18 %	0.23 %	0.07 %	1.21 %	6.839E-02	0.27 %	0.00 %	0.07 %	0.28 %
2000	6.069E-02	1.50 %	0.29 %	0.08 %	1.53 %	5.957E-02	0.32 %	0.00 %	0.08 %	0.33 %
2100	5.323E-02	1.67 %	0.38 %	0.07 %	1.71 %	5.224E-02	0.33 %	0.00 %	0.07 %	0.33 %
2200	4.693E-02	2.11 %	0.45 %	0.06 %	2.16 %	4.615E-02	0.36 %	0.00 %	0.06 %	0.36 %
2300	4.144E-02	2.37 %	0.45 %	0.06 %	2.41 %	4.074E-02	0.38 %	0.00 %	0.06 %	0.39 %
2400	3.628E-02	3.50 %	0.76 %	0.09 %	3.58 %	3.556E-02	0.47 %	0.00 %	0.09 %	0.48 %
2500	3.220E-02	4.43 %	1.46 %	0.08 %	4.66 %	3.167E-02	0.53 %	0.00 %	0.08 %	0.53 %

6.9 Lamp Behaviour

6.9.1 CSIRO Lamps

The following lamps were supplied to CSIRO by NPL:

FEL BN 9101 206 FEL BN 9101 196 FEL BN 9101 247

Measurements were made in the sequence: NPL – CSIRO – NPL – CSIRO.

CSIRO measured all intercomparison wavelengths except 2500 nm for lamp BN 9101 247 in the first round, and all intercomparison wavelengths in the second round.

6.9.2 Lamp electrical stability

The lamp was operated at 8.100 A at both laboratories, the lamp voltage measured was:

Table 6-12 Electrical Potential across lamp as measured by both laboratories

Lamp	Potential first NPL measurement	Potential first CSIRO measurement	Potential second NPL measurement	Potential second CSIRO measurement
FEL BN 9101 206	100.5 V	100.6 V	100.6 V	100.7 V
FEL BN 9101 196	102.2 V	102.4 V	102.5 V	102.5 V
FEL BN 9101 247	104.2 V	104.4 V	104.6 V	104.6 V

CSIRO made the following comments about the lamp voltages: Over the course of these measurements the lamp FEL BN 9101 196 voltage, in round 1

- dropped from an initial value of 102.72 V to 101.97 V over 12 hours of operation,
- then fluctuated between 101.97 V and 102.67 V over the next 5 hours of operation,
- was last measured as 102.40 V at the nominal current of 8.100 A.

In round 2

- dropped from an initial value of 102.77 V to 102.47 V over 7.5 hours of operation,
- then fluctuated between 102.47 V and 102.69 V over four short periods of burning over the next hour at the nominated current of 8.100 A.

Over the course of these measurements the lamp FEL BN 9101 206 voltage, in round 1

- dropped from an initial value of 100.84 V to 100.57 V over 10.7 hours of operation.

In round 2

- dropped from an initial value of 101.10 V to 100.70 V over 2 hours of operation,
- then dropped more gradually between 100.70 V and 100.62 V over the next 6 hours of burning at the nominated current of 8.100 A.

Over the course of these measurements the lamp FEL BN 9101 247 voltage, in round 1

- dropped from an initial value of 104.50 V to 104.36 V over 8 hours of operation,
- then increased from 104.36 V to 104.44 V over the next 0.6 hours of operation.

In round 2

- varied randomly between 104.59 V and 104.55 V over 7.6 hours of operation, at the nominated current of 8.100 A.

6.9.3 Lamp history

Table 6-13 Lamp history for FEL BN 9101 206

Date period	Activity	Burn hours:minutes
June – November 2001	1st round measurements at NPL	9:14
November 2001	Air-freight to CSIRO	
March – June 2002	1st round measurements at CSIRO	18:00
July 2002	Air-freight to NPL	
January – May 2003	2nd round measurements at NPL	10:46
May 2003	Air-freight to CSIRO	
November 2003	2nd round measurements at CSIRO	7:30

Table 6-14 Lamp history for FEL BN 9101 196

Date period	Activity	Burn hours:minutes
June – November 2001	1st round measurements at NPL	6:03
November 2001	Air-freight to CSIRO	
March – June 2002	1st round measurements at CSIRO	18:00
July 2002	Air-freight to NPL	
January – May 2003	2nd round measurements at NPL	12:37
May 2003	Air-freight to CSIRO	
November 2003	2nd round measurements at CSIRO	7:30

Table 6-15 Lamp history for FEL BN 9101 247

Date period	Activity	Burn hours:minutes
June – November 2001	1st round measurements at NPL	14:08
November 2001	Air-freight to CSIRO	
March – June 2002	1st round measurements at CSIRO	18:00
July 2002	Air-freight to NPL	
January – May 2003	2nd round measurements at NPL	15:20
May 2003	Air-freight to CSIRO	
November 2003	2nd round measurements at CSIRO	7:30

6.9.4 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the CSIRO lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

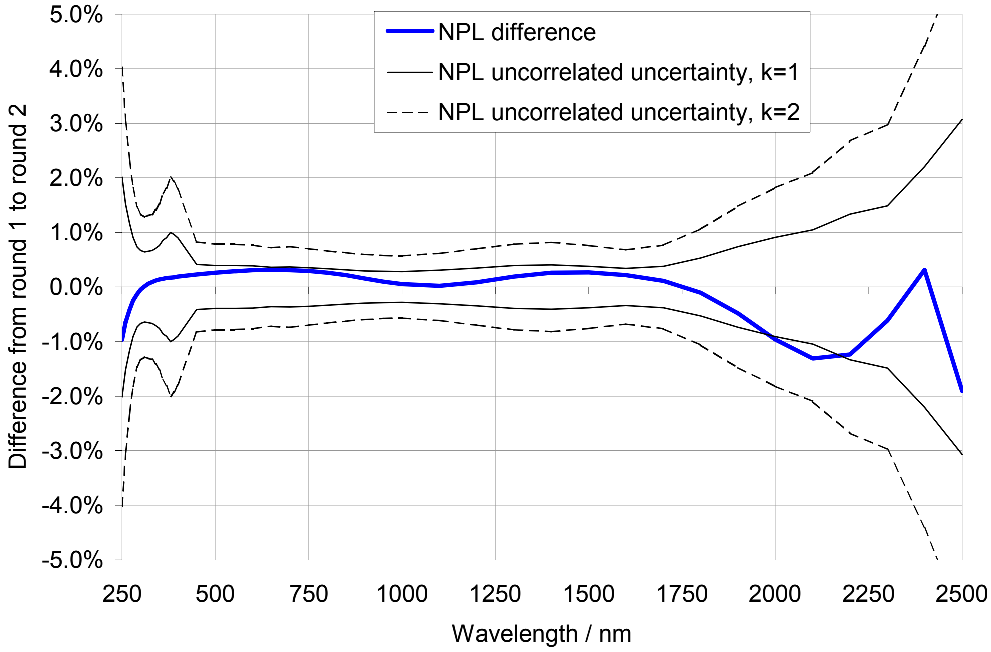

Figure 6-4 Difference between first and second round measurements of FEL BN 9101 196 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

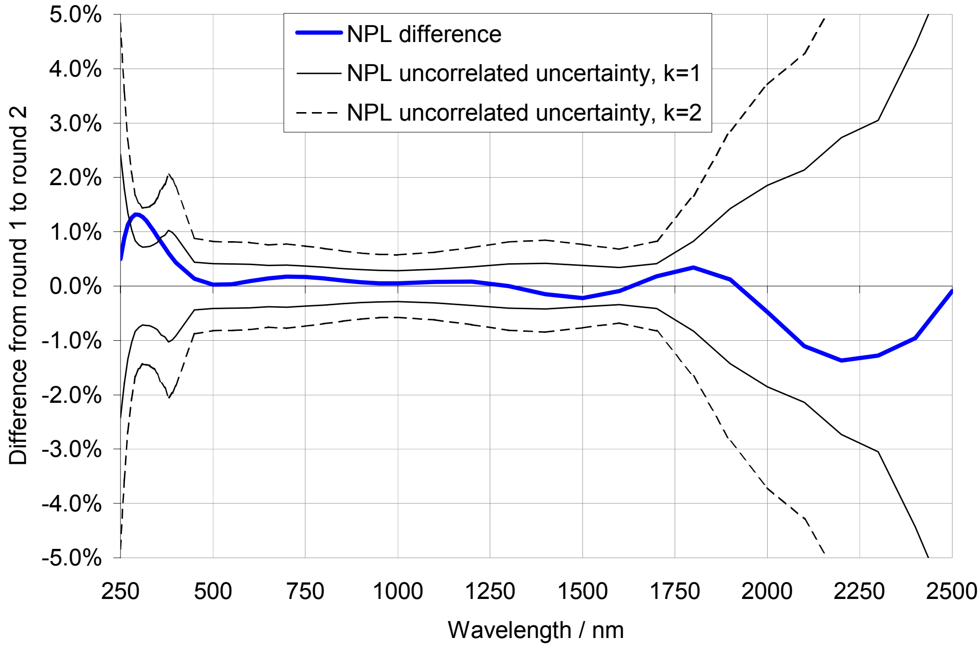

Figure 6-5 Difference between first and second round measurements of FEL BN 9101 206 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

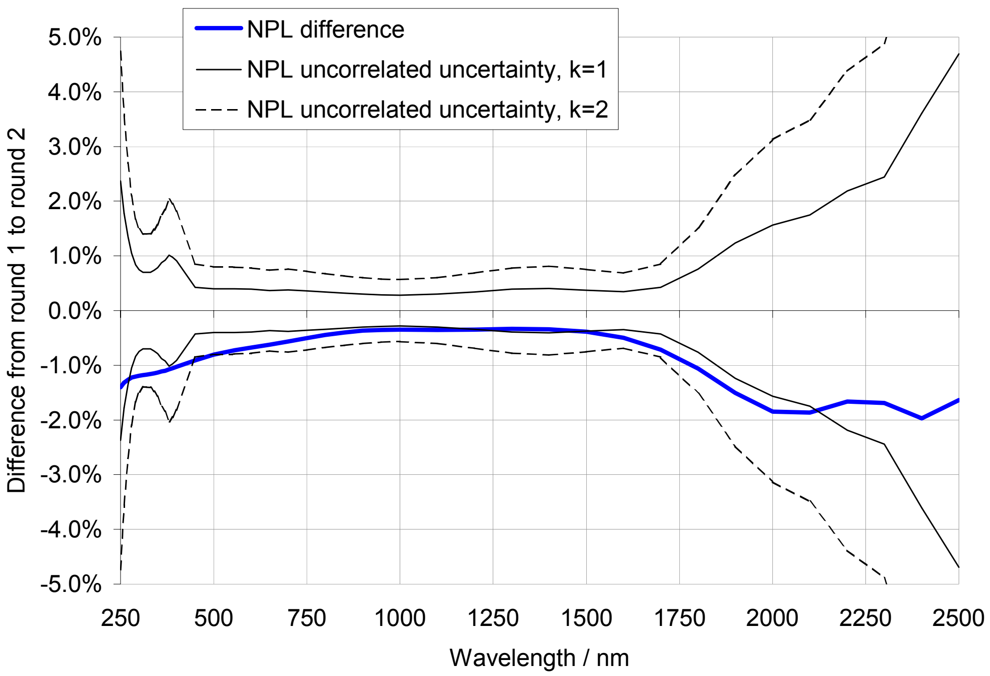

Figure 6-6 Difference between first and second round measurements of FEL BN 9101 247 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

6.9.5 Lamp stability from CSIRO measurements

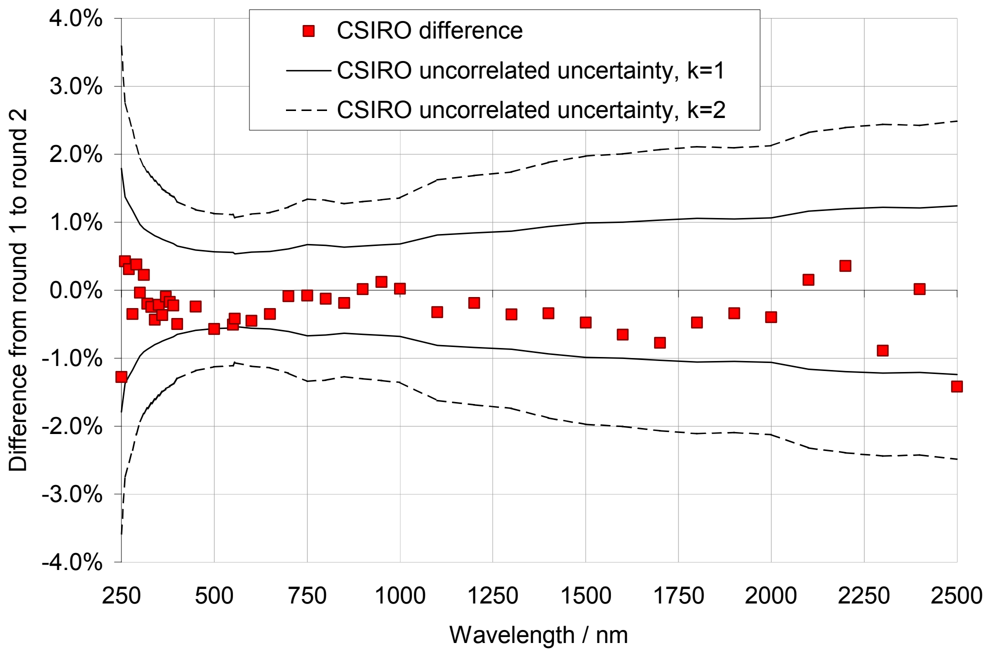

Figure 6-7 Difference between first and second round measurements of FEL BN 9101 196 by CSIRO. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the CSIRO measurements

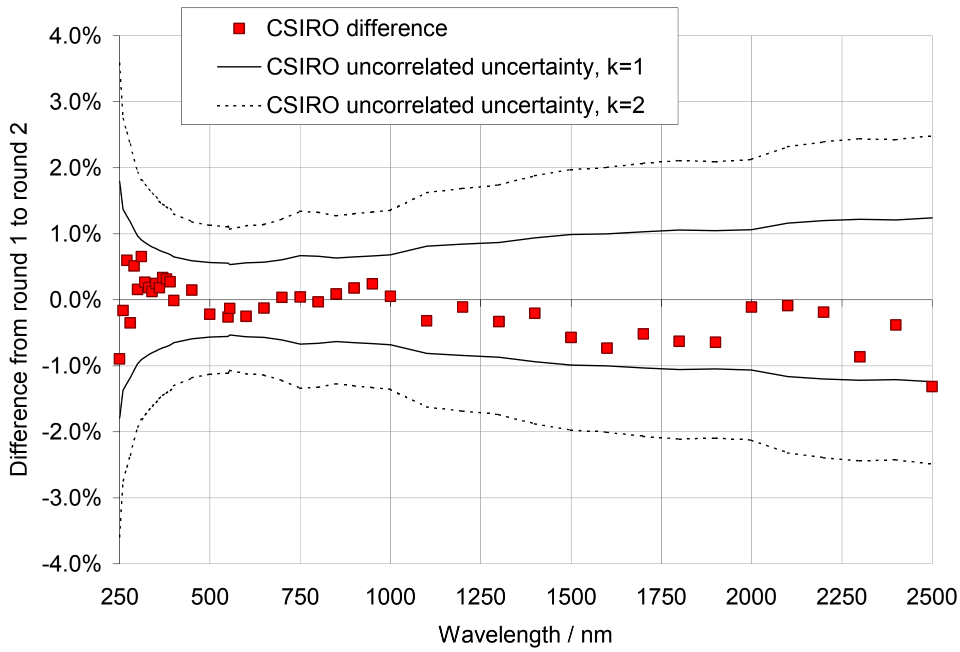

Figure 6-8 Difference between first and second round measurements of FEL BN 9101 206 by CSIRO. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the CSIRO measurements

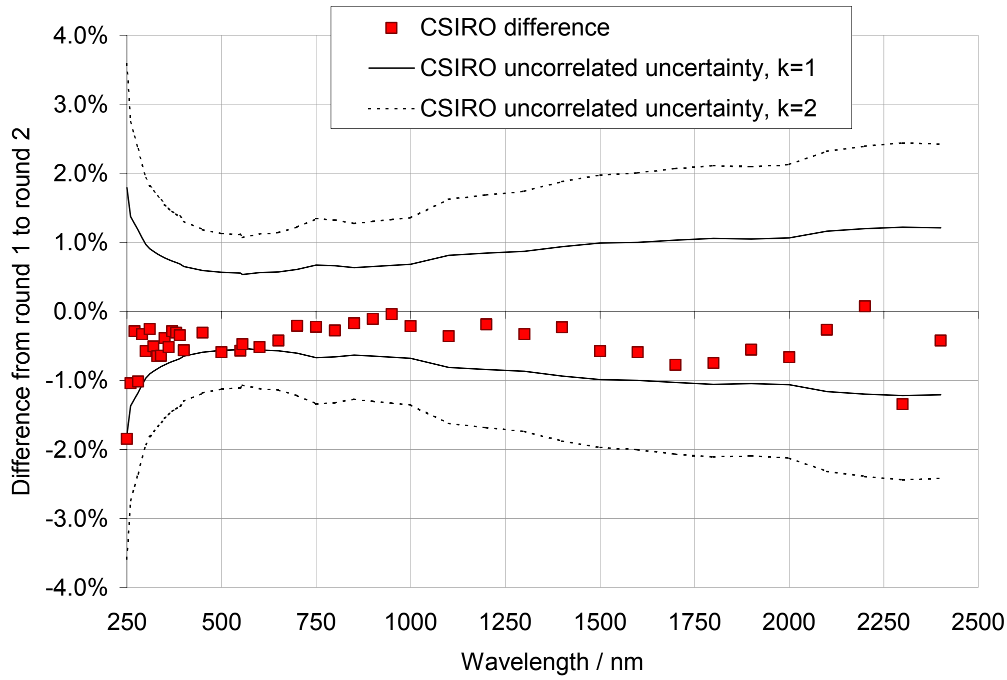

Figure 6-9 Difference between first and second round measurements of FEL BN 9101 247 by CSIRO. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the CSIRO measurements

6.10 Bilateral comparison between CSIRO and the comparison scale

This graph shows the difference between the CSIRO and NPL measurements of the CSIRO lamps. A version of this graph normalised to show the relative difference between the lamps, but not the absolute difference between the measurements was used to assist in choosing which lamp measurements to use.

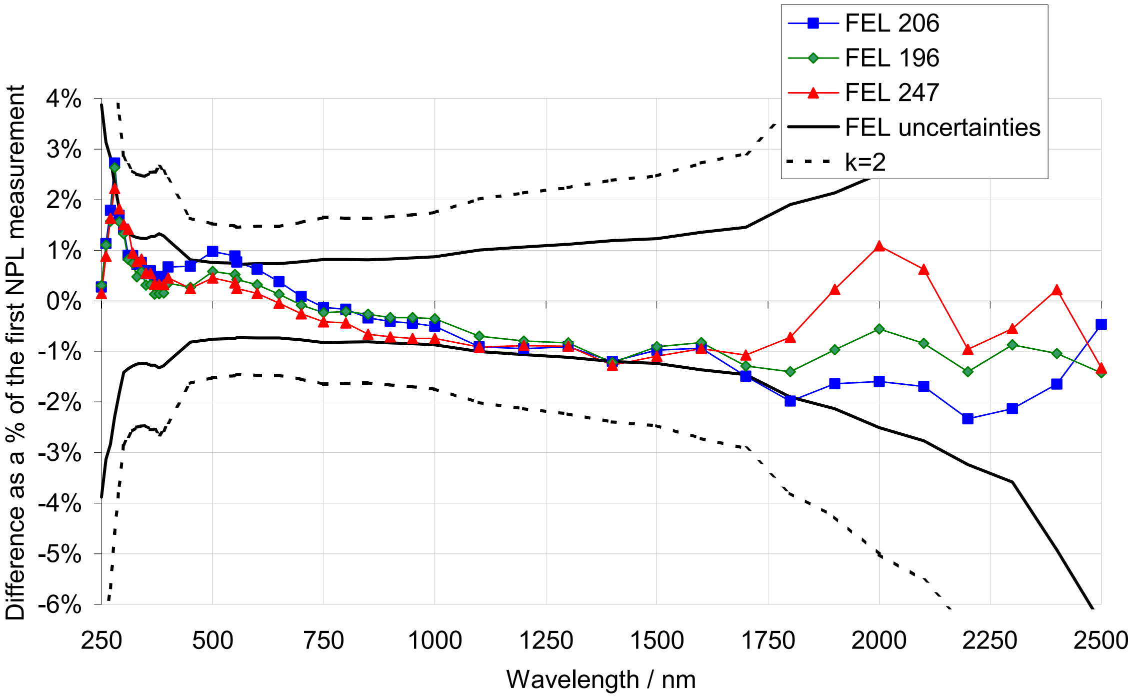

Figure 6-10 Bilateral comparisons of the CSIRO lamps

6.11 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to CSIRO the information in the graphs Figure 6-4 to Figure 6-10. It was decided that both participant measurements and both pilot measurements would be used for both FEL BN 9101 196 and for FEL BN 9101 206, but that only the second pilot measurement would be used for FEL BN 9101 247. This lamp shows a larger difference between the rounds than the other two lamps and also an electrical potential difference. Therefore, it is assumed that the lamp changed on the first journey to CSIRO, but remained stable after that (as shown from the repeatability of the CSIRO measurements).

6.12 References

[1] "Basis of NML2003 scale of relative spectral irradiance", F Wilkinson, December 2003, to be published.

[2] J. L. Gardner, D. J. Butler, E. G. Atkinson and F. J. Wilkinson, "New basis for the Australian realization of the candela" *Metrologia* **35**, 235-239 (1998).

[3] "The NML units of spectral responsivity 240 – 1650 nm", F Wilkinson, CSIRO Technical Memorandum TIPP 253, March 1998.

[4] "A new graphite cavity radiator as blackbody for high temperatures", M Groll and G Neuer, in *Temperature, its measurement and control in science and industry*, **Vol 4**, Part 1, 1978.

[5] "Temperature profiles of the graphite rods for the high temperature blackbody", G Neuer and J Landsperger, IKE Technical report IKE-5TN-1055-90, Stuttgart, Germany, October 1992.

7 Measurements at HUT*

7.1 Primary scale realisation

The calibration was carried out by using the method for the realisation of the detector-based irradiance scale of the Helsinki University of Technology [1,2]. The method utilises a filter radiometer with separately characterised components: a trap detector, a set of temperature-stabilised interference filters and a precision aperture. The trap detector is calibrated by using a cryogenic absolute radiometer. In addition, a pyroelectric radiometer (LaserProbe RS-5900) is used to transfer the calibration into the UV. The transmittances of the interference filters are calibrated with a reference spectrometer. The area of the aperture is measured with the direct optical method (DOM).

The characterised filter radiometer is used to measure the spectral irradiance of the lamp under calibration at a given distance. The filter radiometer is attached on an optical rail in front of the lamp, and the distance is set with the aid of a magnetic distance measurement unit. Photocurrent values of the filter radiometer are recorded with each filter. A current-to-voltage converter from Vinculum and a digital multimeter HP3458A are used in the measurement.

The measured values of photocurrent are used to derive the spectral irradiance values of the lamp at the effective wavelengths of the filters with the methods described in [1,2]. The values are interpolated with modified Planck's radiation law by using the least-squares fitting method. The interpolation was conducted separately in the near UV region and in the VIS-IR regions (2000). In 2002, a sixth degree polynomial was used to interpolate the effective emissivity throughout the whole region. As the result, the spectral irradiance values of the lamp are obtained in the spectral range between the lowest effective wavelength and the highest effective wavelength of the filters used.

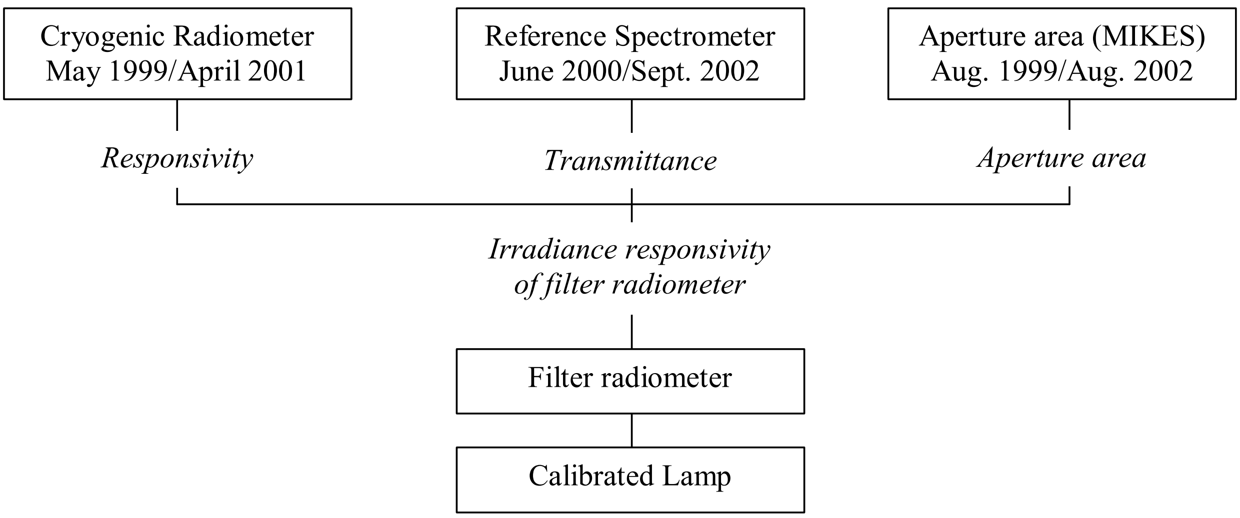

Figure 7-1 Traceability chain for establishing primary scale with calibration dates for the 2000 and 2002 calibrations.

7.1.1 2000 calibration traceability

The trap detector, MRI9909, was calibrated using a trap detector MRI9604. The trap detector MRI9604 was calibrated against the cryogenic absolute radiometer in the visible wavelength region [Calibration certificate T-R 111]. The modelling in UV region was verified with a laser measurement at the wavelength of 325.1 nm using the pyroelectric radiometer [Calibration certificate T-R 259].

* Helsinki University of Technology (HUT in this comparison) and Centre for Metrology and Accreditation (MIKES) have established a joint laboratory in January 2005. The laboratory name will in future be abbreviated as MIKES.

The current-to-voltage converter used to convert the photocurrent of the trap detector was calibrated by VTT [Technical Research Centre of Finland, Certificate of Calibration No. 98KM034]. The HP3458A digital multimeter used to measure the voltage of the current-to-voltage converter was calibrated by the manufacturer [Hewlett-Packard, Certificate of Calibration No. 91008609901].

The area of the precision aperture, A10, [Calibration certificate T-R 84] and the distance measurements needed were traceable to national standards of length.

The set of interference filters and the $V(\lambda)$-filter were calibrated using a reference spectrometer [Calibration certificate T-R 155].

7.1.2 2002 calibration traceability

The trap detector, UVFR-9, was calibrated using a group of three reference trap detectors [Calibration certificate T-R 255]. The reference trap detectors were calibrated against the cryogenic absolute radiometer in the visible wavelength region [Calibration certificate T-R 189]. UVFR-9 was modelled as part of the EU-project SMT4-CT98-2242. The modelling in UV region was verified with a laser measurement at the wavelength of 325.1 nm using the pyroelectric radiometer [Calibration certificate T-R 259].

The current-to-voltage converter used to convert the photocurrent of the trap detector was calibrated by VTT [Technical Research Centre of Finland, Certificate of Calibration No. 98KM034]. The validity of the calibration was checked with a Keithley calibrator. The HP3458A digital multimeter used to measure the voltage of the current-to-voltage converter was calibrated by MIKES [Certificate of Calibration No. M-02E009].

The area of the precision aperture, NFRA-1, [MIKES Certificate of Calibration No. M-02L392, further verified with DOM] and the distance measurements needed were traceable to national standards of length.

The set of interference filters and the $V(\lambda)$-filter were calibrated using a reference spectrometer [Calibration certificate T-R 260].

7.2 Description of measurement facility and measurement procedure

The filter radiometer and the lamp under calibration were aligned onto the same optical axis by using an alignment laser. In the alignment procedure, the position of the radiometer was first adjusted in such a way that the back-reflection from the centre of the device was directed back into the centre of the output aperture of the alignment laser. The lamp was then put into the beam so that the back-reflection from the midpoint of the alignment jig of the lamp hit the centre of the output aperture of the alignment laser. After alignment the alignment jig was removed. The distance between the aperture plane of the filter radiometer and the reference plane of the lamp was set to 500 mm by using the distance measurement unit. The front surface of the lamp housing was used as the reference plane for the lamp (Figure 7-2 and Figure 7-3). One baffle was used between the lamp and the filter radiometer in order to reduce the effect of stray light.

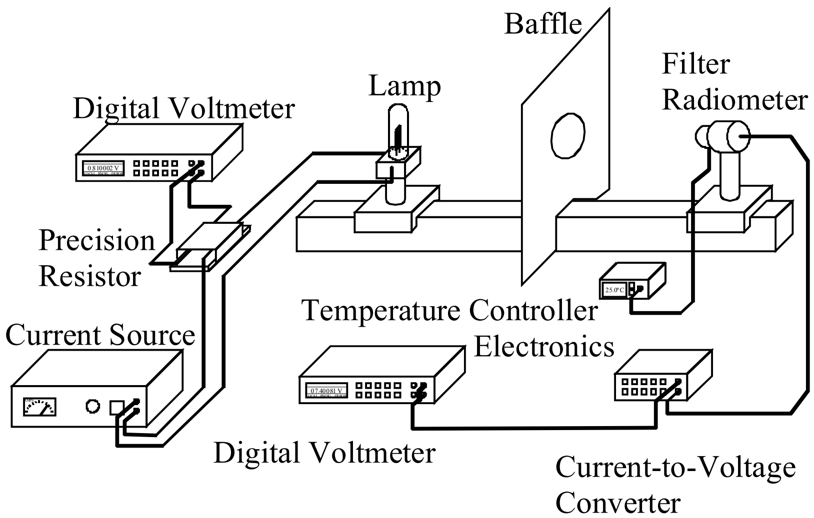

Figure 7-2 Measurement technique for spectral irradiance at HUT.

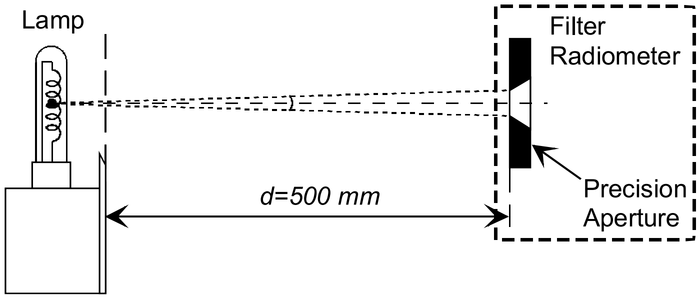

Figure 7-3 Distance setting in spectral irradiance measurements at HUT.

One lamp was measured at a time. Each lamp was allowed to stabilise for 45 min before the measurement started. The values of the currents and the voltages of the lamps were recorded during the measurements. The total burning time was about 2 hours for each lamp.

Two of the lamps were measured once; the third lamp was measured twice with full realignment.

7.3 Laboratory conditions

The laboratory conditions during the first round measurements are given in Table 7-1 and the conditions during the second round measurements are given in Table 7-2.

Table 7-1 Ambient temperature and relative humidity values during the round 1 calibrations.

Date of calibration	Lamp ID number	Temperature [°C]	Relative humidity [%]
22.08.2000	BN-9101-238	21.4 ± 0.2	44 ± 4
23.08.2000	BN-9101-245	21.6 ± 0.2	44 ± 4
23.08.2000	BN-9101-257	22.6 ± 0.2	42 ± 4
01.09.2000	BN-9101-257	22.9 ±0.2	40 ±4

Table 7-2 Ambient temperature and relative humidity values during the round 2 calibrations.

Date of calibration	Lamp ID number	Temperature [°C]	Relative humidity [%]
17.09.2002	BN-9101-257	24.0 ± 0.3	37 ± 4
17.09.2002	BN-9101-238	24.5 ± 0.3	38 ± 4
18.09.2002	BN-9101-245	24.5 ± 0.3	37 ± 4
24.09.2002	BN-9101-238	22.8 ±0.3	28 ±4

7.4 Uncertainty determination

A detailed uncertainty budget of the spectral irradiance measurements is given in Table 7-3. Uncertainty components arising from the detector responsivity, the filter transmittance, the irradiance measurement, the aperture area, the interreflections between the trap detector and the filter, and the interpolation of the spectral irradiance values between the effective wavelengths have been included. In Section 7.5, uncertainties are quoted individually for each measurement result. All uncertainties have been calculated according to the *ISO Guide to the Expression of Uncertainty in Measurement* and are given with a coverage factor k =1.

Table 7-3 also gives information about the correlation between the effects leading to these uncertainties. The effects are categorised as “fully correlated” if they are common for all measurements in both rounds, “uncorrelated” if they are independent for all lamps and “round” for correlations within a round. “Round and λ” describes effects that are correlated for all lamps within a round and for all wavelength measurements. For the purposes of this comparison, the wavelengths are treated independently and the uncertainty on these two types of “round” effects are combined.

Table 7-3 Uncertainty components of the spectral irradiance measurements (%). With correlation information.

Effective wavelength [nm]	**291**	**302**	**315**	**333**	**352**	**382**	**441**	**501**	**572**	**599**	**698**	**801**	**902**	**Correlation**
Detector responsivity	**0.67**	**0.67**	**0.54**	**0.51**	**0.51**	**0.51**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.08**	
Cryogenic radiometer	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	Round and λ
Transfer of the scale	-	-	-	-	-	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	Round
Reflectance modelling	-	-	-	-	-	-	0.04	0.04	0.04	0.04	0.04	0.04	0.02	Round
IQE modelling	-	-	-	-	-	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	Round
Spectral flatness of pyroelectric radiometer	0.50	0.50	0.30	0.30	0.30	0.30	-	-	-	-	-	-	-	Fully correlated
Repeatability	0.40	0.40	0.40	0.40	0.40	0.40	-	-	-	-	-	-	-	Round
Current measurement	0.20	0.20	0.20	0.10	0.10	0.07	0.02	0.02	0.02	0.02	0.02	0.02	0.02	Round
Nonlinearity	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Fully correlated
Filter transmittance	**0.97**	**0.46**	**0.40**	**0.39**	**0.38**	**0.41**	**0.20**	**0.18**	**0.23**	**0.23**	**0.23**	**0.19**	**0.19**	
Peak transmittance	0.89	0.32	0.20	0.30	0.30	0.35	0.15	0.15	0.22	0.22	0.22	0.15	0.15	Round
Wavelength uncertainty (0.06 nm)	0.24	0.21	0.19	0.16	0.14	0.11	0.08	0.05	0.03	0.03	0.01	0.01	0.01	Round
Wavelength repeatability (0.015 nm)	0.08	0.12	0.12	0.15	0.14	0.15	0.11	0.08	0.01	0.07	0.07	0.11	0.11	Round
Temperature	0.03	0.03	0.03	0.03	0.03	0.00	0.03	0.01	0.02	0.00	0.00	0.02	0.02	Round
OOB leakage	0.30	0.22	0.26	0.10	0.11	0.08	0.03	0.04	0.03	0.03	0.04	0.05	0.05	Round
Irradiance measurement	**0.30**	**0.21**	**0.21**	**0.23**	**0.23**	**0.21**	**0.21**	**0.21**	**0.16**	**0.16**	**0.16**	**0.16**	**0.16**	
Distance measurement (0.1 mm)	0.04	0.04	0.04	0.10	0.10	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	Uncorrelated
Repeatability	0.30	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.15	0.15	0.15	0.15	0.15	Uncorrelated
Lamp current (0.4 mA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Uncorrelated
Diffraction	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	Round and λ
Aperture area	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	Round
Interreflections	**0.26**	**0.14**	**0.10**	**0.10**	**0.11**	**0.11**	**0.03**	**0.02**	**0.02**	**0.02**	**0.01**	**0.01**	**0.01**	Fully correlated
Interpolation	**0.57**	**0.27**	**0.27**	**0.27**	**0.27**	**0.27**	**0.27**	**0.27**	**0.27**	**0.27**	**0.27**	**0.27**	**0.27**	Round and λ
Combined standard uncertainty	1.37	0.89	0.76	0.74	0.74	0.74	0.41	0.40	0.40	0.40	0.40	0.38	0.38	
Expanded uncertainty (k=2)	2.7	1.8	1.5	1.5	1.5	1.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	
Fully Uncorrelated	0.30	0.20	0.20	0.22	0.22	0.20	0.20	0.20	0.16	0.16	0.16	0.16	0.16	
Fully correlated in one round	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	
Correlated at each wavelength in one round	1.17	0.66	0.60	0.62	0.61	0.63	0.35	0.33	0.36	0.37	0.37	0.34	0.34	
Fully correlated	0.64	0.57	0.41	0.33	0.34	0.33	0.05	0.05	0.05	0.03	0.05	0.05	0.05	

7.5 HUT Results

HUT measured three lamps. The results for FEL BN 9101 238 are given in Table 7-4 and the results for FEL BN 9101 245 are given in Table 7-5 and the results for FEL BN 9101 257 are given in Table 7-6.

Table 7-4 HUT Results for FEL BN 9101 238. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 238	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290	9.050E-04	0.42 %	1.17 %	0.64 %	1.40 %	8.700E-04	0.42 %	1.17 %	0.64 %	1.40 %
300	1.322E-03	0.24 %	0.66 %	0.57 %	0.90 %	1.279E-03	0.24 %	0.66 %	0.57 %	0.90 %
310	1.876E-03	0.35 %	0.60 %	0.41 %	0.81 %	1.823E-03	0.35 %	0.60 %	0.41 %	0.81 %
320	2.590E-03	0.17 %	0.60 %	0.41 %	0.75 %	2.527E-03	0.17 %	0.60 %	0.41 %	0.75 %
330	3.490E-03	0.26 %	0.62 %	0.33 %	0.75 %	3.415E-03	0.26 %	0.62 %	0.33 %	0.75 %
340	4.610E-03	0.26 %	0.62 %	0.33 %	0.75 %	4.510E-03	0.26 %	0.62 %	0.33 %	0.75 %
350	5.960E-03	0.23 %	0.61 %	0.34 %	0.74 %	5.835E-03	0.23 %	0.61 %	0.34 %	0.74 %
360	7.560E-03	0.23 %	0.61 %	0.34 %	0.74 %	7.415E-03	0.23 %	0.61 %	0.34 %	0.74 %
370	9.420E-03	0.20 %	0.63 %	0.33 %	0.74 %	9.255E-03	0.20 %	0.63 %	0.33 %	0.74 %
380	1.157E-02	0.20 %	0.63 %	0.33 %	0.74 %	1.138E-02	0.20 %	0.63 %	0.33 %	0.74 %
390	1.401E-02	0.30 %	0.54 %	0.33 %	0.70 %	1.378E-02	0.30 %	0.54 %	0.33 %	0.70 %
400	1.675E-02	0.25 %	0.54 %	0.24 %	0.64 %	1.648E-02	0.25 %	0.54 %	0.24 %	0.64 %
450	3.480E-02	0.21 %	0.35 %	0.05 %	0.41 %	3.421E-02	0.21 %	0.35 %	0.05 %	0.41 %
500	5.890E-02	0.21 %	0.34 %	0.05 %	0.40 %	5.785E-02	0.21 %	0.34 %	0.05 %	0.40 %
550	8.620E-02	0.16 %	0.36 %	0.05 %	0.40 %	8.465E-02	0.16 %	0.36 %	0.05 %	0.40 %
555	8.900E-02	0.16 %	0.36 %	0.05 %	0.40 %	8.745E-02	0.16 %	0.36 %	0.05 %	0.40 %
600	1.138E-01	0.15 %	0.37 %	0.03 %	0.40 %	1.119E-01	0.15 %	0.37 %	0.03 %	0.40 %
650	1.391E-01	0.15 %	0.37 %	0.03 %	0.40 %	1.369E-01	0.15 %	0.37 %	0.03 %	0.40 %
700	1.606E-01	0.15 %	0.37 %	0.05 %	0.40 %	1.581E-01	0.15 %	0.37 %	0.05 %	0.40 %
750	1.776E-01	0.16 %	0.34 %	0.05 %	0.38 %	1.746E-01	0.16 %	0.34 %	0.05 %	0.38 %
800	1.896E-01	0.16 %	0.34 %	0.05 %	0.38 %	1.863E-01	0.16 %	0.34 %	0.05 %	0.38 %
850	1.968E-01	0.16 %	0.34 %	0.05 %	0.38 %	1.935E-01	0.16 %	0.34 %	0.05 %	0.38 %
900	1.994E-01	0.16 %	0.34 %	0.05 %	0.38 %	1.962E-01	0.16 %	0.34 %	0.05 %	0.38 %
950										
1000										
1100										
1200										
1300										
1400										
1500										
1600										
1700										
1800										
1900										
2000										
2100										
2200										
2300										
2400										

2500		

Table 7-5 HUT Results for FEL BN 9101 245. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 245	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290	9.230E-04	0.42 %	1.17 %	0.64 %	1.40 %	8.980E-04	0.42 %	1.17 %	0.64 %	1.40 %
300	1.343E-03	0.24 %	0.66 %	0.57 %	0.90 %	1.317E-03	0.24 %	0.66 %	0.57 %	0.90 %
310	1.899E-03	0.35 %	0.60 %	0.41 %	0.81 %	1.873E-03	0.35 %	0.60 %	0.41 %	0.81 %
320	2.620E-03	0.17 %	0.60 %	0.41 %	0.75 %	2.592E-03	0.17 %	0.60 %	0.41 %	0.75 %
330	3.520E-03	0.26 %	0.62 %	0.33 %	0.75 %	3.500E-03	0.26 %	0.62 %	0.33 %	0.75 %
340	4.640E-03	0.26 %	0.62 %	0.33 %	0.75 %	4.610E-03	0.26 %	0.62 %	0.33 %	0.75 %
350	6.000E-03	0.23 %	0.61 %	0.34 %	0.74 %	5.970E-03	0.23 %	0.61 %	0.34 %	0.74 %
360	7.600E-03	0.23 %	0.61 %	0.34 %	0.74 %	7.570E-03	0.23 %	0.61 %	0.34 %	0.74 %
370	9.470E-03	0.20 %	0.63 %	0.33 %	0.74 %	9.440E-03	0.20 %	0.63 %	0.33 %	0.74 %
380	1.161E-02	0.20 %	0.63 %	0.33 %	0.74 %	1.160E-02	0.20 %	0.63 %	0.33 %	0.74 %
390	1.406E-02	0.30 %	0.54 %	0.33 %	0.70 %	1.404E-02	0.30 %	0.54 %	0.33 %	0.70 %
400	1.681E-02	0.25 %	0.54 %	0.24 %	0.64 %	1.678E-02	0.25 %	0.54 %	0.24 %	0.64 %
450	3.490E-02	0.21 %	0.35 %	0.05 %	0.41 %	3.479E-02	0.21 %	0.35 %	0.05 %	0.41 %
500	5.900E-02	0.21 %	0.34 %	0.05 %	0.40 %	5.870E-02	0.21 %	0.34 %	0.05 %	0.40 %
550	8.630E-02	0.16 %	0.36 %	0.05 %	0.40 %	8.590E-02	0.16 %	0.36 %	0.05 %	0.40 %
555	8.900E-02	0.16 %	0.36 %	0.05 %	0.40 %	8.870E-02	0.16 %	0.36 %	0.05 %	0.40 %
600	1.138E-01	0.15 %	0.37 %	0.03 %	0.40 %	1.133E-01	0.15 %	0.37 %	0.03 %	0.40 %
650	1.391E-01	0.15 %	0.37 %	0.03 %	0.40 %	1.386E-01	0.15 %	0.37 %	0.03 %	0.40 %
700	1.607E-01	0.15 %	0.37 %	0.05 %	0.40 %	1.600E-01	0.15 %	0.37 %	0.05 %	0.40 %
750	1.777E-01	0.16 %	0.34 %	0.05 %	0.38 %	1.767E-01	0.16 %	0.34 %	0.05 %	0.38 %
800	1.897E-01	0.16 %	0.34 %	0.05 %	0.38 %	1.885E-01	0.16 %	0.34 %	0.05 %	0.38 %
850	1.970E-01	0.16 %	0.34 %	0.05 %	0.38 %	1.956E-01	0.16 %	0.34 %	0.05 %	0.38 %
900	1.997E-01	0.16 %	0.34 %	0.05 %	0.38 %	1.983E-01	0.16 %	0.34 %	0.05 %	0.38 %
950										
1000										
1100										
1200										
1300										
1400										
1500										
1600										
1700										
1800										
1900										
2000										
2100										
2200										
2300										
2400										
2500										

Table 7-6 HUT Results for FEL BN 9101 257. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 257	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290	1.171E-03	0.42 %	1.17 %	0.64 %	1.40 %	1.153E-03	0.42 %	1.17 %	0.64 %	1.40 %
300	1.688E-03	0.24 %	0.66 %	0.57 %	0.90 %	1.673E-03	0.24 %	0.66 %	0.57 %	0.90 %
310	2.370E-03	0.35 %	0.60 %	0.41 %	0.81 %	2.357E-03	0.35 %	0.60 %	0.41 %	0.81 %
320	3.235E-03	0.17 %	0.60 %	0.41 %	0.75 %	3.233E-03	0.17 %	0.60 %	0.41 %	0.75 %
330	4.330E-03	0.26 %	0.62 %	0.33 %	0.75 %	4.330E-03	0.26 %	0.62 %	0.33 %	0.75 %
340	5.655E-03	0.26 %	0.62 %	0.33 %	0.75 %	5.670E-03	0.26 %	0.62 %	0.33 %	0.75 %
350	7.260E-03	0.23 %	0.61 %	0.34 %	0.74 %	7.270E-03	0.23 %	0.61 %	0.34 %	0.74 %
360	9.150E-03	0.23 %	0.61 %	0.34 %	0.74 %	9.170E-03	0.23 %	0.61 %	0.34 %	0.74 %
370	1.133E-02	0.20 %	0.63 %	0.33 %	0.74 %	1.137E-02	0.20 %	0.63 %	0.33 %	0.74 %
380	1.383E-02	0.20 %	0.63 %	0.33 %	0.74 %	1.388E-02	0.20 %	0.63 %	0.33 %	0.74 %
390	1.666E-02	0.30 %	0.54 %	0.33 %	0.70 %	1.672E-02	0.30 %	0.54 %	0.33 %	0.70 %
400	1.982E-02	0.25 %	0.54 %	0.24 %	0.64 %	1.989E-02	0.25 %	0.54 %	0.24 %	0.64 %
450	4.030E-02	0.21 %	0.35 %	0.05 %	0.41 %	4.035E-02	0.21 %	0.35 %	0.05 %	0.41 %
500	6.705E-02	0.21 %	0.34 %	0.05 %	0.40 %	6.700E-02	0.21 %	0.34 %	0.05 %	0.40 %
550	9.680E-02	0.16 %	0.36 %	0.05 %	0.40 %	9.670E-02	0.16 %	0.36 %	0.05 %	0.40 %
555	9.980E-02	0.16 %	0.36 %	0.05 %	0.40 %	9.970E-02	0.16 %	0.36 %	0.05 %	0.40 %
600	1.263E-01	0.15 %	0.37 %	0.03 %	0.40 %	1.262E-01	0.15 %	0.37 %	0.03 %	0.40 %
650	1.531E-01	0.15 %	0.37 %	0.03 %	0.40 %	1.528E-01	0.15 %	0.37 %	0.03 %	0.40 %
700	1.754E-01	0.15 %	0.37 %	0.05 %	0.40 %	1.750E-01	0.15 %	0.37 %	0.05 %	0.40 %
750	1.926E-01	0.16 %	0.34 %	0.05 %	0.38 %	1.919E-01	0.16 %	0.34 %	0.05 %	0.38 %
800	2.044E-01	0.16 %	0.34 %	0.05 %	0.38 %	2.035E-01	0.16 %	0.34 %	0.05 %	0.38 %
850	2.110E-01	0.16 %	0.34 %	0.05 %	0.38 %	2.100E-01	0.16 %	0.34 %	0.05 %	0.38 %
900	2.127E-01	0.16 %	0.34 %	0.05 %	0.38 %	2.119E-01	0.16 %	0.34 %	0.05 %	0.38 %
950										
1000										
1100										
1200										
1300										
1400										
1500										
1600										
1700										
1800										
1900										
2000										
2100										
2200										
2300										
2400										
2500										

7.6 Pilot Results

NPL's results for FEL BN 9101 238 are given in Table 7-7 and the results for FEL BN 9101 245 are given in Table 7-8 and the results for FEL BN 9101 257 are given in Table 7-9.

Table 7-7 NPL Results for FEL BN 9101 238. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 238	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290	8.573E-04	0.25 %	0.41 %	1.00 %	1.11 %	8.514E-04	0.24 %	0.38 %	1.00 %	1.10 %
300	1.268E-03	0.21 %	0.40 %	0.25 %	0.52 %	1.261E-03	0.21 %	0.37 %	0.25 %	0.50 %
310	1.816E-03	0.19 %	0.39 %	0.28 %	0.52 %	1.807E-03	0.20 %	0.36 %	0.28 %	0.50 %
320	2.526E-03	0.18 %	0.37 %	0.25 %	0.48 %	2.514E-03	0.18 %	0.35 %	0.25 %	0.47 %
330	3.423E-03	0.17 %	0.36 %	0.28 %	0.49 %	3.408E-03	0.17 %	0.34 %	0.28 %	0.47 %
340	4.531E-03	0.17 %	0.35 %	0.33 %	0.51 %	4.512E-03	0.17 %	0.33 %	0.33 %	0.49 %
350	5.873E-03	0.16 %	0.34 %	0.36 %	0.52 %	5.847E-03	0.16 %	0.32 %	0.36 %	0.51 %
360	7.466E-03	0.16 %	0.33 %	0.43 %	0.57 %	7.432E-03	0.15 %	0.31 %	0.43 %	0.55 %
370	9.326E-03	0.15 %	0.32 %	0.46 %	0.58 %	9.283E-03	0.15 %	0.30 %	0.46 %	0.57 %
380	1.147E-02	0.15 %	0.31 %	0.52 %	0.63 %	1.141E-02	0.14 %	0.29 %	0.52 %	0.61 %
390	1.389E-02	0.15 %	0.31 %	0.50 %	0.61 %	1.382E-02	0.14 %	0.29 %	0.50 %	0.59 %
400	1.661E-02	0.15 %	0.30 %	0.46 %	0.57 %	1.653E-02	0.14 %	0.28 %	0.46 %	0.56 %
450	3.445E-02	0.15 %	0.27 %	0.10 %	0.32 %	3.424E-02	0.14 %	0.25 %	0.10 %	0.30 %
500	5.815E-02	0.14 %	0.24 %	0.01 %	0.28 %	5.775E-02	0.13 %	0.22 %	0.01 %	0.26 %
550	8.508E-02	0.12 %	0.22 %	0.00 %	0.25 %	8.450E-02	0.11 %	0.20 %	0.00 %	0.23 %
555	8.784E-02	0.12 %	0.22 %	0.00 %	0.25 %	8.724E-02	0.11 %	0.20 %	0.00 %	0.23 %
600	1.124E-01	0.11 %	0.20 %	0.00 %	0.23 %	1.116E-01	0.10 %	0.19 %	0.00 %	0.21 %
650	1.376E-01	0.11 %	0.18 %	0.00 %	0.21 %	1.368E-01	0.10 %	0.17 %	0.00 %	0.20 %
700	1.590E-01	0.11 %	0.17 %	0.00 %	0.20 %	1.582E-01	0.10 %	0.16 %	0.00 %	0.19 %
750	1.757E-01	0.10 %	0.16 %	0.01 %	0.19 %	1.750E-01	0.09 %	0.15 %	0.01 %	0.17 %
800	1.876E-01	0.09 %	0.15 %	0.00 %	0.18 %	1.869E-01	0.09 %	0.14 %	0.00 %	0.16 %
850	1.949E-01	0.09 %	0.14 %	0.00 %	0.17 %	1.943E-01	0.08 %	0.13 %	0.00 %	0.16 %
900	1.982E-01	0.08 %	0.13 %	0.00 %	0.16 %	1.975E-01	0.08 %	0.12 %	0.00 %	0.15 %
950										
1000										
1100										
1200										
1300										
1400										
1500										
1600										
1700										
1800										
1900										
2000										
2100										
2200										
2300										
2400										
2500										

Table 7-8 NPL Results for FEL BN 9101 245. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 245	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290	8.834E-04	0.22 %	0.41 %	1.00 %	1.10 %	8.891E-04	0.26 %	0.38 %	1.00 %	1.10 %
300	1.303E-03	0.20 %	0.40 %	0.25 %	0.51 %	1.312E-03	0.24 %	0.37 %	0.25 %	0.51 %
310	1.862E-03	0.18 %	0.39 %	0.28 %	0.51 %	1.874E-03	0.23 %	0.36 %	0.28 %	0.51 %
320	2.585E-03	0.17 %	0.37 %	0.25 %	0.48 %	2.600E-03	0.22 %	0.35 %	0.25 %	0.48 %
330	3.498E-03	0.16 %	0.36 %	0.28 %	0.49 %	3.516E-03	0.20 %	0.34 %	0.28 %	0.48 %
340	4.623E-03	0.15 %	0.35 %	0.33 %	0.51 %	4.644E-03	0.19 %	0.33 %	0.33 %	0.50 %
350	5.984E-03	0.15 %	0.34 %	0.36 %	0.52 %	6.006E-03	0.19 %	0.32 %	0.36 %	0.52 %
360	7.598E-03	0.14 %	0.33 %	0.43 %	0.56 %	7.621E-03	0.18 %	0.31 %	0.43 %	0.56 %
370	9.482E-03	0.14 %	0.32 %	0.46 %	0.58 %	9.504E-03	0.17 %	0.30 %	0.46 %	0.58 %
380	1.165E-02	0.13 %	0.31 %	0.52 %	0.62 %	1.167E-02	0.17 %	0.29 %	0.52 %	0.62 %
390	1.410E-02	0.13 %	0.31 %	0.50 %	0.60 %	1.412E-02	0.16 %	0.29 %	0.50 %	0.60 %
400	1.685E-02	0.13 %	0.30 %	0.46 %	0.56 %	1.686E-02	0.16 %	0.28 %	0.46 %	0.56 %
450	3.486E-02	0.13 %	0.27 %	0.10 %	0.31 %	3.480E-02	0.16 %	0.25 %	0.10 %	0.31 %
500	5.873E-02	0.12 %	0.24 %	0.01 %	0.27 %	5.861E-02	0.14 %	0.22 %	0.01 %	0.26 %
550	8.584E-02	0.10 %	0.22 %	0.00 %	0.24 %	8.568E-02	0.12 %	0.20 %	0.00 %	0.24 %
555	8.861E-02	0.10 %	0.22 %	0.00 %	0.24 %	8.845E-02	0.12 %	0.20 %	0.00 %	0.23 %
600	1.133E-01	0.10 %	0.20 %	0.00 %	0.22 %	1.131E-01	0.11 %	0.19 %	0.00 %	0.22 %
650	1.386E-01	0.09 %	0.18 %	0.00 %	0.21 %	1.385E-01	0.11 %	0.17 %	0.00 %	0.20 %
700	1.601E-01	0.09 %	0.17 %	0.00 %	0.19 %	1.600E-01	0.11 %	0.16 %	0.00 %	0.19 %
750	1.769E-01	0.09 %	0.16 %	0.01 %	0.18 %	1.769E-01	0.10 %	0.15 %	0.01 %	0.18 %
800	1.889E-01	0.08 %	0.15 %	0.00 %	0.17 %	1.888E-01	0.10 %	0.14 %	0.00 %	0.17 %
850	1.962E-01	0.08 %	0.14 %	0.00 %	0.16 %	1.961E-01	0.09 %	0.13 %	0.00 %	0.16 %
900	1.995E-01	0.08 %	0.13 %	0.00 %	0.15 %	1.993E-01	0.09 %	0.12 %	0.00 %	0.15 %
950										
1000										
1100										
1200										
1300										
1400										
1500										
1600										
1700										
1800										
1900										
2000										
2100										
2200										
2300										
2400										
2500										

Table 7-9 NPL Results for FEL BN 9101 257. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 257	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290	1.128E-03	0.23 %	0.41 %	1.00 %	1.11 %	1.143E-03	0.24 %	0.38 %	1.00 %	1.10 %
300	1.650E-03	0.20 %	0.40 %	0.25 %	0.51 %	1.669E-03	0.22 %	0.37 %	0.25 %	0.50 %
310	2.338E-03	0.18 %	0.39 %	0.28 %	0.51 %	2.362E-03	0.20 %	0.36 %	0.28 %	0.50 %
320	3.221E-03	0.17 %	0.37 %	0.25 %	0.48 %	3.249E-03	0.18 %	0.35 %	0.25 %	0.47 %
330	4.326E-03	0.16 %	0.36 %	0.28 %	0.48 %	4.357E-03	0.17 %	0.34 %	0.28 %	0.47 %
340	5.677E-03	0.15 %	0.35 %	0.33 %	0.51 %	5.712E-03	0.16 %	0.33 %	0.33 %	0.49 %
350	7.298E-03	0.14 %	0.34 %	0.36 %	0.52 %	7.335E-03	0.16 %	0.32 %	0.36 %	0.51 %
360	9.207E-03	0.14 %	0.33 %	0.43 %	0.56 %	9.247E-03	0.15 %	0.31 %	0.43 %	0.55 %
370	1.142E-02	0.13 %	0.32 %	0.46 %	0.58 %	1.146E-02	0.15 %	0.30 %	0.46 %	0.57 %
380	1.395E-02	0.13 %	0.31 %	0.52 %	0.62 %	1.399E-02	0.14 %	0.29 %	0.52 %	0.61 %
390	1.679E-02	0.13 %	0.31 %	0.50 %	0.60 %	1.683E-02	0.14 %	0.29 %	0.50 %	0.59 %
400	1.996E-02	0.13 %	0.30 %	0.46 %	0.56 %	2.000E-02	0.14 %	0.28 %	0.46 %	0.56 %
450	4.037E-02	0.13 %	0.27 %	0.10 %	0.31 %	4.042E-02	0.14 %	0.25 %	0.10 %	0.30 %
500	6.687E-02	0.12 %	0.24 %	0.01 %	0.27 %	6.694E-02	0.14 %	0.22 %	0.01 %	0.26 %
550	9.643E-02	0.11 %	0.22 %	0.00 %	0.24 %	9.658E-02	0.12 %	0.20 %	0.00 %	0.24 %
555	9.943E-02	0.11 %	0.22 %	0.00 %	0.24 %	9.958E-02	0.12 %	0.20 %	0.00 %	0.23 %
600	1.259E-01	0.10 %	0.20 %	0.00 %	0.22 %	1.261E-01	0.11 %	0.19 %	0.00 %	0.22 %
650	1.526E-01	0.10 %	0.18 %	0.00 %	0.21 %	1.529E-01	0.11 %	0.17 %	0.00 %	0.20 %
700	1.749E-01	0.09 %	0.17 %	0.00 %	0.19 %	1.752E-01	0.11 %	0.16 %	0.00 %	0.19 %
750	1.920E-01	0.09 %	0.16 %	0.01 %	0.18 %	1.923E-01	0.10 %	0.15 %	0.01 %	0.18 %
800	2.037E-01	0.08 %	0.15 %	0.00 %	0.17 %	2.040E-01	0.10 %	0.14 %	0.00 %	0.17 %
850	2.105E-01	0.08 %	0.14 %	0.00 %	0.16 %	2.107E-01	0.09 %	0.13 %	0.00 %	0.16 %
900	2.131E-01	0.08 %	0.13 %	0.00 %	0.15 %	2.131E-01	0.09 %	0.12 %	0.00 %	0.15 %
950										
1000										
1100										
1200										
1300										
1400										
1500										
1600										
1700										
1800										
1900										
2000										
2100										
2200										
2300										
2400										
2500										

7.7 Lamp Behaviour

7.7.1 HUT Lamps

The following lamps were supplied to HUT by NPL:

FEL BN 9101 238 FEL BN 9101 257 FEL BN 9101 245

Measurements were made in the sequence: HUT – NPL – HUT – NPL

There was an initial measurement of the lamps at NPL prior to this sequence, however the decision was made to ignore those results in light of the improvements made subsequently to the facility and hence to the measurement accuracy at NPL.

HUT measured all intercomparison wavelengths between 290 nm and 900 nm.

7.7.2 Lamp electrical stability

The lamp was operated at 8.100 A at both laboratories, the lamp voltage measured was:

Table 7-10 Electrical Potential across lamp as measured by both laboratories.

Lamp	Potential first HUT measurement	Potential first NPL measurement	Potential second HUT measurement	Potential second NPL measurement
FEL BN 9101 238	105.23 V	104.9 V	104.84 V	104.8 V
FEL BN 9101 257	110.01 V	109.8 V	109.87 V	109.8 V
FEL BN 9101 245	105.05 V	104.9 V	104.94 V	104.8 V

7.7.3 Other comments on lamps

HUT has reported in the second measurement report (T-R 275.doc) that: “It was noticed that NPL aligns the lamps with the alignment jig flipped 180 degrees as compared with the routines of HUT. The second measurement with lamp BN-9101-238 was done with the NPL alignment. As can be seen, the change is of the same order of magnitude as the repeatability of the measurements.”

Both the first report (T-R 163B.doc) and the second report (T-R 275.doc) also reported that: “Transfer standard ID No. *BN-9101-238* was observed to have strongly fogged glass envelope. The similar effect was noticed also for the lamp *BN-9101-245* in somewhat smaller extent.”

The second report also included: “The voltages of lamps 238 and 245 have dropped by approximately 0.5 V during transportations. Corresponding significant changes can be seen in the spectral irradiances.” And “Lamp 257 works correctly. With the other two lamps the changes have to be taken into account.”

7.7.4 Lamp history

Table 7-11 Lamp history for FEL BN 9101 238.

Date period	Activity	Burn hours:minutes
July – August 2000	0th round measurements at NPL (not used)	10:30
August 2000	Hand-carried to HUT	
Aug. – Sept. 2000	1st round measurements at HUT	2:00
September 2000	Hand-carried to NPL	
February – July 2002	1st round measurements at NPL	14:01
August 2002	Hand-carried to HUT	
September 2002	2nd round measurements at HUT	3:33
October 2002	Hand-carried to NPL	
June – August 2003	2nd round measurements at NPL	16:27
November 2003	Hand-carried to HUT	

Table 7-12 Lamp history for FEL BN 9101 257.

Date period	Activity	Burn hours:minutes
July – August 2000	0th round measurements at NPL (not used)	6:56
August 2000	Hand-carried to HUT	
Aug. – Sept. 2000	1st round measurements at HUT	3:27
September 2000	Hand-carried to NPL	
February – July 2002	1st round measurements at NPL	10:45
August 2002	Hand-carried to HUT	
September 2002	2nd round measurements at HUT	1:55
October 2002	Hand-carried to NPL	
June – August 2003	2nd round measurements at NPL	12:02
November 2003	Hand-carried to HUT	

Table 7-13 Lamp history for FEL BN 9101 245.

Date period	Activity	Burn hours:minutes
July – August 2000	0th round measurements at NPL (not used)	7:01
August 2000	Hand-carried to HUT	
Aug. – Sept. 2000	1st round measurements at HUT	2:00
September 2000	Hand-carried to NPL	
February – July 2002	1st round measurements at NPL	15:34
August 2002	Hand-carried to HUT	
September 2002	2nd round measurements at HUT	1:45
October 2002	Hand-carried to NPL	
June – August 2003	2nd round measurements at NPL	14:08
November 2003	Hand-carried to HUT	

7.7.5 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the HUT lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

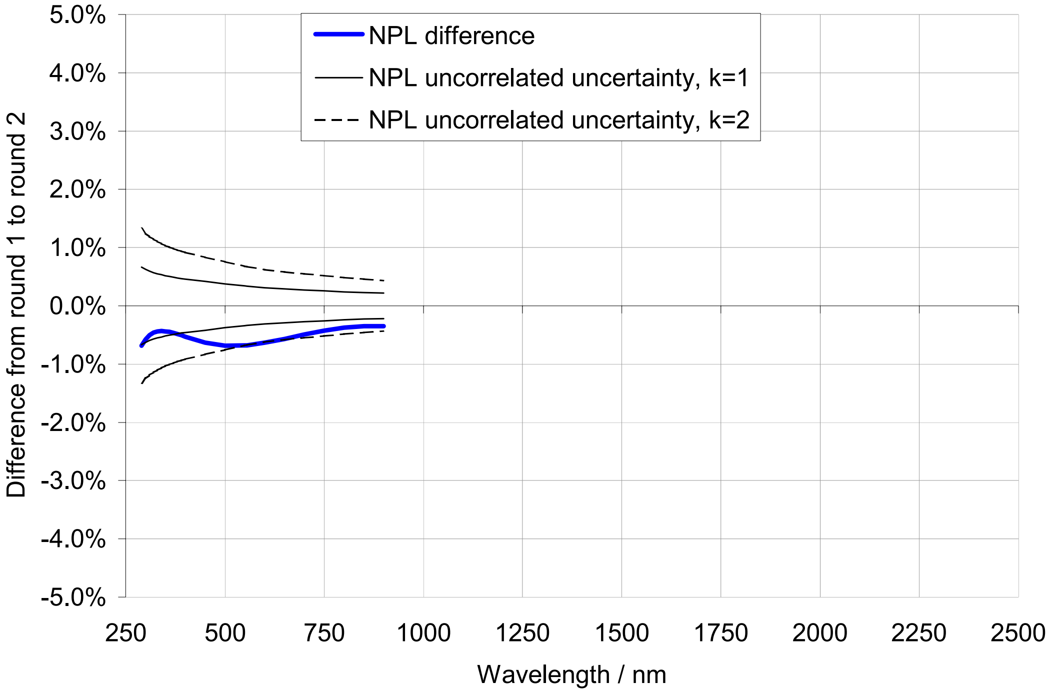

Figure 7-4 Difference between first and second round measurements of FEL BN 9101 238 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements.

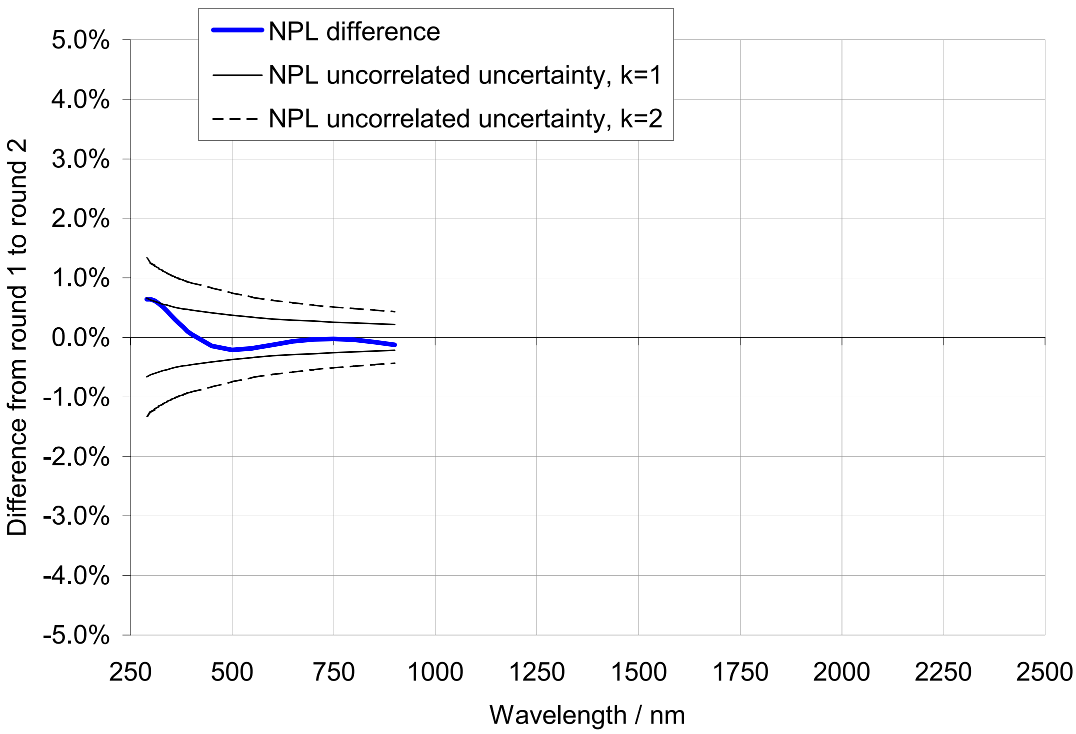

Figure 7-5 Difference between first and second round measurements of FEL BN 9101 245 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements.

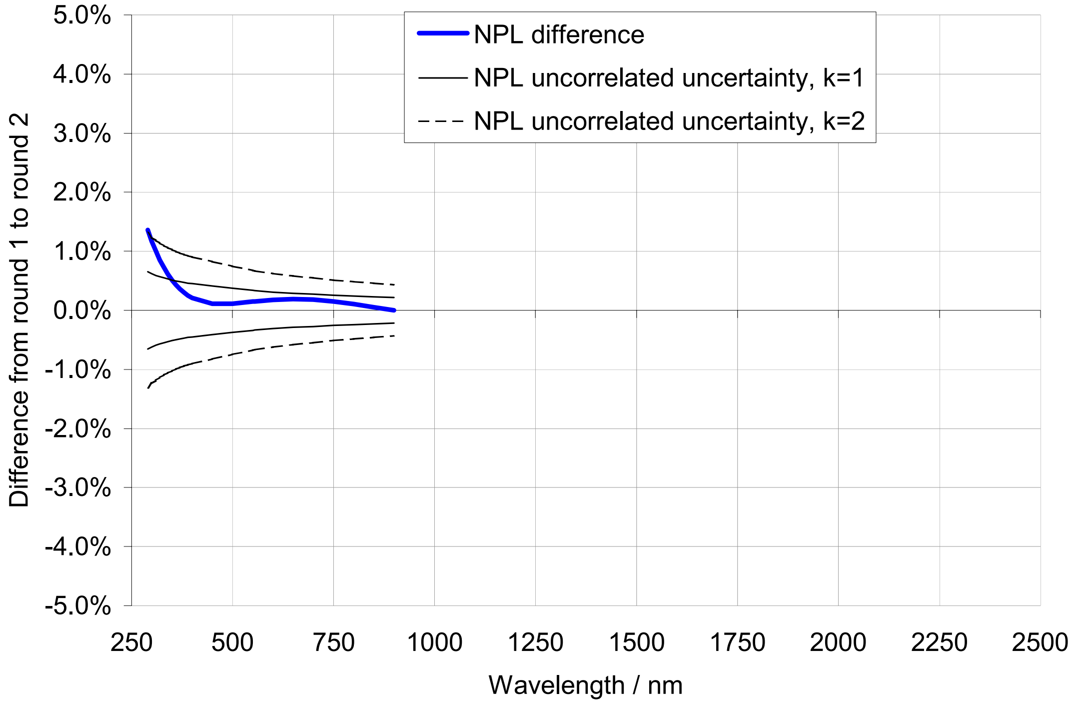

Figure 7-6 Difference between first and second round measurements of FEL BN 9101 257 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements.

7.7.6 Lamp stability from HUT measurements

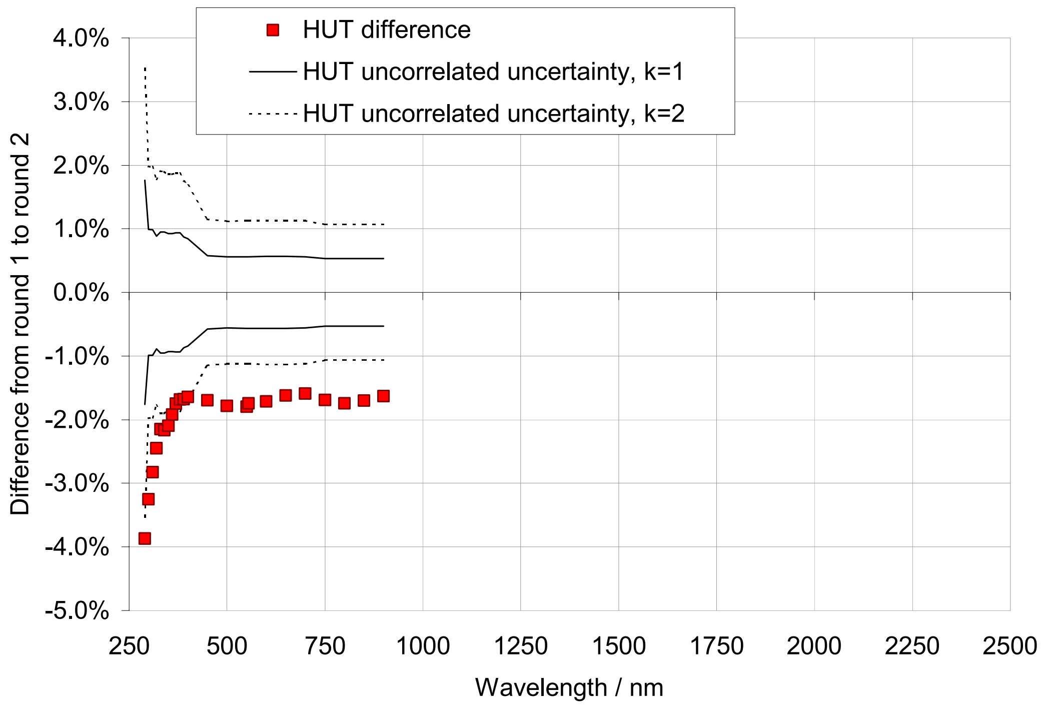

Figure 7-7 Difference between first and second round measurements of FEL BN 9101 238 by HUT. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the HUT measurements.

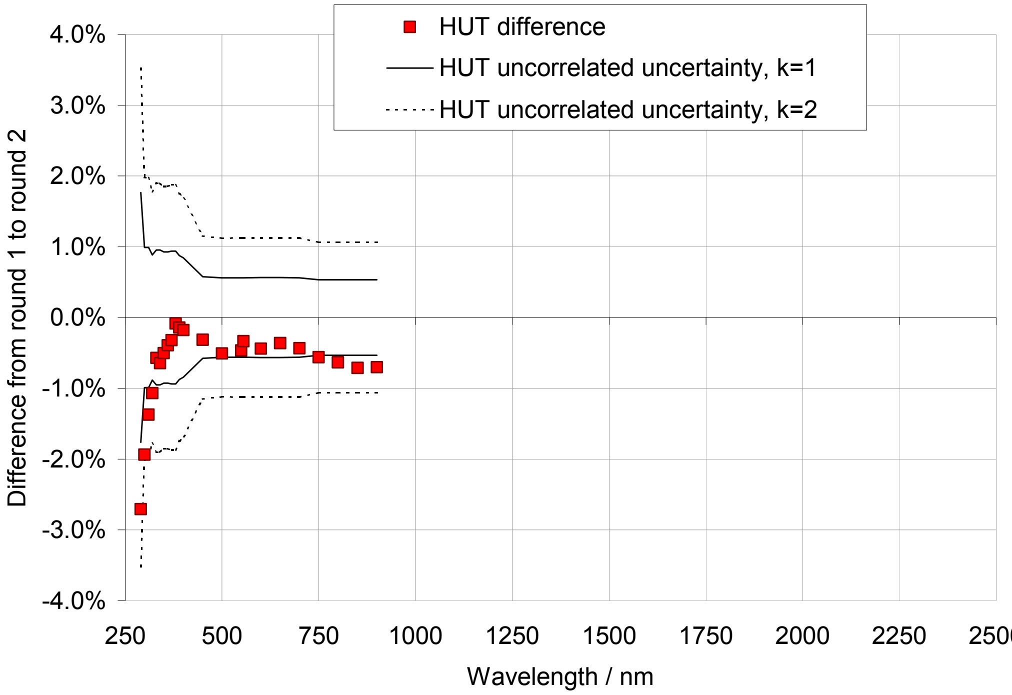

Figure 7-8 Difference between first and second round measurements of FEL BN 9101 245 by HUT. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the HUT measurements.

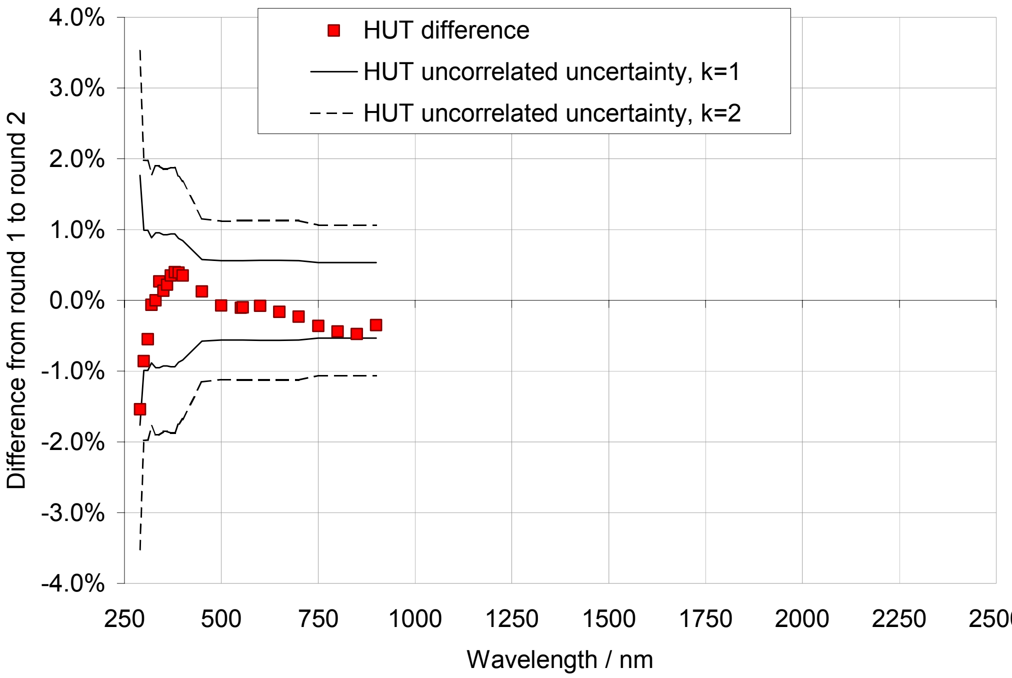

Figure 7-9 Difference between first and second round measurements of FEL BN 9101 257 by HUT. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the HUT measurements.

7.8 Bilateral comparison between HUT and the comparison scale

This graph shows the difference between the HUT and NPL measurements of the HUT lamps. A version of this graph normalised to show the relative difference between the lamps, but not the absolute difference between the measurements was used to assist in choosing which lamp measurements to use.

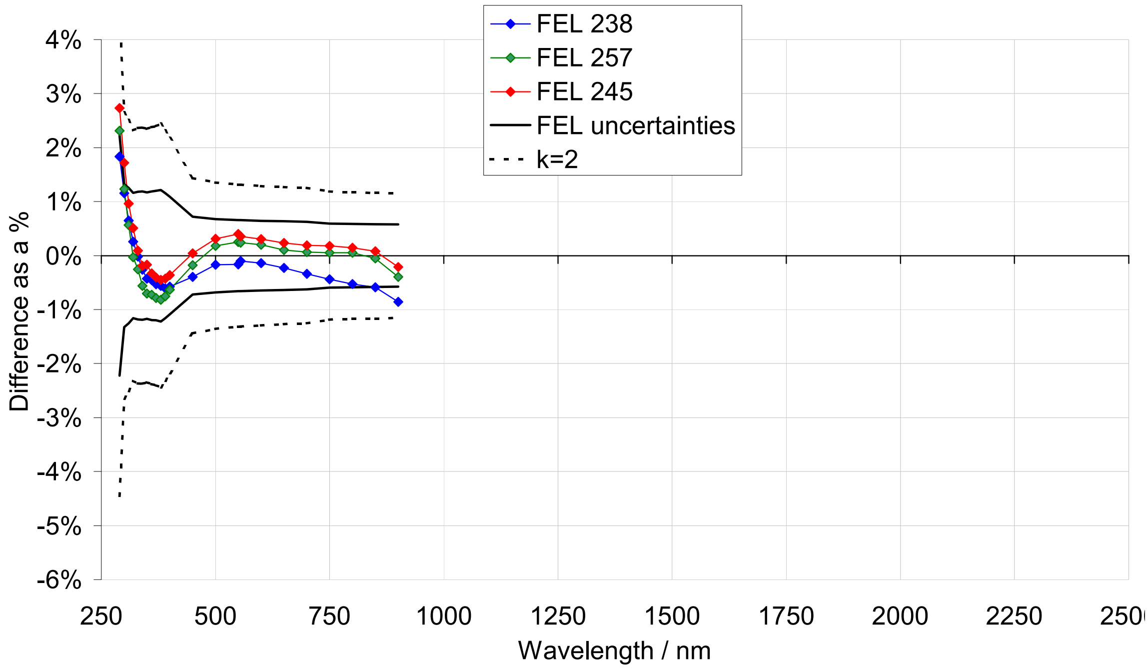

Figure 7-10 Bilateral comparisons of the HUT lamps.

7.8.1 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to HUT the information in the graphs Figure 7-4 to Figure 7-10. It was decided that both participant measurements and both pilot measurements would be used for both FEL BN 9101 257 and for FEL BN 9101 245, but that only the second HUT measurement would be used for FEL BN 9101 238. This lamp shows a difference between the rounds that is larger than HUT's uncertainties and also an electrical potential difference. Therefore, it is assumed that the lamp changed on the first journey from HUT to NPL. Following the end of this comparison, HUT made an additional quick measurement of FEL BN 9101 238. This measurement was slightly lower than the 2002 measurements, which supports the theory that the lamp has been slowly dropping throughout the measurement sequence: HUT1 – NPL1 – HUT2 – NPL2 – HUT extra. It also supports the assumption that the lamp showed a step change on the first transportation.

7.9 References

[1] P. Kärhä, P. Toivanen, F Manoochehri, and E. Ikonen, "Development of a detector-based absolute spectral irradiance scale in the 380-900-nm spectral range," *Appl. Opt.* **36**, 8909-8918 (1997).

[2] T. Kübarsepp, P. Kärhä, F. Manoocheri, S. Nevas, L. Ylianttila, and E. Ikonen, "Spectral irradiance measurements of tungsten lamps with filter radiometers in the spectral range 290 nm to 900 nm," *Metrologia* **37**, 305-312 (2000)

8 Measurements at IFA-CSIC

8.1 Primary scale realisation

The realisation of the scale for spectral irradiance at the Instituto de Física Aplicada (Consejo Superior de Investigaciones Científicas) (IFA-CSIC) was made by measuring the spectral irradiance of a series of tungsten halogen lamps with an absolute pyroelectric radiometer and a set of interference filters. A full description of the method used is reported in [1] for the range up to 800 nm and in [2] for the longer wavelength range.

8.2 Description of the measurement facility

The measurements have been done in a purpose built spectroradiometer. The system consists of two different spectroradiometers: one for the UV/Visible spectral range (300-800 nm) and a second one for the NIR spectral range (800-2200 nm). The characteristics of the monochromators are given in Table 8-1 and those of the detectors in Table 8-2.

Table 8-1 Monochromator characteristics

Monochromator values	VISIBLE-ULTRAVIOLET	NEAR INFRARED
Manufacturer	Jarrell-Ash	Jovin-Ivon
Model	78-490	H-225
Type	Grating (single)	Grating (double)
Groves/mm	1180	600 (800-1600nm) 300 (1600-2900nm)
Focal length	0.75 m	250 mm
f number	*f*/6.5	*f*/3.5
Slit width used	2 mm	4 mm

Table 8-2 Detector characteristics

	VISIBLE-ULTRAVIOLET	NEAR INFRARED	
		800-1100 nm	1100-2200 nm
Type	Photomultiplier (S-20)	Si photodiode	InGaAs photodiode
Manufacturer	EMI	EG&G	Hamamatsu
Model	9558 QB	UV444B	G5852-01

8.2.1 Spectroradiometer characterisation

- **Spectral bandpass:** The effective spectral bandpass was determined by the indirect method using fixed wavelength monochromatic beams (first and higher orders of cw Kr laser lines).
- **Wavelength:** The wavelength setting accuracy has been checked with several pencil style spectral calibration lamps and cw Kr laser lines. Uncertainties of ±0.058 nm, ±0.2 nm and ±0.5 nm have been obtained for the UV-VIS, first NIR gratings pair and second NIR gratings pair respectively.
- **Linearity:** The linear response of the detectors used was checked by using the stimuli addition method.
- **Scattered light:** Scattered light was checked by measuring the spectral transmittance of blocking filters. The results agreed well with the specifications of the instrument. As a result, no contribution of this effect to uncertainty has been considered.
- Long wave pass filters were to eliminate second order wavelength radiation.

8.2.2 Measurement facility

Measurements were made using the direct comparison method. Figure 8-1 is a diagram of the measurement facility.

The source positioning system consists of a mobile platform that slides on two rigid rails and can be fixed at two predetermined positions. In these positions, two kinematic lamp mounts allow for a precise and reproducible positioning of both sources. They are provided with micrometric displacements along the three axes and two rotations, one around the vertical axis and the other around the horizontal axis parallel to the entrance aperture plane of the spectroradiometer. Optical axes are defined by a He-Ne laser beam.

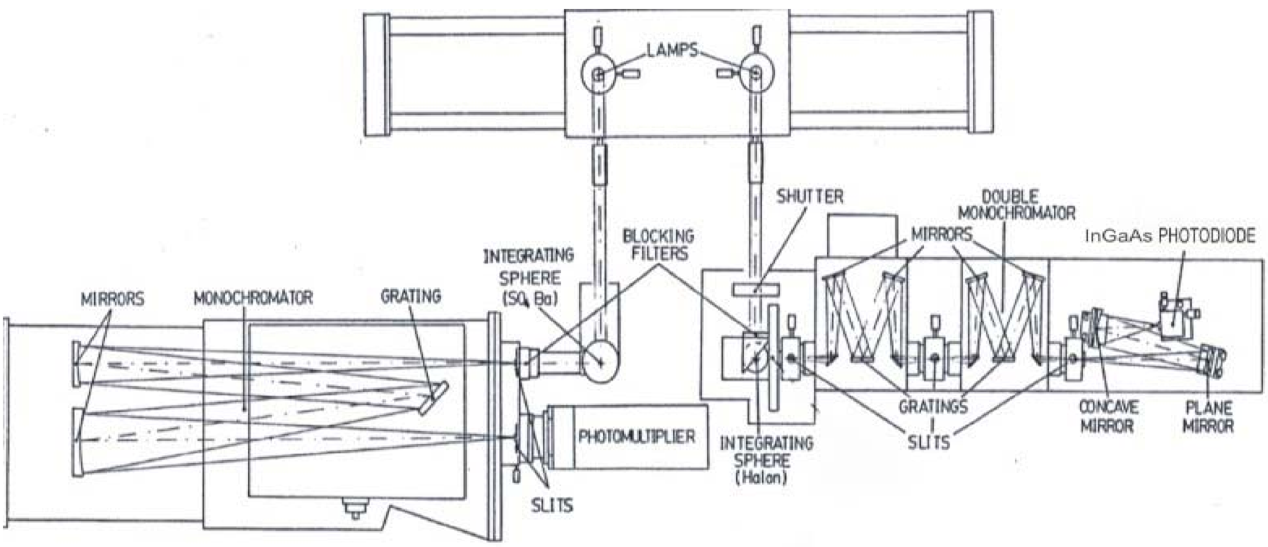

Figure 8-1 IFA-CSIC measurement facility

8.3 Laboratory conditions

The room temperature and humidity were monitored but not controlled. The room temperature was in the range 22 ºC to 26 ºC and the relative humidity was always under 45 %.

8.4 Laboratory standards

Type FEL (1000 W) quartz-halogen, tungsten coiled coil filament lamps.

8.4.1 Lamp configurations

The IFA-CSIC standard lamps were aligned to the optical axis using the NIST-style alignment jig to position the lamp socket at the correct angle and positions for measurement.

The comparison lamps were aligned using the instructions received by email from E.R. Woolliams in January 2002.

The electrical supply to the lamps was derived from high-stability (Vinculum) DC power supplies operating in current control. The current supplied to the lamps was measured using calibrated standard resistors (0.01 Ω) in the standard four-terminal measuring configuration. The voltage at the lamps was measured using the terminals supplied at the lamp assembly.

8.5 Measurement procedure

The basic procedure used is a direct comparison method. Each lamp was measured completely throughout a given wavelength range, before placing another lamp onto the optical axis to repeat the process.

The spectral range measured at IFA-CSIC (300 to 2200 nm) was split into four regions, corresponding to wavelengths measurable on each of the gratings in Table 8-1 and the three detectors in Table 8-2. Each wavelength region overlapped with the longer wavelength regions by at least two wavelengths. All the lamps were measured in all spectral regions on three occasions. The lamps were realigned between measurements. On each occasion only one scan was made with a number of repeated measurements at each wavelength.

First all the lamps were measured in the UV/VIS region (300 to 800 nm).

Then the NIR region (700 - 1100 nm), with the Si detector and the first pair of holographic gratings (600 groves/mm), was measured.

Then the NIR region (1000 - 1600 nm) was measured, again using the first pair of holographic gratings and the InGaAs detector.

Finally, all the lamps were measured in the IR region (1500 - 2200 nm). The InGaAs detector and the second pair of holographic gratings (300 groves/mm) were used.

The spectral irradiance was calculated according to the expression:

$$E(\lambda) = E_s(\lambda)\frac{R(\lambda)}{R_s(\lambda)} \tag{8-1}$$

Where $E(\lambda)$ is the spectral irradiance of the test source; $R(\lambda)/R_S(\lambda)$ is the ratio of the test source signal to the standard lamp signal, obtained in the spectroradiometer, and $E_S(\lambda)$ is the spectral irradiance of the standard lamp.

8.6 Uncertainty determination

8.6.1 IFA -CSIC Primary Scale Uncertainty Budget

Table 8-3 summarises the uncertainty components in the primary scale realisation.

Table 8-3 Primary scale uncertainties

(300-800 nm)		(700-2400 nm)	
Relative spectral response of Si detector	±1.0 %	Filter Bandwidth	± 0.1 %
Absolute spectral response of Si detector		Temperature	± 0.1 %
ECPR absolute accuracy	±1.0 %	Wavelength shift	± 0.5 %
Filter transmittance	±0.4 %	Transmittance	± 1.5 %
Lamp flux variations	±0.05 %	Radiometer accuracy	± 1.0 %
Spectral irradiance measurements		Measurement precision	± 0.2 %
Filter transmittance	±0.4 %	Radiometer-lamp distance	± 0.2 %
Detector-source distance	±0.2 %	Lamp flux variations	± 0.1 %
Aperture area	±0.1 %	Lamp orientation	± 0.1 %
Lamp flux variations	±0.05 %		
Combined standard uncertainty (k = 1)	±1.5 %	Combined standard uncertainty (k = 1)	± 1.9 %

8.6.2 Comparison spectral irradiance uncertainty

The measurement equation used is as expressed in Equation (8-1), but corrected with a series of factors to give:

$$E = E_s \cdot \alpha \Delta t \cdot F \frac{(R + \delta'_{res} + \delta R_\lambda)\left(\dfrac{c'_j V'_j}{J'_R R'_j}\right)^m \cos^h(\varphi')\cos^f(\upsilon')\, d_1^2}{(R_s + \delta_{res} + \delta R_{s\lambda})\left(\dfrac{c_j V_j}{J_R R_j}\right)^m \cos^h(\varphi)\cos^f(\upsilon) d_2^2} \tag{8-2}$$

Where:

E	output quantity—actual spectral irradiance of the test source
E_s	spectral irradiance of the standard. Certified value
$\alpha\Delta t$	relative correction for aging of standard lamp.
F	factor that takes into account the different instrument scales used for the measurement of test and standard lamp signals. Linearity factor. Certified value.
R	mean value, averaged from the number of readings, of the test source signal
R_s	mean value of the standard lamp signal
c'_j , c_j	calibration factors of the multimeters used to measure the voltage across the standard resistors for test and standard lamp respectively. Certified values.
V'_j , V_j	mean values of voltages measured across the standard resistor.
J'_R , J_R	established values of current for test and standard lamp respectively. No uncertainty.
R'_j , R_j	values of standard resistances used for the measurement of lamp current. Certified values.
m	exponent for changes of lamp current affecting the spectral irradiance. Depends on which wavelength is considered.
$\cos^h\varphi$; $\cos^f\nu$	correction factors for angular misalignment of the lamp around the vertical (angle φ) and horizontal (angle ν) axis.
d_1 , d_2	measurement distance for test and standard lamp respectively. A distance of 500 mm has been used for both lamps.

δ'_{res} and δ_{res} correction factors for resolution of measurement system.

δR_λ and $\delta R_{S\lambda}$ correction factors for uncertainty in wavelength. The uncertainty is calculated as:

$$\begin{aligned} u(\delta R_\lambda) &= \frac{\partial R}{\partial \lambda}\, u(\lambda) \\ u(\delta R_{S\lambda}) &= \frac{\partial R_s}{\partial \lambda}\, u(\lambda) \end{aligned} \tag{8-3}$$

where $u(\lambda)$ is the uncertainty in the monochromator wavelength calibration (in nm).

The uncertainty values have been calculated by applying the partial derivative rule to Equation (8-2) as recommended by the ISO Guide.

A detailed uncertainty budget of the spectral irradiance measurements is given in Table 8-4.

The value reported for uncertainty in orientation is the combined uncertainty of both terms of the angular misalignment. Similarly, values reported for the uncertainty in current are the combined uncertainties of contributions: c_j, R_j and V_j.

The Type A uncertainty is calculated as the root mean square of the measurement standard deviations of the three individual calibrations of each lamp, divided by $\sqrt{3}$ combined in quadrature with the reference repeatability and transfer repeatability.

8.6.3 Correlation

The Type A uncertainties are entirely uncorrelated. Type B contributions have been separated into those components that are entirely uncorrelated from lamp to lamp and round to round (distance, orientation and current), those components that are correlated between lamps, but not between rounds (wavelength accuracy, which was recalibrated from the first round to the second round) and those components that are entirely correlated (factor F).

Table 8-4 Uncertainty components (%) of the spectral irradiance measurements. All uncertainties are standard uncertainties (k=1)

Wavelength / nm	Type A Uncertainty in value (%)	Type B Scale (Entirely Correlated)	Uncertainty in Value (%): Entirely uncorrelated from lamp to lamp and round to round — Distance 2 contributions	Current 2 contributions	Orientation 2 contributions	Correlated between lamps but not between rounds — Wavelength 2 contributions	Entirely correlated — Factor *F*	Combined standard uncertainty u_c(%)
300	1.67	1.5	0.06	0.04	0.02	0.25	0.06	2.3
310	1.23	1.5	0.06	0.04	0.02	0.20	0.06	2.0
320	1.15	1.5	0.06	0.04	0.02	0.18	0.06	1.9
330	0.88	1.5	0.06	0.04	0.02	0.17	0.06	1.8
340	0.97	1.5	0.06	0.04	0.02	0.15	0.06	1.8
350	0.71	1.5	0.06	0.04	0.02	0.14	0.06	1.7
360	0.66	1.5	0.06	0.04	0.02	0.13	0.06	1.7
370	0.64	1.5	0.06	0.03	0.02	0.12	0.06	1.6
380	0.69	1.5	0.06	0.03	0.02	0.12	0.06	1.7
390	0.71	1.5	0.06	0.03	0.02	0.11	0.06	1.7
400	0.61	1.5	0.06	0.03	0.02	0.11	0.06	1.6
450	0.58	1.5	0.06	0.02	0.02	0.07	0.06	1.6
500	0.69	1.5	0.06	0.02	0.02	0.05	0.05	1.7
550	0.76	1.5	0.06	0.02	0.02	0.04	0.05	1.7
555	0.92	1.5	0.06	0.02	0.02	0.04	0.05	1.8
600	0.83	1.5	0.06	0.02	0.02	0.03	0.05	1.7
650	0.98	1.5	0.06	0.02	0.02	0.02	0.05	1.8
700	0.61	1.5	0.06	0.02	0.02	0.01	0.05	1.6
750	0.41	1.5	0.06	0.02	0.02	0.01	0.05	1.6
800	0.44	1.5	0.06	0.00	0.02	0.01	0.05	1.6
850	0.36	1.9	0.06	0.01	0.02	0.01	0.05	1.9
900	0.30	1.9	0.06	0.01	0.02	0.00	0.05	1.9
950	0.38	1.9	0.06	0.01	0.02	0.00	0.05	1.9
1000	0.18	1.9	0.06	0.01	0.02	0.01	0.05	1.9
1100	1.31	1.9	0.06	0.01	0.02	0.01	0.05	2.3
1200	1.15	1.9	0.06	0.01	0.02	0.02	0.05	2.2
1300	0.66	1.9	0.06	0.01	0.02	0.02	0.05	2.0
1400	0.87	1.9	0.06	0.01	0.02	0.03	0.05	2.1
1500	0.87	1.9	0.06	0.00	0.02	0.03	0.05	2.1
1600	0.70	1.9	0.06	0.00	0.02	0.07	0.05	2.0
1700	1.26	1.9	0.06	0.00	0.02	0.07	0.05	2.3
1800	1.17	1.9	0.06	0.00	0.02	0.06	0.05	2.2
1900	0.94	1.9	0.06	0.00	0.02	0.06	0.05	2.1
2000	0.92	1.9	0.06	0.00	0.02	0.07	0.05	2.1
2100	1.01	1.9	0.06	0.00	0.02	0.07	0.05	2.2
2200	1.83	1.9	0.06	0.00	0.02	0.07	0.05	2.6

8.7 IFA-CSIC Results

IFA-CSIC measured three lamps. The results for FEL BN 9101 249 are given in Table 8-5, the results for FEL BN 9101 207 are given in Table 8-6 and the results for FEL BN 9101 209 are given in Table 8-7.

Table 8-5 IFA-CSIC Results for FEL BN 9101 249. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 249	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.410E-03	1.69 %	0.25 %	1.50 %	2.27 %	1.390E-03	1.97 %	0.25 %	1.50 %	2.49 %
310	2.019E-03	1.25 %	0.20 %	1.50 %	1.96 %	1.960E-03	1.36 %	0.20 %	1.50 %	2.04 %
320	2.798E-03	1.17 %	0.18 %	1.50 %	1.91 %	2.712E-03	1.25 %	0.18 %	1.50 %	1.96 %
330	3.737E-03	0.90 %	0.17 %	1.50 %	1.76 %	3.629E-03	0.95 %	0.17 %	1.50 %	1.79 %
340	4.922E-03	0.99 %	0.15 %	1.50 %	1.80 %	4.802E-03	1.02 %	0.15 %	1.50 %	1.82 %
350	6.314E-03	0.73 %	0.14 %	1.50 %	1.67 %	6.127E-03	0.73 %	0.14 %	1.50 %	1.68 %
360	7.977E-03	0.68 %	0.13 %	1.50 %	1.65 %	7.753E-03	0.70 %	0.13 %	1.50 %	1.66 %
370	9.911E-03	0.66 %	0.12 %	1.50 %	1.64 %	9.707E-03	0.68 %	0.12 %	1.50 %	1.65 %
380	1.216E-02	0.70 %	0.12 %	1.50 %	1.66 %	1.185E-02	0.72 %	0.12 %	1.50 %	1.67 %
390	1.469E-02	0.72 %	0.11 %	1.50 %	1.67 %	1.436E-02	0.75 %	0.11 %	1.50 %	1.68 %
400	1.754E-02	0.63 %	0.11 %	1.50 %	1.63 %	1.703E-02	0.64 %	0.11 %	1.50 %	1.63 %
450	3.603E-02	0.59 %	0.07 %	1.50 %	1.61 %	3.528E-02	0.61 %	0.07 %	1.50 %	1.62 %
500	6.047E-02	0.70 %	0.05 %	1.50 %	1.66 %	5.917E-02	0.70 %	0.05 %	1.50 %	1.66 %
550	8.783E-02	0.77 %	0.04 %	1.50 %	1.69 %	8.668E-02	0.77 %	0.04 %	1.50 %	1.69 %
555	9.037E-02	0.92 %	0.04 %	1.50 %	1.76 %	8.856E-02	0.92 %	0.04 %	1.50 %	1.76 %
600	1.155E-01	0.83 %	0.03 %	1.50 %	1.72 %	1.128E-01	0.83 %	0.03 %	1.50 %	1.72 %
650	1.411E-01	0.98 %	0.02 %	1.50 %	1.79 %	1.370E-01	0.98 %	0.02 %	1.50 %	1.79 %
700	1.621E-01	0.62 %	0.01 %	1.50 %	1.62 %	1.578E-01	0.62 %	0.01 %	1.50 %	1.62 %
750	1.783E-01	0.42 %	0.01 %	1.50 %	1.56 %	1.733E-01	0.42 %	0.01 %	1.50 %	1.56 %
800	1.899E-01	0.45 %	0.01 %	1.50 %	1.57 %	1.846E-01	0.46 %	0.01 %	1.50 %	1.57 %
850	1.958E-01	0.37 %	0.01 %	1.90 %	1.94 %	1.886E-01	0.39 %	0.01 %	1.90 %	1.94 %
900	1.983E-01	0.31 %	0.00 %	1.90 %	1.93 %	1.910E-01	0.31 %	0.00 %	1.90 %	1.93 %
950	1.976E-01	0.39 %	0.00 %	1.90 %	1.94 %	1.906E-01	0.39 %	0.00 %	1.90 %	1.94 %
1000	1.943E-01	0.20 %	0.01 %	1.90 %	1.91 %	1.875E-01	0.20 %	0.01 %	1.90 %	1.91 %
1100	1.831E-01	1.31 %	0.01 %	1.90 %	2.31 %	1.772E-01	1.31 %	0.01 %	1.90 %	2.31 %
1200	1.695E-01	1.16 %	0.02 %	1.90 %	2.23 %	1.622E-01	1.17 %	0.02 %	1.90 %	2.23 %
1300	1.511E-01	0.66 %	0.02 %	1.90 %	2.01 %	1.453E-01	0.67 %	0.02 %	1.90 %	2.01 %
1400	1.329E-01	0.88 %	0.03 %	1.90 %	2.09 %	1.275E-01	0.88 %	0.03 %	1.90 %	2.09 %
1500	1.160E-01	0.88 %	0.03 %	1.90 %	2.09 %	1.106E-01	0.88 %	0.03 %	1.90 %	2.10 %
1600	1.016E-01	0.71 %	0.07 %	1.90 %	2.03 %	9.818E-02	0.72 %	0.07 %	1.90 %	2.03 %
1700	8.806E-02	1.25 %	0.07 %	1.90 %	2.28 %	8.271E-02	1.26 %	0.07 %	1.90 %	2.28 %
1800	7.652E-02	1.18 %	0.06 %	1.90 %	2.24 %	7.281E-02	1.20 %	0.06 %	1.90 %	2.25 %
1900	6.719E-02	0.94 %	0.06 %	1.90 %	2.12 %	6.430E-02	0.94 %	0.06 %	1.90 %	2.12 %
2000	5.884E-02	0.92 %	0.07 %	1.90 %	2.11 %	5.647E-02	0.94 %	0.07 %	1.90 %	2.12 %
2100	5.142E-02	1.02 %	0.07 %	1.90 %	2.16 %	4.963E-02	1.03 %	0.07 %	1.90 %	2.16 %
2200	4.511E-02	1.83 %	0.07 %	1.90 %	2.64 %	4.358E-02	1.83 %	0.07 %	1.90 %	2.64 %
2300										
2400										

2500		

Table 8-6 IFA-CSIC Results for FEL BN 9101 207. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 207	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.248E-03	1.68 %	0.25 %	1.50 %	2.27 %	1.220E-03	1.72 %	0.25 %	1.50 %	2.29 %
310	1.748E-03	1.25 %	0.20 %	1.50 %	1.96 %	1.712E-03	1.42 %	0.20 %	1.50 %	2.08 %
320	2.427E-03	1.17 %	0.18 %	1.50 %	1.91 %	2.382E-03	1.27 %	0.18 %	1.50 %	1.97 %
330	3.273E-03	0.90 %	0.17 %	1.50 %	1.76 %	3.213E-03	0.96 %	0.17 %	1.50 %	1.79 %
340	4.319E-03	0.99 %	0.15 %	1.50 %	1.80 %	4.224E-03	1.03 %	0.15 %	1.50 %	1.83 %
350	5.552E-03	0.73 %	0.14 %	1.50 %	1.68 %	5.528E-03	0.73 %	0.14 %	1.50 %	1.68 %
360	7.032E-03	0.68 %	0.13 %	1.50 %	1.65 %	6.989E-03	0.67 %	0.13 %	1.50 %	1.65 %
370	8.758E-03	0.66 %	0.12 %	1.50 %	1.64 %	8.705E-03	0.69 %	0.12 %	1.50 %	1.66 %
380	1.076E-02	0.70 %	0.12 %	1.50 %	1.66 %	1.068E-02	0.72 %	0.12 %	1.50 %	1.67 %
390	1.301E-02	0.72 %	0.11 %	1.50 %	1.67 %	1.294E-02	0.77 %	0.11 %	1.50 %	1.69 %
400	1.562E-02	0.63 %	0.11 %	1.50 %	1.63 %	1.550E-02	0.65 %	0.11 %	1.50 %	1.64 %
450	3.232E-02	0.59 %	0.07 %	1.50 %	1.61 %	3.212E-02	0.61 %	0.07 %	1.50 %	1.62 %
500	5.470E-02	0.70 %	0.05 %	1.50 %	1.66 %	5.429E-02	0.70 %	0.05 %	1.50 %	1.66 %
550	8.025E-02	0.77 %	0.04 %	1.50 %	1.69 %	7.945E-02	0.77 %	0.04 %	1.50 %	1.69 %
555	8.290E-02	0.92 %	0.04 %	1.50 %	1.76 %	8.192E-02	0.92 %	0.04 %	1.50 %	1.76 %
600	1.059E-01	0.83 %	0.03 %	1.50 %	1.72 %	1.048E-01	0.83 %	0.03 %	1.50 %	1.72 %
650	1.294E-01	0.98 %	0.02 %	1.50 %	1.79 %	1.279E-01	0.98 %	0.02 %	1.50 %	1.79 %
700	1.496E-01	0.62 %	0.01 %	1.50 %	1.62 %	1.480E-01	0.62 %	0.01 %	1.50 %	1.62 %
750	1.647E-01	0.42 %	0.01 %	1.50 %	1.56 %	1.634E-01	0.42 %	0.01 %	1.50 %	1.56 %
800	1.766E-01	0.45 %	0.01 %	1.50 %	1.57 %	1.744E-01	0.47 %	0.01 %	1.50 %	1.57 %
850	1.822E-01	0.37 %	0.01 %	1.90 %	1.94 %	1.822E-01	0.43 %	0.01 %	1.90 %	1.95 %
900	1.849E-01	0.31 %	0.00 %	1.90 %	1.93 %	1.850E-01	0.31 %	0.00 %	1.90 %	1.93 %
950	1.845E-01	0.39 %	0.00 %	1.90 %	1.94 %	1.847E-01	0.39 %	0.00 %	1.90 %	1.94 %
1000	1.817E-01	0.20 %	0.01 %	1.90 %	1.91 %	1.821E-01	0.20 %	0.01 %	1.90 %	1.91 %
1100	1.703E-01	1.31 %	0.01 %	1.90 %	2.31 %	1.688E-01	1.31 %	0.01 %	1.90 %	2.31 %
1200	1.567E-01	1.16 %	0.02 %	1.90 %	2.23 %	1.550E-01	1.16 %	0.02 %	1.90 %	2.23 %
1300	1.407E-01	0.66 %	0.02 %	1.90 %	2.01 %	1.401E-01	0.68 %	0.02 %	1.90 %	2.02 %
1400	1.250E-01	0.87 %	0.03 %	1.90 %	2.09 %	1.238E-01	0.88 %	0.03 %	1.90 %	2.10 %
1500	1.095E-01	0.88 %	0.03 %	1.90 %	2.09 %	1.084E-01	0.88 %	0.03 %	1.90 %	2.09 %
1600	9.586E-02	0.71 %	0.07 %	1.90 %	2.03 %	9.461E-02	0.72 %	0.07 %	1.90 %	2.03 %
1700	8.226E-02	1.27 %	0.07 %	1.90 %	2.29 %	8.150E-02	1.31 %	0.07 %	1.90 %	2.31 %
1800	7.275E-02	1.18 %	0.06 %	1.90 %	2.24 %	7.202E-02	1.19 %	0.06 %	1.90 %	2.24 %
1900	6.364E-02	0.94 %	0.06 %	1.90 %	2.12 %	6.258E-02	0.95 %	0.06 %	1.90 %	2.12 %
2000	5.578E-02	0.92 %	0.07 %	1.90 %	2.11 %	5.479E-02	0.94 %	0.07 %	1.90 %	2.12 %
2100	4.855E-02	1.02 %	0.07 %	1.90 %	2.16 %	4.775E-02	1.03 %	0.07 %	1.90 %	2.16 %
2200	4.242E-02	1.83 %	0.07 %	1.90 %	2.64 %	4.154E-02	1.84 %	0.07 %	1.90 %	2.65 %
2300										
2400										
2500										

Table 8-7 IFA-CSIC Results for FEL BN 9101 209. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 209	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.214E-03	1.69 %	0.25 %	1.50 %	2.27 %	1.192E-03	1.98 %	0.25 %	1.50 %	2.49 %
310	1.732E-03	1.25 %	0.20 %	1.50 %	1.96 %	1.702E-03	1.47 %	0.20 %	1.50 %	2.11 %
320	2.416E-03	1.17 %	0.18 %	1.50 %	1.91 %	2.381E-03	1.29 %	0.18 %	1.50 %	1.99 %
330	3.238E-03	0.90 %	0.17 %	1.50 %	1.76 %	3.210E-03	0.99 %	0.17 %	1.50 %	1.81 %
340	4.273E-03	0.99 %	0.15 %	1.50 %	1.80 %	4.219E-03	1.07 %	0.15 %	1.50 %	1.85 %
350	5.496E-03	0.73 %	0.14 %	1.50 %	1.67 %	5.428E-03	0.76 %	0.14 %	1.50 %	1.69 %
360	6.958E-03	0.68 %	0.13 %	1.50 %	1.65 %	6.876E-03	0.73 %	0.13 %	1.50 %	1.67 %
370	8.680E-03	0.66 %	0.12 %	1.50 %	1.65 %	8.570E-03	0.68 %	0.12 %	1.50 %	1.65 %
380	1.063E-02	0.70 %	0.12 %	1.50 %	1.66 %	1.053E-02	0.73 %	0.12 %	1.50 %	1.67 %
390	1.290E-02	0.72 %	0.11 %	1.50 %	1.67 %	1.276E-02	0.75 %	0.11 %	1.50 %	1.68 %
400	1.546E-02	0.63 %	0.11 %	1.50 %	1.63 %	1.516E-02	0.64 %	0.11 %	1.50 %	1.64 %
450	3.206E-02	0.59 %	0.07 %	1.50 %	1.61 %	3.155E-02	0.61 %	0.07 %	1.50 %	1.62 %
500	5.433E-02	0.70 %	0.05 %	1.50 %	1.66 %	5.349E-02	0.70 %	0.05 %	1.50 %	1.66 %
550	7.973E-02	0.77 %	0.04 %	1.50 %	1.69 %	7.844E-02	0.77 %	0.04 %	1.50 %	1.69 %
555	8.232E-02	0.92 %	0.04 %	1.50 %	1.76 %	8.189E-02	0.92 %	0.04 %	1.50 %	1.76 %
600	1.053E-01	0.83 %	0.03 %	1.50 %	1.72 %	1.035E-01	0.83 %	0.03 %	1.50 %	1.72 %
650	1.290E-01	0.98 %	0.02 %	1.50 %	1.79 %	1.265E-01	0.99 %	0.02 %	1.50 %	1.80 %
700	1.483E-01	0.62 %	0.01 %	1.50 %	1.62 %	1.473E-01	0.62 %	0.01 %	1.50 %	1.62 %
750	1.639E-01	0.42 %	0.01 %	1.50 %	1.56 %	1.629E-01	0.42 %	0.01 %	1.50 %	1.56 %
800	1.749E-01	0.45 %	0.01 %	1.50 %	1.57 %	1.741E-01	0.45 %	0.01 %	1.50 %	1.57 %
850	1.807E-01	0.37 %	0.01 %	1.90 %	1.94 %	1.804E-01	0.37 %	0.01 %	1.90 %	1.94 %
900	1.834E-01	0.31 %	0.00 %	1.90 %	1.93 %	1.836E-01	0.31 %	0.00 %	1.90 %	1.93 %
950	1.831E-01	0.39 %	0.00 %	1.90 %	1.94 %	1.834E-01	0.39 %	0.00 %	1.90 %	1.94 %
1000	1.805E-01	0.20 %	0.01 %	1.90 %	1.91 %	1.809E-01	0.20 %	0.01 %	1.90 %	1.91 %
1100	1.738E-01	1.31 %	0.01 %	1.90 %	2.31 %	1.713E-01	1.31 %	0.01 %	1.90 %	2.31 %
1200	1.587E-01	1.16 %	0.02 %	1.90 %	2.23 %	1.572E-01	1.17 %	0.02 %	1.90 %	2.23 %
1300	1.404E-01	0.66 %	0.02 %	1.90 %	2.01 %	1.400E-01	0.67 %	0.02 %	1.90 %	2.02 %
1400	1.242E-01	0.88 %	0.03 %	1.90 %	2.09 %	1.229E-01	0.88 %	0.03 %	1.90 %	2.09 %
1500	1.090E-01	0.88 %	0.03 %	1.90 %	2.09 %	1.092E-01	0.88 %	0.03 %	1.90 %	2.09 %
1600	9.541E-02	0.71 %	0.07 %	1.90 %	2.03 %	9.536E-02	0.72 %	0.07 %	1.90 %	2.03 %
1700	8.226E-02	1.26 %	0.07 %	1.90 %	2.28 %	8.132E-02	1.26 %	0.07 %	1.90 %	2.28 %
1800	7.225E-02	1.19 %	0.06 %	1.90 %	2.24 %	7.101E-02	1.20 %	0.06 %	1.90 %	2.25 %
1900	6.366E-02	0.94 %	0.06 %	1.90 %	2.12 %	6.333E-02	0.94 %	0.06 %	1.90 %	2.12 %
2000	5.596E-02	0.92 %	0.07 %	1.90 %	2.11 %	5.540E-02	0.93 %	0.07 %	1.90 %	2.12 %
2100	4.901E-02	1.02 %	0.07 %	1.90 %	2.16 %	4.878E-02	1.03 %	0.07 %	1.90 %	2.16 %
2200	4.267E-02	1.83 %	0.07 %	1.90 %	2.64 %	4.173E-02	1.84 %	0.07 %	1.90 %	2.65 %
2300										
2400										
2500										

8.8 Pilot Results

NPL's results for FEL BN 9101 249 are given in Table 8-8 and the results for FEL BN 9101 207 are given in Table 8-9 and the results for FEL BN 9101 209 are given in Table 8-10.

Table 8-8 NPL Results for FEL BN 9101 249. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 249	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.461E-03	0.78 %	0.33 %	0.45 %	0.96 %	1.368E-03	0.19 %	0.15 %	0.45 %	0.51 %
310	2.078E-03	0.65 %	0.38 %	0.43 %	0.87 %	1.950E-03	0.18 %	0.20 %	0.43 %	0.51 %
320	2.872E-03	0.57 %	0.43 %	0.37 %	0.81 %	2.699E-03	0.17 %	0.25 %	0.37 %	0.48 %
330	3.871E-03	0.51 %	0.47 %	0.36 %	0.78 %	3.640E-03	0.16 %	0.28 %	0.36 %	0.49 %
340	5.097E-03	0.45 %	0.53 %	0.35 %	0.78 %	4.796E-03	0.15 %	0.33 %	0.35 %	0.51 %
350	6.574E-03	0.44 %	0.58 %	0.34 %	0.80 %	6.188E-03	0.15 %	0.36 %	0.34 %	0.52 %
360	8.321E-03	0.41 %	0.67 %	0.33 %	0.85 %	7.833E-03	0.14 %	0.43 %	0.33 %	0.56 %
370	1.035E-02	0.38 %	0.72 %	0.32 %	0.87 %	9.745E-03	0.14 %	0.46 %	0.32 %	0.58 %
380	1.268E-02	0.35 %	0.81 %	0.31 %	0.94 %	1.194E-02	0.13 %	0.52 %	0.31 %	0.62 %
390	1.531E-02	0.33 %	0.78 %	0.31 %	0.90 %	1.441E-02	0.13 %	0.50 %	0.31 %	0.60 %
400	1.825E-02	0.32 %	0.72 %	0.30 %	0.84 %	1.717E-02	0.13 %	0.46 %	0.30 %	0.56 %
450	3.736E-02	0.27 %	0.31 %	0.27 %	0.49 %	3.510E-02	0.13 %	0.10 %	0.27 %	0.31 %
500	6.248E-02	0.24 %	0.31 %	0.24 %	0.46 %	5.865E-02	0.12 %	0.00 %	0.24 %	0.27 %
550	9.084E-02	0.21 %	0.33 %	0.22 %	0.45 %	8.523E-02	0.10 %	0.00 %	0.22 %	0.24 %
555	9.373E-02	0.20 %	0.33 %	0.22 %	0.45 %	8.795E-02	0.10 %	0.00 %	0.22 %	0.24 %
600	1.194E-01	0.19 %	0.33 %	0.20 %	0.43 %	1.120E-01	0.10 %	0.00 %	0.20 %	0.22 %
650	1.455E-01	0.16 %	0.32 %	0.18 %	0.41 %	1.366E-01	0.09 %	0.00 %	0.18 %	0.21 %
700	1.675E-01	0.20 %	0.31 %	0.17 %	0.41 %	1.573E-01	0.09 %	0.00 %	0.17 %	0.19 %
750	1.845E-01	0.18 %	0.30 %	0.16 %	0.39 %	1.734E-01	0.09 %	0.00 %	0.16 %	0.18 %
800	1.965E-01	0.16 %	0.29 %	0.15 %	0.36 %	1.846E-01	0.08 %	0.00 %	0.15 %	0.17 %
850	2.037E-01	0.14 %	0.28 %	0.14 %	0.34 %	1.913E-01	0.08 %	0.00 %	0.14 %	0.16 %
900	2.067E-01	0.12 %	0.26 %	0.13 %	0.32 %	1.942E-01	0.07 %	0.00 %	0.13 %	0.15 %
950	2.064E-01	0.11 %	0.25 %	0.13 %	0.31 %	1.938E-01	0.07 %	0.00 %	0.13 %	0.15 %
1000	2.034E-01	0.12 %	0.25 %	0.12 %	0.30 %	1.909E-01	0.07 %	0.00 %	0.12 %	0.14 %
1100	1.916E-01	0.14 %	0.25 %	0.11 %	0.31 %	1.798E-01	0.08 %	0.00 %	0.11 %	0.14 %
1200	1.753E-01	0.16 %	0.28 %	0.10 %	0.34 %	1.646E-01	0.09 %	0.00 %	0.10 %	0.14 %
1300	1.573E-01	0.18 %	0.32 %	0.09 %	0.38 %	1.477E-01	0.10 %	0.00 %	0.09 %	0.14 %
1400	1.393E-01	0.19 %	0.33 %	0.09 %	0.39 %	1.308E-01	0.11 %	0.00 %	0.09 %	0.14 %
1500	1.225E-01	0.18 %	0.30 %	0.08 %	0.36 %	1.150E-01	0.11 %	0.00 %	0.08 %	0.14 %
1600	1.074E-01	0.19 %	0.26 %	0.08 %	0.33 %	1.007E-01	0.11 %	0.00 %	0.08 %	0.13 %
1700	9.392E-02	0.32 %	0.23 %	0.08 %	0.40 %	8.805E-02	0.15 %	0.00 %	0.08 %	0.16 %
1800	8.206E-02	0.70 %	0.21 %	0.08 %	0.73 %	7.687E-02	0.19 %	0.00 %	0.08 %	0.21 %
1900	7.167E-02	1.17 %	0.23 %	0.07 %	1.20 %	6.699E-02	0.23 %	0.00 %	0.07 %	0.24 %
2000	6.263E-02	1.49 %	0.29 %	0.08 %	1.52 %	5.839E-02	0.26 %	0.00 %	0.08 %	0.27 %
2100	5.484E-02	1.72 %	0.38 %	0.07 %	1.77 %	5.109E-02	0.24 %	0.00 %	0.07 %	0.25 %
2200	4.810E-02	2.29 %	0.45 %	0.06 %	2.33 %	4.499E-02	0.25 %	0.00 %	0.06 %	0.26 %
2300										
2400										
2500										

Table 8-9 NPL Results for FEL BN 9101 207. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 207	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.238E-03	0.30 %	0.33 %	0.45 %	0.63 %	1.229E-03	0.28 %	0.15 %	0.45 %	0.55 %
310	1.765E-03	0.27 %	0.38 %	0.43 %	0.64 %	1.754E-03	0.25 %	0.20 %	0.43 %	0.54 %
320	2.446E-03	0.24 %	0.43 %	0.37 %	0.62 %	2.432E-03	0.24 %	0.25 %	0.37 %	0.51 %
330	3.302E-03	0.21 %	0.47 %	0.36 %	0.63 %	3.286E-03	0.22 %	0.28 %	0.36 %	0.51 %
340	4.358E-03	0.15 %	0.53 %	0.35 %	0.66 %	4.339E-03	0.21 %	0.33 %	0.35 %	0.52 %
350	5.631E-03	0.19 %	0.58 %	0.34 %	0.70 %	5.610E-03	0.20 %	0.36 %	0.34 %	0.53 %
360	7.140E-03	0.18 %	0.67 %	0.33 %	0.77 %	7.117E-03	0.19 %	0.43 %	0.33 %	0.57 %
370	8.899E-03	0.18 %	0.72 %	0.32 %	0.81 %	8.873E-03	0.18 %	0.46 %	0.32 %	0.59 %
380	1.092E-02	0.17 %	0.81 %	0.31 %	0.88 %	1.089E-02	0.18 %	0.52 %	0.31 %	0.63 %
390	1.321E-02	0.17 %	0.78 %	0.31 %	0.85 %	1.318E-02	0.18 %	0.50 %	0.31 %	0.61 %
400	1.577E-02	0.16 %	0.72 %	0.30 %	0.80 %	1.573E-02	0.18 %	0.46 %	0.30 %	0.58 %
450	3.258E-02	0.15 %	0.31 %	0.27 %	0.43 %	3.248E-02	0.20 %	0.10 %	0.27 %	0.34 %
500	5.493E-02	0.14 %	0.31 %	0.24 %	0.42 %	5.471E-02	0.19 %	0.00 %	0.24 %	0.30 %
550	8.041E-02	0.13 %	0.33 %	0.22 %	0.42 %	8.003E-02	0.17 %	0.00 %	0.22 %	0.28 %
555	8.302E-02	0.13 %	0.33 %	0.22 %	0.42 %	8.262E-02	0.17 %	0.00 %	0.22 %	0.27 %
600	1.063E-01	0.12 %	0.33 %	0.20 %	0.41 %	1.057E-01	0.16 %	0.00 %	0.20 %	0.26 %
650	1.302E-01	0.06 %	0.32 %	0.18 %	0.38 %	1.295E-01	0.17 %	0.00 %	0.18 %	0.25 %
700	1.505E-01	0.14 %	0.31 %	0.17 %	0.38 %	1.498E-01	0.16 %	0.00 %	0.17 %	0.23 %
750	1.665E-01	0.12 %	0.30 %	0.16 %	0.36 %	1.657E-01	0.15 %	0.00 %	0.16 %	0.22 %
800	1.779E-01	0.11 %	0.29 %	0.15 %	0.34 %	1.770E-01	0.13 %	0.00 %	0.15 %	0.20 %
850	1.850E-01	0.10 %	0.28 %	0.14 %	0.33 %	1.840E-01	0.11 %	0.00 %	0.14 %	0.18 %
900	1.883E-01	0.09 %	0.26 %	0.13 %	0.31 %	1.872E-01	0.10 %	0.00 %	0.13 %	0.17 %
950	1.883E-01	0.09 %	0.25 %	0.13 %	0.30 %	1.873E-01	0.09 %	0.00 %	0.13 %	0.16 %
1000	1.858E-01	0.09 %	0.25 %	0.12 %	0.29 %	1.848E-01	0.09 %	0.00 %	0.12 %	0.15 %
1100	1.753E-01	0.09 %	0.25 %	0.11 %	0.29 %	1.744E-01	0.12 %	0.00 %	0.11 %	0.16 %
1200	1.606E-01	0.09 %	0.28 %	0.10 %	0.31 %	1.597E-01	0.14 %	0.00 %	0.10 %	0.18 %
1300	1.444E-01	0.09 %	0.32 %	0.09 %	0.35 %	1.433E-01	0.17 %	0.00 %	0.09 %	0.20 %
1400	1.283E-01	0.09 %	0.33 %	0.09 %	0.35 %	1.270E-01	0.20 %	0.00 %	0.09 %	0.22 %
1500	1.130E-01	0.09 %	0.30 %	0.08 %	0.32 %	1.118E-01	0.19 %	0.00 %	0.08 %	0.21 %
1600	9.896E-02	0.09 %	0.26 %	0.08 %	0.28 %	9.824E-02	0.18 %	0.00 %	0.08 %	0.20 %
1700	8.657E-02	0.12 %	0.23 %	0.08 %	0.27 %	8.621E-02	0.26 %	0.00 %	0.08 %	0.27 %
1800	7.586E-02	0.30 %	0.21 %	0.08 %	0.38 %	7.552E-02	0.37 %	0.00 %	0.08 %	0.38 %
1900	6.663E-02	0.51 %	0.23 %	0.07 %	0.56 %	6.600E-02	0.48 %	0.00 %	0.07 %	0.49 %
2000	5.852E-02	0.57 %	0.29 %	0.08 %	0.65 %	5.761E-02	0.55 %	0.00 %	0.08 %	0.56 %
2100	5.127E-02	0.71 %	0.38 %	0.07 %	0.81 %	5.043E-02	0.52 %	0.00 %	0.07 %	0.52 %
2200	4.494E-02	0.80 %	0.45 %	0.06 %	0.92 %	4.439E-02	0.55 %	0.00 %	0.06 %	0.55 %
2300										
2400										
2500										

Table 8-10 NPL Results for FEL BN 9101 209. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 209	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.200E-03	0.31 %	0.33 %	0.45 %	0.64 %	1.188E-03	0.35 %	0.15 %	0.45 %	0.59 %
310	1.714E-03	0.28 %	0.38 %	0.43 %	0.64 %	1.696E-03	0.32 %	0.20 %	0.43 %	0.58 %
320	2.378E-03	0.25 %	0.43 %	0.37 %	0.62 %	2.353E-03	0.29 %	0.25 %	0.37 %	0.54 %
330	3.216E-03	0.22 %	0.47 %	0.36 %	0.63 %	3.183E-03	0.27 %	0.28 %	0.36 %	0.53 %
340	4.249E-03	0.17 %	0.53 %	0.35 %	0.66 %	4.206E-03	0.25 %	0.33 %	0.35 %	0.54 %
350	5.497E-03	0.21 %	0.58 %	0.34 %	0.70 %	5.443E-03	0.23 %	0.36 %	0.34 %	0.55 %
360	6.978E-03	0.21 %	0.67 %	0.33 %	0.78 %	6.911E-03	0.22 %	0.43 %	0.33 %	0.59 %
370	8.707E-03	0.21 %	0.72 %	0.32 %	0.81 %	8.624E-03	0.21 %	0.46 %	0.32 %	0.60 %
380	1.069E-02	0.20 %	0.81 %	0.31 %	0.89 %	1.060E-02	0.20 %	0.52 %	0.31 %	0.64 %
390	1.295E-02	0.20 %	0.78 %	0.31 %	0.86 %	1.283E-02	0.20 %	0.50 %	0.31 %	0.62 %
400	1.547E-02	0.20 %	0.72 %	0.30 %	0.81 %	1.534E-02	0.20 %	0.46 %	0.30 %	0.58 %
450	3.206E-02	0.18 %	0.31 %	0.27 %	0.44 %	3.180E-02	0.20 %	0.10 %	0.27 %	0.35 %
500	5.417E-02	0.16 %	0.31 %	0.24 %	0.43 %	5.378E-02	0.19 %	0.00 %	0.24 %	0.30 %
550	7.942E-02	0.15 %	0.33 %	0.22 %	0.43 %	7.891E-02	0.16 %	0.00 %	0.22 %	0.27 %
555	8.202E-02	0.15 %	0.33 %	0.22 %	0.42 %	8.149E-02	0.16 %	0.00 %	0.22 %	0.27 %
600	1.051E-01	0.14 %	0.33 %	0.20 %	0.41 %	1.045E-01	0.15 %	0.00 %	0.20 %	0.25 %
650	1.290E-01	0.09 %	0.32 %	0.18 %	0.38 %	1.282E-01	0.15 %	0.00 %	0.18 %	0.24 %
700	1.493E-01	0.16 %	0.31 %	0.17 %	0.39 %	1.485E-01	0.15 %	0.00 %	0.17 %	0.23 %
750	1.654E-01	0.14 %	0.30 %	0.16 %	0.37 %	1.645E-01	0.14 %	0.00 %	0.16 %	0.21 %
800	1.768E-01	0.12 %	0.29 %	0.15 %	0.35 %	1.759E-01	0.13 %	0.00 %	0.15 %	0.20 %
850	1.839E-01	0.11 %	0.28 %	0.14 %	0.33 %	1.830E-01	0.12 %	0.00 %	0.14 %	0.19 %
900	1.871E-01	0.10 %	0.26 %	0.13 %	0.31 %	1.863E-01	0.11 %	0.00 %	0.13 %	0.17 %
950	1.871E-01	0.09 %	0.25 %	0.13 %	0.30 %	1.865E-01	0.10 %	0.00 %	0.13 %	0.16 %
1000	1.845E-01	0.09 %	0.25 %	0.12 %	0.29 %	1.841E-01	0.10 %	0.00 %	0.12 %	0.16 %
1100	1.741E-01	0.10 %	0.25 %	0.11 %	0.29 %	1.740E-01	0.14 %	0.00 %	0.11 %	0.18 %
1200	1.596E-01	0.10 %	0.28 %	0.10 %	0.32 %	1.598E-01	0.18 %	0.00 %	0.10 %	0.21 %
1300	1.436E-01	0.11 %	0.32 %	0.09 %	0.35 %	1.437E-01	0.21 %	0.00 %	0.09 %	0.23 %
1400	1.276E-01	0.12 %	0.33 %	0.09 %	0.36 %	1.276E-01	0.24 %	0.00 %	0.09 %	0.25 %
1500	1.124E-01	0.11 %	0.30 %	0.08 %	0.33 %	1.124E-01	0.23 %	0.00 %	0.08 %	0.25 %
1600	9.854E-02	0.10 %	0.26 %	0.08 %	0.29 %	9.858E-02	0.22 %	0.00 %	0.08 %	0.24 %
1700	8.613E-02	0.15 %	0.23 %	0.08 %	0.28 %	8.630E-02	0.31 %	0.00 %	0.08 %	0.32 %
1800	7.522E-02	0.32 %	0.21 %	0.08 %	0.39 %	7.541E-02	0.42 %	0.00 %	0.08 %	0.42 %
1900	6.569E-02	0.52 %	0.23 %	0.07 %	0.57 %	6.578E-02	0.50 %	0.00 %	0.07 %	0.51 %
2000	5.745E-02	0.55 %	0.29 %	0.08 %	0.63 %	5.736E-02	0.56 %	0.00 %	0.08 %	0.57 %
2100	5.037E-02	0.64 %	0.38 %	0.07 %	0.75 %	5.015E-02	0.56 %	0.00 %	0.07 %	0.57 %
2200	4.425E-02	0.78 %	0.45 %	0.06 %	0.90 %	4.406E-02	0.65 %	0.00 %	0.06 %	0.66 %
2300										
2400										
2500										

8.9 Lamp Behaviour

8.9.1 IFA-CSIC Lamps

The following lamps were supplied to IFA-CSIC by NPL:

FEL BN 9101 207 FEL BN 9101 209 FEL BN 9101 249

Measurements were made in the sequence: NPL – IFA-CSIC – NPL – IFA-CSIC

IFA-CSIC measured all intercomparison wavelengths from 300 to 2200 nm. The comparison will therefore be made only at these wavelengths.

8.9.2 Lamp electrical stability

The lamp was operated at 8.100 A at both laboratories, the lamp voltage measured is shown in Table 8-11.

During the second round of measurements, and after the first set of measurements, the ceramic terminal of the lamp identified as BN-9101-249 was partially broken. Therefore, the given voltage value for this lamp in the second round, corresponds only to a single measurement.

Table 8-11 Electrical potential across lamp as measured by both laboratories

Lamp	Potential first NPL measurement	Potential first IFA-CSIC measurement	Potential second NPL measurement	Potential second IFA-CSIC measurement
FEL BN 9101 207	101.9 V	102.17 V	102.1 V	102.33 V
FEL BN 9101 209	100.9 V	101.62 V	100.7 V	101.68 V
FEL BN 9101 249	106.6 V	106.69 V	105.9 – 107.2 V	106.47 V

8.9.3 Lamp history

Table 8-12 Lamp history for FEL BN 9101 207

Date period	Activity	Burn hours:minutes
June – November 2001	1st round measurements at NPL	11:48
December 2001	Air-freight to IFA-CSIC	
February – March 2002	1st round measurements at IFA-CSIC	4:30
March 2002	Air-freight to NPL	
January – May 2003	2nd round measurements at NPL	10:53
June 2003	Air-freight to IFA-CSIC	
November 2003	2nd round measurements at IFA-CSIC	5:10

Table 8-13 Lamp history for FEL BN 9101 209

Date period	Activity	Burn hours:minutes
June – November 2001	1st round measurements at NPL	16:48
December 2001	Air-freight to IFA-CSIC	
February – March 2002	1st round measurements at IFA-CSIC	5:20
March 2002	Air-freight to NPL	
January – May 2003	2nd round measurements at NPL	10:38
June 2003	Air-freight to IFA-CSIC	
November 2003	2nd round measurements at IFA-CSIC	4:45

Table 8-14 Lamp history for FEL BN 9101 249

Date period	Activity	Burn hours:minutes
June – November 2001	1st round measurements at NPL	11:37
December 2001	Air-freight to IFA-CSIC	
February – March 2002	1st round measurements at IFA-CSIC	5:34
March 2002	Air-freight to NPL	
January – May 2003	2nd round measurements at NPL	9:28
June 2003	Air-freight to IFA-CSIC	
November 2003	2nd round measurements at IFA-CSIC	5:00

8.9.4 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the IFA-CSIC lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

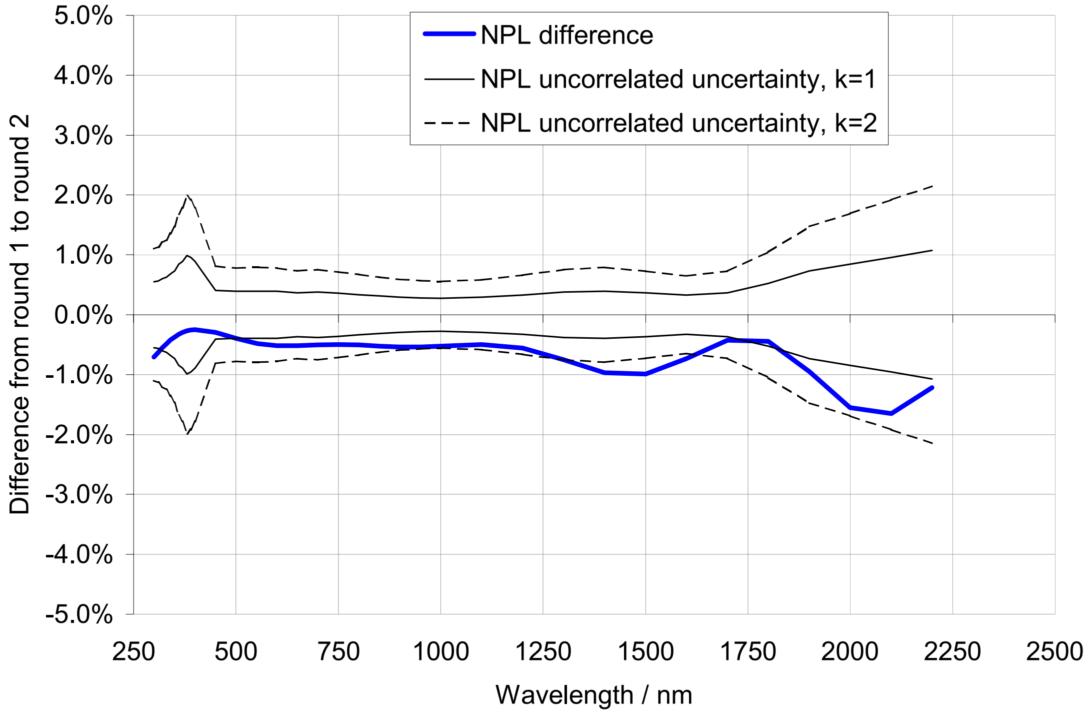

Figure 8-2 Difference between first and second round measurements of FEL BN 9101 207 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

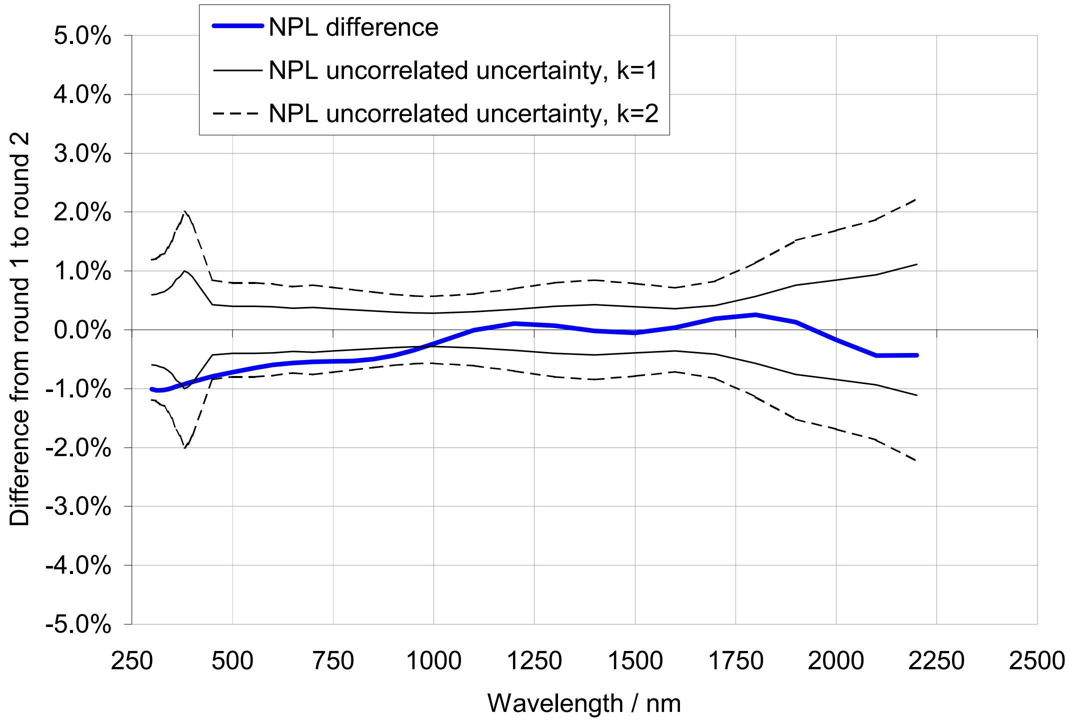

Figure 8-3 Difference between first and second round measurements of FEL BN 9101 209 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

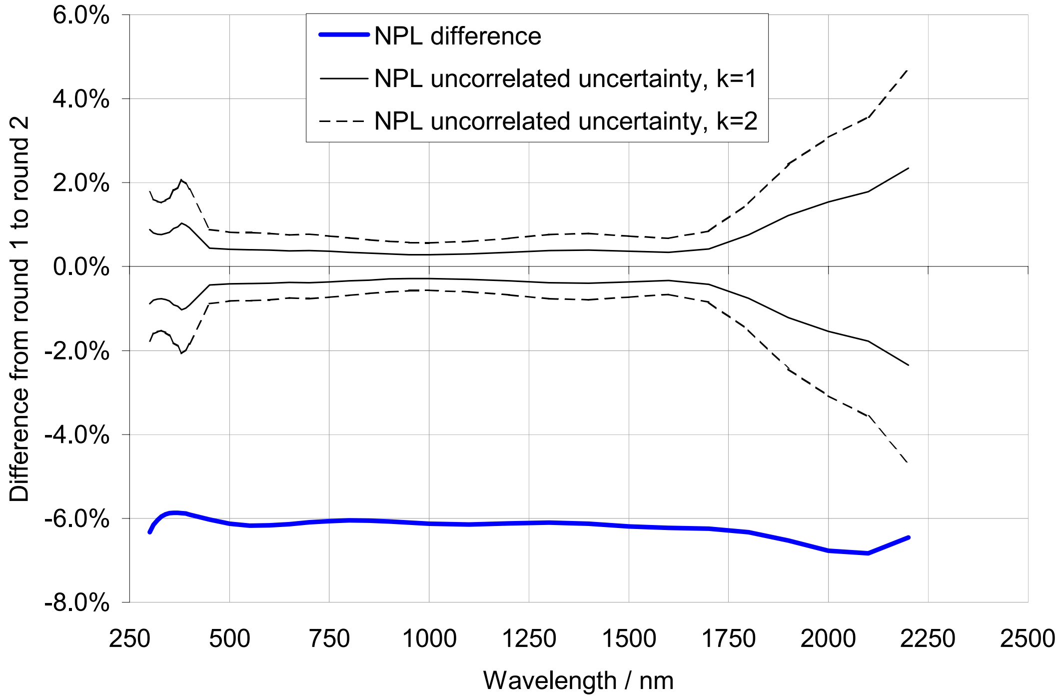

Figure 8-4 Difference between first and second round measurements of FEL BN 9101 249 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

8.9.5 Lamp stability from IFA-CSIC measurements

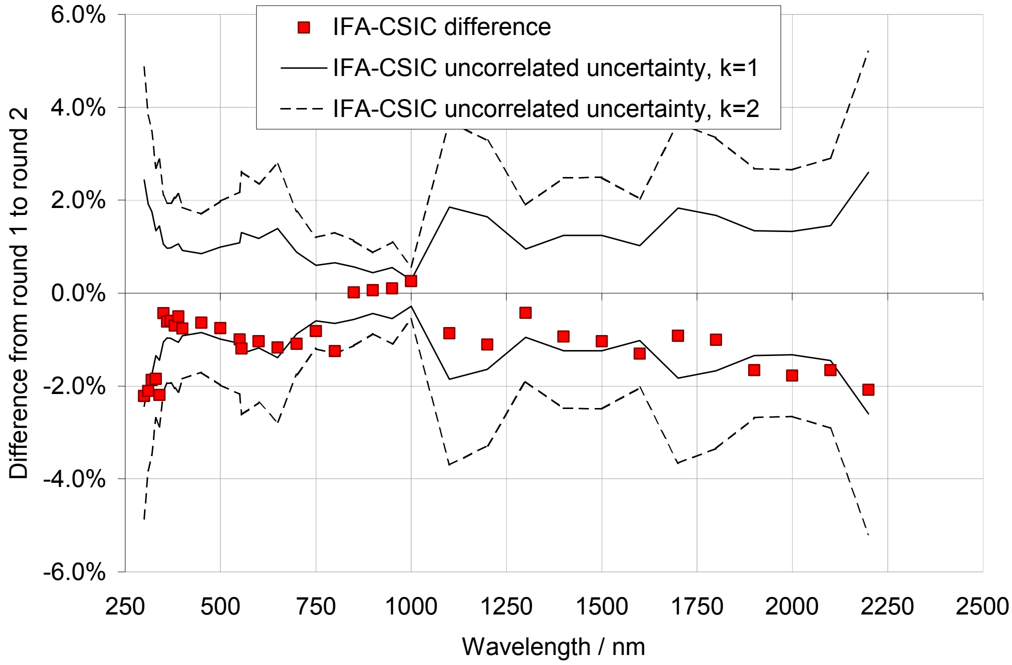

Figure 8-5 Difference between first and second round measurements of FEL BN 9101 207 by IFA-CSIC. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the IFA-CSIC measurements

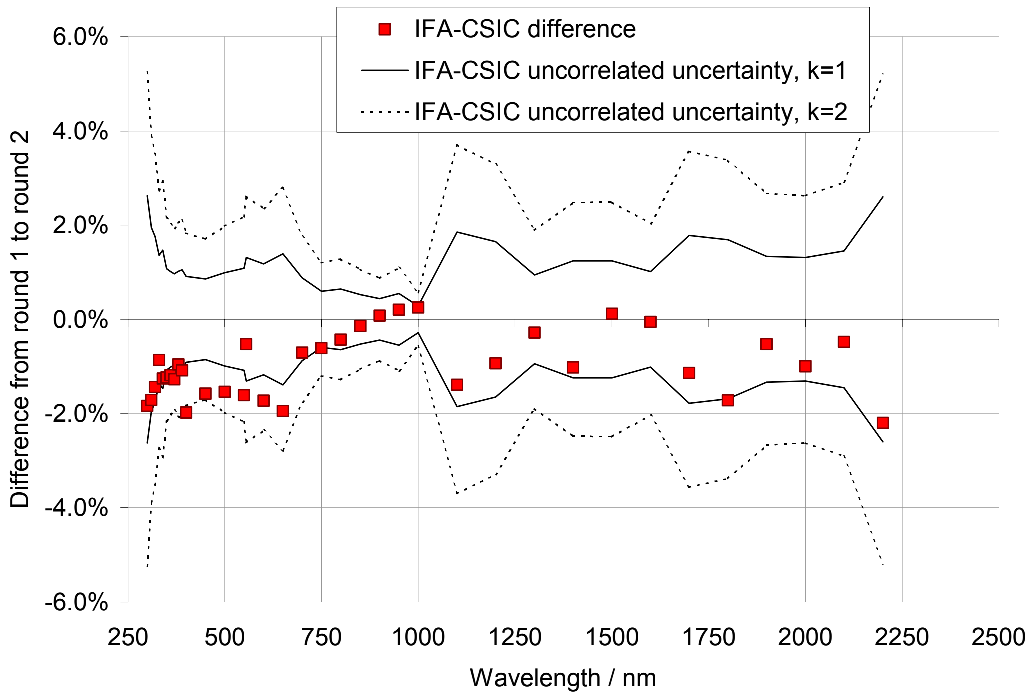

Figure 8-6 Difference between first and second round measurements of FEL BN 9101 209 by IFA-CSIC. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the IFA-CSIC measurements

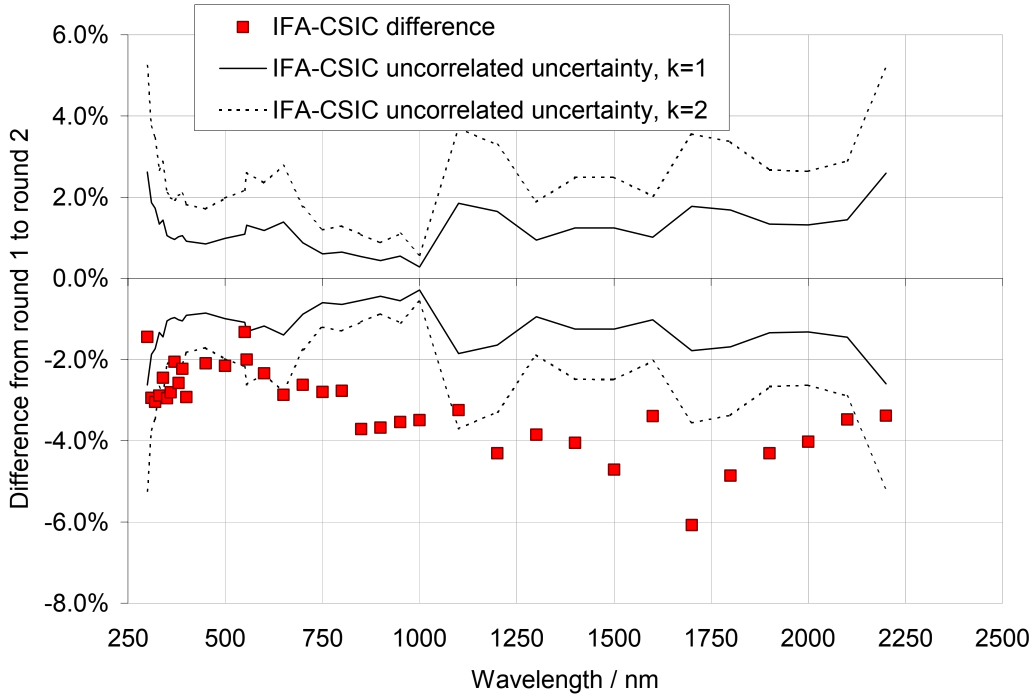

Figure 8-7 Difference between first and second round measurements of FEL BN 9101 249 by IFA-CSIC. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the IFA-CSIC measurements

8.10 Bilateral comparison between IFA-CSIC and the comparison scale

This graph shows the difference between the IFA-CSIC and NPL measurements of the IFA-CSIC lamps. A version of this graph normalised to show the relative difference between the lamps, but not the absolute difference between the measurements was used to assist in choosing which lamp measurements to use.

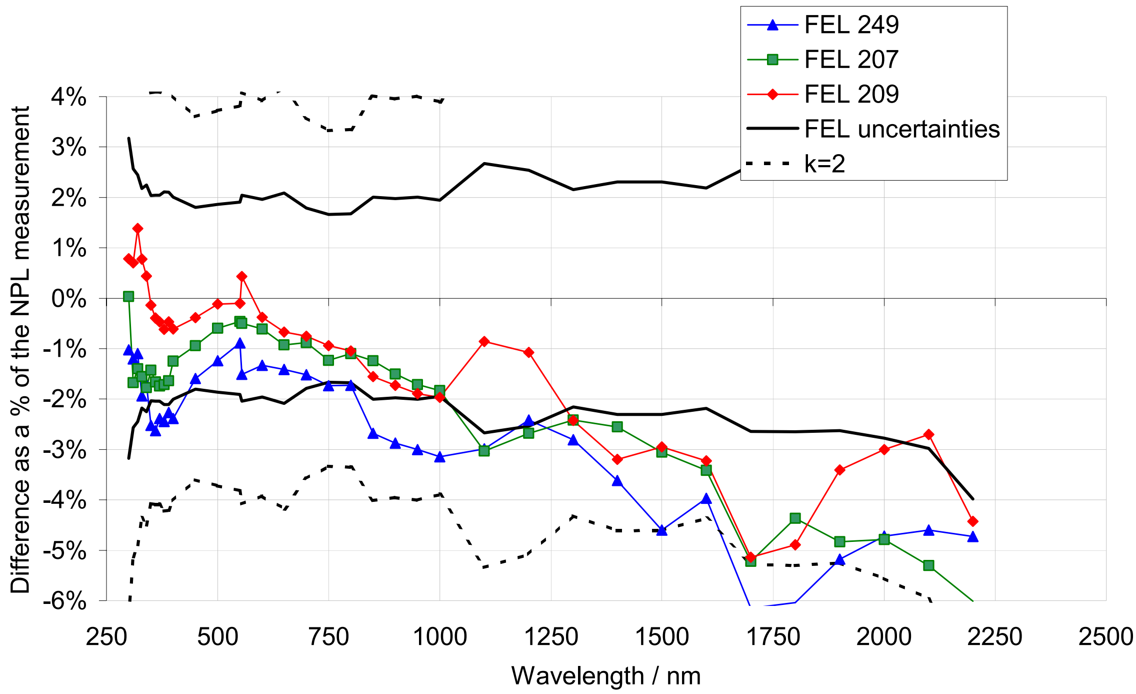

Figure 8-8 Bilateral comparisons of the IFA-CSIC lamps

8.10.1 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to IFA-CSIC the information in the graphs Figure 8-2 to Table 8-8. It was decided that both participant measurements and both pilot measurements would be used for both FEL BN 9101 207 and for FEL BN 9101 209, but that lamp FEL BN 9101 249 would be entirely ignored for this comparison, since both laboratories noticed changes far in excess of their uncertainties and this lamp showed significant voltage fluctuations.

8.11 References

[1] "Absolute spectroradiometric and photometric scales based on an electrically calibrated pyroelectric radiometer" by C. Carreras and A. Corróns. Appl. Optcs. 1981, **20**, pp 1174-1177

[2] "Absolute spectral irradiance scale in the 700-2400nm spectral range" by P. Corredera, A. Corróns, A. Pons and J. Campos. Appl. Optcs 1990, **29**, pp 3530-3534

9 Measurements at MSL-IRL

9.1 Primary scale realisation

The MSL-IRL scale is based on calibrated FEL lamps purchased from NIST. For the first round measurements, made in May and June 2002, the latest lamp calibration from NIST was March 2001. For the second round measurements, made in July and August 2003, the latest lamp calibration from NIST was September 2002.

9.2 Description of the measurement facility

9.2.1 Spectroradiometer

The measurement facility is based around a McPherson 2035 0.35 m double-monochromator and is shown schematically in Figure 9-1.

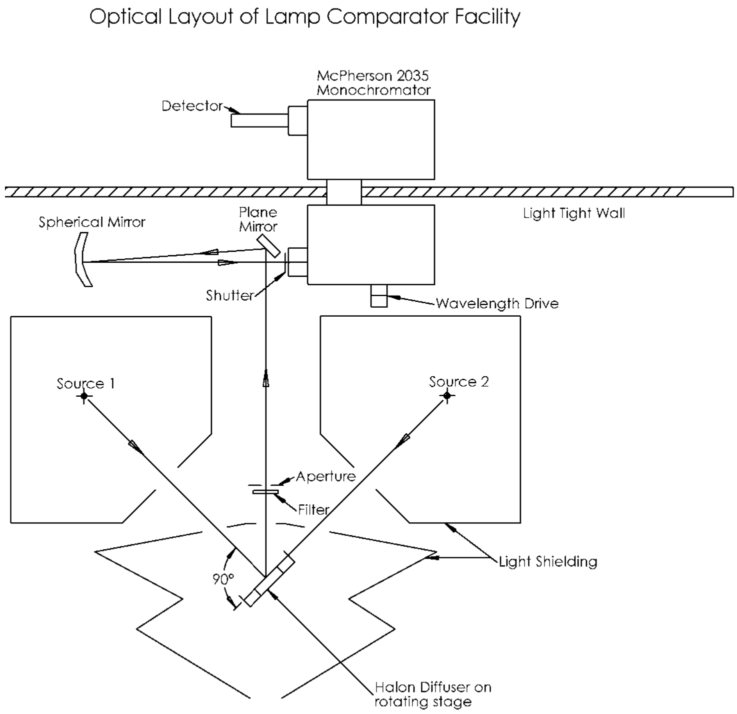

Figure 9-1 Optical layout of lamp comparator facility

9.3 Laboratory transfer standards used

FEL 1 kW lamps.

9.4 Description of calibration laboratory conditions:

Laboratory temperature in the detector area set to 20.0 °C ± 1.0 °C. Humidity uncontrolled. Measurements were made with a spectral bandpass of 2 nm.

9.5 Description of measuring technique

A flat pressed halon plate is located on the entrance optical axis of a monochromator system. The reference lamp and the test lamp are located at 45° on either side of the optical axis with respect to the halon plate. The halon plate is on a motorised rotating stage and is set at normal incidence and at a distance of 50.0 cm from the lamp being measured. Each lamp can be adjusted horizontally and vertically and can be rotated around its vertical axis but no rotational adjustment is available around the horizontal axis. The diffusely reflected light is collected by a spherical mirror and focussed onto the entrance slits of a 0.35 m focal length double monochromator. Filters are used to reduce stray light to less than 1 part in 10^5.

9.6 Uncertainty Determination

Table 9-1 gives the breakdown of the Type B uncertainties for the lamps measured in this comparison. In addition to these uncertainties, Type A uncertainties are given for each lamp calculated from the short-term stability of the test lamp. These uncertainties are from uncorrelated effects and are given as the uncorrelated component in Table 9-2 to Table 9-4.

Table 9-1 Type B uncertainty components

	Type B: all other uncertainty components /%						
Wavelength /nm	NIST Irradiance Scale	Drift in Primary	Wavelength Setting (effect of 0.06 nm on irradiance	Current setting 2 contributions (effect of ±0.8 mA on irradiance	Distance setting 2 contributions (effect of ±0.5 mm on irradiance)	Angular placement of halon plate 2 contributions (effect of ±0.05 on irradiance)	Total Type B /%
	Fully correlated	Fully correlated	Round correlated	Round correlated	Round correlated	Round correlated	
250	0.91	0.69	0.36	0.12	0.2	0.1	1.25
260	0.87	0.66	0.32	0.12	0.2	0.1	1.20
270	0.84	0.63	0.29	0.11	0.2	0.1	1.14
280	0.80	0.60	0.26	0.11	0.2	0.1	1.09
290	0.76	0.57	0.23	0.10	0.2	0.1	1.04
300	0.73	0.55	0.21	0.10	0.2	0.1	1.00
310	0.69	0.52	0.20	0.10	0.2	0.1	0.95
320	0.65	0.49	0.18	0.09	0.2	0.1	0.90
330	0.62	0.46	0.17	0.09	0.2	0.1	0.86
340	0.58	0.43	0.15	0.09	0.2	0.1	0.81
350	0.55	0.40	0.14	0.09	0.2	0.1	0.77
360	0.54	0.40	0.13	0.08	0.2	0.1	0.76
370	0.54	0.40	0.12	0.08	0.2	0.1	0.76
380	0.54	0.40	0.11	0.08	0.2	0.1	0.76
390	0.53	0.40	0.11	0.08	0.2	0.1	0.75
400	0.53	0.40	0.10	0.08	0.2	0.1	0.75
450	0.52	0.40	0.07	0.07	0.2	0.1	0.73
500	0.50	0.40	0.05	0.06	0.2	0.1	0.72
550	0.55	0.39	0.04	0.05	0.2	0.1	0.75
555	0.48	0.39	0.04	0.05	0.2	0.1	0.70
600	0.47	0.39	0.03	0.05	0.2	0.1	0.69
650	0.53	0.39	0.02	0.05	0.2	0.1	0.73
700	0.47	0.39	0.01	0.04	0.2	0.1	0.69
750	0.55	0.39	0.01	0.04	0.2	0.1	0.75
800	0.51	0.39	0.01	0.04	0.2	0.1	0.71
850	0.58	0.39	0.00	0.04	0.2	0.1	0.77

9.7 MSL-IRL Results

MSL-IRL measured three lamps. The results for FEL BN 9101 258 are given in Table 9-2, the results for FEL BN 9101 214 are given in Table 9-3 and the results for FEL BN 9101 215 are given in Table 9-4.

Table 9-2 MSL-IRL Results for FEL BN 9101 258. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 258	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.247E-04	0.50 %	0.51 %	1.14 %	1.35 %	1.257E-04	0.42 %	0.51 %	1.14 %	1.32 %
260	2.230E-04	0.40 %	0.48 %	1.09 %	1.26 %	2.241E-04	0.32 %	0.48 %	1.09 %	1.24 %
270	3.757E-04	0.37 %	0.46 %	1.05 %	1.20 %	3.780E-04	0.26 %	0.46 %	1.05 %	1.17 %
280	5.941E-04	0.38 %	0.44 %	1.00 %	1.16 %	6.019E-04	0.24 %	0.44 %	1.00 %	1.12 %
290	9.108E-04	0.35 %	0.42 %	0.95 %	1.09 %	9.174E-04	0.22 %	0.42 %	0.95 %	1.06 %
300	1.341E-03	0.29 %	0.41 %	0.91 %	1.04 %	1.351E-03	0.21 %	0.41 %	0.91 %	1.02 %
310	1.913E-03	0.27 %	0.40 %	0.86 %	0.99 %	1.928E-03	0.20 %	0.40 %	0.86 %	0.97 %
320	2.650E-03	0.28 %	0.39 %	0.81 %	0.94 %	2.666E-03	0.20 %	0.39 %	0.81 %	0.92 %
330	3.584E-03	0.26 %	0.38 %	0.77 %	0.90 %	3.598E-03	0.19 %	0.38 %	0.77 %	0.88 %
340	4.721E-03	0.26 %	0.37 %	0.72 %	0.85 %	4.744E-03	0.19 %	0.37 %	0.72 %	0.83 %
350	6.112E-03	0.28 %	0.37 %	0.68 %	0.82 %	6.129E-03	0.19 %	0.37 %	0.68 %	0.80 %
360	7.748E-03	0.27 %	0.36 %	0.67 %	0.81 %	7.779E-03	0.18 %	0.36 %	0.67 %	0.78 %
370	9.663E-03	0.26 %	0.36 %	0.67 %	0.80 %	9.707E-03	0.18 %	0.36 %	0.67 %	0.78 %
380	1.192E-02	0.26 %	0.35 %	0.67 %	0.80 %	1.191E-02	0.18 %	0.35 %	0.67 %	0.78 %
390	1.443E-02	0.27 %	0.35 %	0.66 %	0.80 %	1.444E-02	0.18 %	0.35 %	0.66 %	0.77 %
400	1.715E-02	0.24 %	0.35 %	0.66 %	0.79 %	1.722E-02	0.17 %	0.35 %	0.66 %	0.77 %
450	3.537E-02	0.23 %	0.34 %	0.66 %	0.77 %	3.561E-02	0.17 %	0.34 %	0.66 %	0.76 %
500	5.937E-02	0.23 %	0.33 %	0.64 %	0.76 %	5.994E-02	0.17 %	0.33 %	0.64 %	0.74 %
550	8.727E-02	0.23 %	0.33 %	0.67 %	0.78 %	8.776E-02	0.16 %	0.33 %	0.67 %	0.77 %
555	8.957E-02	0.22 %	0.33 %	0.62 %	0.73 %	9.032E-02	0.16 %	0.33 %	0.62 %	0.72 %
600	1.157E-01	0.21 %	0.33 %	0.61 %	0.72 %	1.154E-01	0.16 %	0.33 %	0.61 %	0.71 %
650	1.405E-01	0.22 %	0.32 %	0.66 %	0.77 %	1.409E-01	0.16 %	0.32 %	0.66 %	0.75 %
700	1.617E-01	0.21 %	0.32 %	0.61 %	0.72 %	1.624E-01	0.16 %	0.32 %	0.61 %	0.71 %
750	1.782E-01	0.23 %	0.32 %	0.67 %	0.78 %	1.789E-01	0.16 %	0.32 %	0.67 %	0.76 %
800	1.898E-01	0.23 %	0.32 %	0.64 %	0.75 %	1.909E-01	0.17 %	0.32 %	0.64 %	0.74 %
850	1.977E-01	0.26 %	0.32 %	0.70 %	0.81 %	1.973E-01	0.22 %	0.32 %	0.70 %	0.80 %
900										
950										
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2500										

Table 9-3 MSL-IRL Results for FEL BN 9101 214. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 214	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.211E-04	0.49 %	0.51 %	1.14 %	1.34 %	1.204E-04	0.42 %	0.51 %	1.14 %	1.32 %
260	2.153E-04	0.36 %	0.48 %	1.09 %	1.25 %	2.123E-04	0.32 %	0.48 %	1.09 %	1.24 %
270	3.611E-04	0.32 %	0.46 %	1.05 %	1.19 %	3.584E-04	0.26 %	0.46 %	1.05 %	1.17 %
280	5.716E-04	0.31 %	0.44 %	1.00 %	1.13 %	5.702E-04	0.24 %	0.44 %	1.00 %	1.12 %
290	8.741E-04	0.27 %	0.42 %	0.95 %	1.07 %	8.681E-04	0.22 %	0.42 %	0.95 %	1.06 %
300	1.282E-03	0.24 %	0.41 %	0.91 %	1.03 %	1.277E-03	0.21 %	0.41 %	0.91 %	1.02 %
310	1.823E-03	0.23 %	0.40 %	0.86 %	0.98 %	1.817E-03	0.20 %	0.40 %	0.86 %	0.97 %
320	2.522E-03	0.23 %	0.39 %	0.81 %	0.93 %	2.513E-03	0.20 %	0.39 %	0.81 %	0.92 %
330	3.408E-03	0.22 %	0.38 %	0.77 %	0.89 %	3.393E-03	0.19 %	0.38 %	0.77 %	0.88 %
340	4.484E-03	0.22 %	0.37 %	0.72 %	0.84 %	4.470E-03	0.19 %	0.37 %	0.72 %	0.83 %
350	5.795E-03	0.24 %	0.37 %	0.68 %	0.81 %	5.778E-03	0.19 %	0.37 %	0.68 %	0.80 %
360	7.361E-03	0.21 %	0.36 %	0.67 %	0.79 %	7.325E-03	0.18 %	0.36 %	0.67 %	0.78 %
370	9.119E-03	0.21 %	0.36 %	0.67 %	0.79 %	9.143E-03	0.18 %	0.36 %	0.67 %	0.78 %
380	1.129E-02	0.20 %	0.35 %	0.67 %	0.79 %	1.122E-02	0.18 %	0.35 %	0.67 %	0.78 %
390	1.368E-02	0.21 %	0.35 %	0.66 %	0.78 %	1.360E-02	0.18 %	0.35 %	0.66 %	0.77 %
400	1.627E-02	0.22 %	0.35 %	0.66 %	0.78 %	1.624E-02	0.17 %	0.35 %	0.66 %	0.77 %
450	3.368E-02	0.20 %	0.34 %	0.66 %	0.76 %	3.363E-02	0.17 %	0.34 %	0.66 %	0.76 %
500	5.648E-02	0.19 %	0.33 %	0.64 %	0.75 %	5.673E-02	0.17 %	0.33 %	0.64 %	0.74 %
550	8.332E-02	0.19 %	0.33 %	0.67 %	0.77 %	8.314E-02	0.16 %	0.33 %	0.67 %	0.77 %
555	8.570E-02	0.20 %	0.33 %	0.62 %	0.73 %	8.571E-02	0.16 %	0.33 %	0.62 %	0.72 %
600	1.108E-01	0.19 %	0.33 %	0.61 %	0.72 %	1.097E-01	0.16 %	0.33 %	0.61 %	0.71 %
650	1.346E-01	0.18 %	0.32 %	0.66 %	0.76 %	1.342E-01	0.16 %	0.32 %	0.66 %	0.75 %
700	1.553E-01	0.19 %	0.32 %	0.61 %	0.72 %	1.550E-01	0.16 %	0.32 %	0.61 %	0.71 %
750	1.716E-01	0.19 %	0.32 %	0.67 %	0.77 %	1.711E-01	0.16 %	0.32 %	0.67 %	0.76 %
800	1.827E-01	0.19 %	0.32 %	0.64 %	0.74 %	1.826E-01	0.17 %	0.32 %	0.64 %	0.74 %
850	1.901E-01	0.23 %	0.32 %	0.70 %	0.80 %	1.896E-01	0.22 %	0.32 %	0.70 %	0.80 %
900										
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Table 9-4 MSL-IRL Results for FEL BN 9101 215. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 215	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.545E-04	0.48 %	0.51 %	1.14 %	1.34 %	1.445E-04	0.42 %	0.51 %	1.14 %	1.32 %
260	2.723E-04	0.37 %	0.48 %	1.09 %	1.25 %	2.541E-04	0.32 %	0.48 %	1.09 %	1.24 %
270	4.519E-04	0.33 %	0.46 %	1.05 %	1.19 %	4.244E-04	0.26 %	0.46 %	1.05 %	1.17 %
280	6.999E-04	0.32 %	0.44 %	1.00 %	1.14 %	6.597E-04	0.24 %	0.44 %	1.00 %	1.12 %
290	1.075E-03	0.29 %	0.42 %	0.95 %	1.08 %	1.012E-03	0.22 %	0.42 %	0.95 %	1.06 %
300	1.568E-03	0.25 %	0.41 %	0.91 %	1.03 %	1.479E-03	0.21 %	0.41 %	0.91 %	1.02 %
310	2.225E-03	0.24 %	0.40 %	0.86 %	0.98 %	2.103E-03	0.20 %	0.40 %	0.86 %	0.97 %
320	3.048E-03	0.23 %	0.39 %	0.81 %	0.93 %	2.879E-03	0.20 %	0.39 %	0.81 %	0.92 %
330	4.084E-03	0.22 %	0.38 %	0.77 %	0.89 %	3.867E-03	0.19 %	0.38 %	0.77 %	0.88 %
340	5.350E-03	0.22 %	0.37 %	0.72 %	0.84 %	5.074E-03	0.19 %	0.37 %	0.72 %	0.83 %
350	6.886E-03	0.22 %	0.37 %	0.68 %	0.80 %	6.521E-03	0.19 %	0.37 %	0.68 %	0.80 %
360	8.714E-03	0.22 %	0.36 %	0.67 %	0.79 %	8.240E-03	0.18 %	0.36 %	0.67 %	0.78 %
370	1.077E-02	0.22 %	0.36 %	0.67 %	0.79 %	1.024E-02	0.18 %	0.36 %	0.67 %	0.78 %
380	1.325E-02	0.21 %	0.35 %	0.67 %	0.79 %	1.252E-02	0.18 %	0.35 %	0.67 %	0.78 %
390	1.597E-02	0.22 %	0.35 %	0.66 %	0.78 %	1.513E-02	0.18 %	0.35 %	0.66 %	0.77 %
400	1.894E-02	0.21 %	0.35 %	0.66 %	0.78 %	1.799E-02	0.17 %	0.35 %	0.66 %	0.77 %
450	3.854E-02	0.19 %	0.34 %	0.66 %	0.76 %	3.675E-02	0.17 %	0.34 %	0.66 %	0.76 %
500	6.378E-02	0.19 %	0.33 %	0.64 %	0.75 %	6.132E-02	0.17 %	0.33 %	0.64 %	0.74 %
550	9.287E-02	0.19 %	0.33 %	0.67 %	0.77 %	8.905E-02	0.16 %	0.33 %	0.67 %	0.77 %
555	9.549E-02	0.19 %	0.33 %	0.62 %	0.72 %	9.171E-02	0.16 %	0.33 %	0.62 %	0.72 %
600	1.223E-01	0.18 %	0.33 %	0.61 %	0.72 %	1.165E-01	0.16 %	0.33 %	0.61 %	0.71 %
650	1.476E-01	0.18 %	0.32 %	0.66 %	0.76 %	1.416E-01	0.16 %	0.32 %	0.66 %	0.75 %
700	1.693E-01	0.18 %	0.32 %	0.61 %	0.71 %	1.626E-01	0.16 %	0.32 %	0.61 %	0.71 %
750	1.859E-01	0.18 %	0.32 %	0.67 %	0.77 %	1.787E-01	0.16 %	0.32 %	0.67 %	0.76 %
800	1.968E-01	0.19 %	0.32 %	0.64 %	0.74 %	1.897E-01	0.17 %	0.32 %	0.64 %	0.74 %
850	2.041E-01	0.21 %	0.32 %	0.70 %	0.80 %	1.965E-01	0.22 %	0.32 %	0.70 %	0.80 %
900										
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9.8 Pilot Results

NPL's results for FEL BN 9101 258 are given in Table 9-5, the results for FEL BN 9101 214 are given in Table 9-6 and the results for FEL BN 9101 215 are given in

Table 9-7.

Table 9-5 NPL Results for FEL BN 9101 258. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 258	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.269E-04	1.03 %	0.32 %	2.06 %	2.32 %	1.254E-04	0.61 %	0.00 %	2.06 %	2.15 %
260	2.238E-04	0.70 %	0.32 %	2.05 %	2.19 %	2.217E-04	0.41 %	0.00 %	2.05 %	2.09 %
270	3.741E-04	0.49 %	0.31 %	2.05 %	2.13 %	3.712E-04	0.33 %	0.00 %	2.05 %	2.07 %
280	5.966E-04	0.37 %	0.29 %	1.56 %	1.63 %	5.927E-04	0.29 %	0.00 %	1.56 %	1.59 %
290	9.130E-04	0.29 %	0.27 %	1.08 %	1.15 %	9.076E-04	0.27 %	0.00 %	1.08 %	1.12 %
300	1.347E-03	0.25 %	0.33 %	0.45 %	0.61 %	1.340E-03	0.25 %	0.15 %	0.45 %	0.53 %
310	1.924E-03	0.22 %	0.38 %	0.43 %	0.61 %	1.914E-03	0.23 %	0.20 %	0.43 %	0.53 %
320	2.669E-03	0.19 %	0.43 %	0.37 %	0.60 %	2.656E-03	0.20 %	0.25 %	0.37 %	0.49 %
330	3.607E-03	0.17 %	0.47 %	0.36 %	0.62 %	3.591E-03	0.18 %	0.28 %	0.36 %	0.49 %
340	4.763E-03	0.10 %	0.53 %	0.35 %	0.65 %	4.743E-03	0.17 %	0.33 %	0.35 %	0.51 %
350	6.157E-03	0.17 %	0.58 %	0.34 %	0.69 %	6.134E-03	0.16 %	0.36 %	0.34 %	0.52 %
360	7.809E-03	0.16 %	0.67 %	0.33 %	0.77 %	7.783E-03	0.15 %	0.43 %	0.33 %	0.56 %
370	9.734E-03	0.15 %	0.72 %	0.32 %	0.80 %	9.706E-03	0.15 %	0.46 %	0.32 %	0.58 %
380	1.194E-02	0.15 %	0.81 %	0.31 %	0.88 %	1.192E-02	0.15 %	0.52 %	0.31 %	0.63 %
390	1.445E-02	0.15 %	0.78 %	0.31 %	0.85 %	1.442E-02	0.15 %	0.50 %	0.31 %	0.61 %
400	1.724E-02	0.14 %	0.72 %	0.30 %	0.80 %	1.722E-02	0.15 %	0.46 %	0.30 %	0.57 %
450	3.553E-02	0.13 %	0.31 %	0.27 %	0.43 %	3.557E-02	0.17 %	0.10 %	0.27 %	0.33 %
500	5.975E-02	0.13 %	0.31 %	0.24 %	0.41 %	5.990E-02	0.17 %	0.00 %	0.24 %	0.29 %
550	8.724E-02	0.12 %	0.33 %	0.22 %	0.42 %	8.746E-02	0.16 %	0.00 %	0.22 %	0.27 %
555	9.005E-02	0.12 %	0.33 %	0.22 %	0.41 %	9.027E-02	0.16 %	0.00 %	0.22 %	0.27 %
600	1.150E-01	0.12 %	0.33 %	0.20 %	0.40 %	1.152E-01	0.15 %	0.00 %	0.20 %	0.25 %
650	1.406E-01	0.04 %	0.32 %	0.18 %	0.37 %	1.408E-01	0.15 %	0.00 %	0.18 %	0.24 %
700	1.623E-01	0.13 %	0.31 %	0.17 %	0.38 %	1.624E-01	0.15 %	0.00 %	0.17 %	0.23 %
750	1.792E-01	0.12 %	0.30 %	0.16 %	0.36 %	1.793E-01	0.14 %	0.00 %	0.16 %	0.21 %
800	1.912E-01	0.10 %	0.29 %	0.15 %	0.34 %	1.914E-01	0.12 %	0.00 %	0.15 %	0.19 %
850	1.985E-01	0.09 %	0.28 %	0.14 %	0.32 %	1.988E-01	0.11 %	0.00 %	0.14 %	0.18 %
900										
950										
1000										
1100										
1200										
1300										
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2400										
2500										

Table 9-6 NPL Results for FEL BN 9101 214. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1

FEL 214	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.217E-04	0.72 %	0.32 %	2.06 %	2.20 %	1.211E-04	0.92 %	0.00 %	2.06 %	2.25 %
260	2.136E-04	0.49 %	0.32 %	2.05 %	2.14 %	2.121E-04	0.68 %	0.00 %	2.05 %	2.16 %
270	3.557E-04	0.36 %	0.31 %	2.05 %	2.10 %	3.529E-04	0.53 %	0.00 %	2.05 %	2.11 %
280	5.657E-04	0.29 %	0.29 %	1.56 %	1.61 %	5.609E-04	0.42 %	0.00 %	1.56 %	1.62 %
290	8.640E-04	0.25 %	0.27 %	1.08 %	1.14 %	8.565E-04	0.35 %	0.00 %	1.08 %	1.14 %
300	1.273E-03	0.23 %	0.33 %	0.45 %	0.60 %	1.262E-03	0.31 %	0.15 %	0.45 %	0.56 %
310	1.816E-03	0.21 %	0.38 %	0.43 %	0.61 %	1.801E-03	0.28 %	0.20 %	0.43 %	0.55 %
320	2.518E-03	0.19 %	0.43 %	0.37 %	0.60 %	2.497E-03	0.26 %	0.25 %	0.37 %	0.52 %
330	3.402E-03	0.17 %	0.47 %	0.36 %	0.62 %	3.375E-03	0.24 %	0.28 %	0.36 %	0.52 %
340	4.490E-03	0.10 %	0.53 %	0.35 %	0.65 %	4.458E-03	0.22 %	0.33 %	0.35 %	0.53 %
350	5.804E-03	0.17 %	0.58 %	0.34 %	0.69 %	5.765E-03	0.20 %	0.36 %	0.34 %	0.54 %
360	7.361E-03	0.16 %	0.67 %	0.33 %	0.77 %	7.316E-03	0.19 %	0.43 %	0.33 %	0.58 %
370	9.175E-03	0.15 %	0.72 %	0.32 %	0.80 %	9.126E-03	0.18 %	0.46 %	0.32 %	0.59 %
380	1.126E-02	0.15 %	0.81 %	0.31 %	0.88 %	1.121E-02	0.17 %	0.52 %	0.31 %	0.63 %
390	1.362E-02	0.14 %	0.78 %	0.31 %	0.85 %	1.356E-02	0.17 %	0.50 %	0.31 %	0.61 %
400	1.626E-02	0.14 %	0.72 %	0.30 %	0.80 %	1.620E-02	0.17 %	0.46 %	0.30 %	0.57 %
450	3.355E-02	0.13 %	0.31 %	0.27 %	0.43 %	3.351E-02	0.17 %	0.10 %	0.27 %	0.33 %
500	5.650E-02	0.13 %	0.31 %	0.24 %	0.41 %	5.653E-02	0.16 %	0.00 %	0.24 %	0.29 %
550	8.264E-02	0.12 %	0.33 %	0.22 %	0.42 %	8.275E-02	0.14 %	0.00 %	0.22 %	0.26 %
555	8.532E-02	0.12 %	0.33 %	0.22 %	0.41 %	8.544E-02	0.14 %	0.00 %	0.22 %	0.26 %
600	1.092E-01	0.12 %	0.33 %	0.20 %	0.40 %	1.094E-01	0.13 %	0.00 %	0.20 %	0.24 %
650	1.337E-01	0.04 %	0.32 %	0.18 %	0.37 %	1.340E-01	0.13 %	0.00 %	0.18 %	0.23 %
700	1.545E-01	0.13 %	0.31 %	0.17 %	0.38 %	1.549E-01	0.13 %	0.00 %	0.17 %	0.21 %
750	1.709E-01	0.12 %	0.30 %	0.16 %	0.36 %	1.713E-01	0.12 %	0.00 %	0.16 %	0.20 %
800	1.825E-01	0.10 %	0.29 %	0.15 %	0.34 %	1.829E-01	0.11 %	0.00 %	0.15 %	0.19 %
850	1.897E-01	0.09 %	0.28 %	0.14 %	0.32 %	1.901E-01	0.10 %	0.00 %	0.14 %	0.18 %
900										
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Table 9-7 NPL Results for FEL BN 9101 215. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 215	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.604E-04	2.27 %	0.32 %	2.06 %	3.08 %	1.506E-04	0.46 %	0.00 %	2.06 %	2.11 %
260	2.774E-04	1.69 %	0.32 %	2.05 %	2.68 %	2.633E-04	0.31 %	0.00 %	2.05 %	2.08 %
270	4.562E-04	1.27 %	0.31 %	2.05 %	2.43 %	4.361E-04	0.25 %	0.00 %	2.05 %	2.06 %
280	7.179E-04	0.97 %	0.29 %	1.56 %	1.86 %	6.892E-04	0.23 %	0.00 %	1.56 %	1.58 %
290	1.086E-03	0.76 %	0.27 %	1.08 %	1.35 %	1.046E-03	0.22 %	0.00 %	1.08 %	1.10 %
300	1.587E-03	0.61 %	0.33 %	0.45 %	0.83 %	1.530E-03	0.20 %	0.15 %	0.45 %	0.51 %
310	2.247E-03	0.52 %	0.38 %	0.43 %	0.77 %	2.168E-03	0.19 %	0.20 %	0.43 %	0.51 %
320	3.095E-03	0.45 %	0.43 %	0.37 %	0.73 %	2.987E-03	0.17 %	0.25 %	0.37 %	0.48 %
330	4.156E-03	0.41 %	0.47 %	0.36 %	0.72 %	4.011E-03	0.16 %	0.28 %	0.36 %	0.48 %
340	5.455E-03	0.35 %	0.53 %	0.35 %	0.73 %	5.265E-03	0.15 %	0.33 %	0.35 %	0.50 %
350	7.015E-03	0.36 %	0.58 %	0.34 %	0.76 %	6.771E-03	0.14 %	0.36 %	0.34 %	0.52 %
360	8.854E-03	0.33 %	0.67 %	0.33 %	0.82 %	8.546E-03	0.14 %	0.43 %	0.33 %	0.56 %
370	1.099E-02	0.31 %	0.72 %	0.32 %	0.85 %	1.061E-02	0.14 %	0.46 %	0.32 %	0.58 %
380	1.342E-02	0.29 %	0.81 %	0.31 %	0.91 %	1.297E-02	0.13 %	0.52 %	0.31 %	0.62 %
390	1.617E-02	0.27 %	0.78 %	0.31 %	0.88 %	1.563E-02	0.13 %	0.50 %	0.31 %	0.60 %
400	1.924E-02	0.26 %	0.72 %	0.30 %	0.82 %	1.860E-02	0.14 %	0.46 %	0.30 %	0.57 %
450	3.902E-02	0.22 %	0.31 %	0.27 %	0.46 %	3.790E-02	0.16 %	0.10 %	0.27 %	0.32 %
500	6.479E-02	0.20 %	0.31 %	0.24 %	0.44 %	6.323E-02	0.17 %	0.00 %	0.24 %	0.29 %
550	9.365E-02	0.17 %	0.33 %	0.22 %	0.43 %	9.170E-02	0.16 %	0.00 %	0.22 %	0.27 %
555	9.658E-02	0.17 %	0.33 %	0.22 %	0.43 %	9.459E-02	0.16 %	0.00 %	0.22 %	0.27 %
600	1.225E-01	0.16 %	0.33 %	0.20 %	0.42 %	1.201E-01	0.15 %	0.00 %	0.20 %	0.25 %
650	1.487E-01	0.13 %	0.32 %	0.18 %	0.39 %	1.460E-01	0.15 %	0.00 %	0.18 %	0.24 %
700	1.707E-01	0.18 %	0.31 %	0.17 %	0.40 %	1.677E-01	0.14 %	0.00 %	0.17 %	0.22 %
750	1.876E-01	0.16 %	0.30 %	0.16 %	0.38 %	1.845E-01	0.13 %	0.00 %	0.16 %	0.21 %
800	1.993E-01	0.14 %	0.29 %	0.15 %	0.35 %	1.961E-01	0.11 %	0.00 %	0.15 %	0.19 %
850	2.061E-01	0.12 %	0.28 %	0.14 %	0.33 %	2.030E-01	0.09 %	0.00 %	0.14 %	0.17 %
900										
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9.9 Lamp Behaviour

9.9.1 MSL-IRL Lamps

The following lamps were supplied to MSL-IRL by NPL:

FEL BN 9101 258 FEL BN 9101 214 FEL BN 9101 215

Measurements were made in the sequence: NPL – MSL-IRL – NPL – MSL-IRL

MSL-IRL measured all intercomparison wavelengths between 250 and 850 nm.

9.9.2 Lamp electrical stability

The lamp was operated at 8.100 A at both laboratories, the lamp voltage measured is shown in Table 9-8.

Table 9-8 Electrical potential across lamp as measured by both laboratories:

Lamp	Potential first NPL measurement	Potential first MSL-IRL measurement	Potential second NPL measurement	Potential second MSL-IRL measurement
FEL BN 9101 258	105.1 V	105.3 V (then 105.28 – 105.16 V)	105.4 V	105.2 V
FEL BN 9101 214	101.7 V	102.3 – 101.8 V	101.9 V	101.9 V
FEL BN 9101 215	109.7 V	109.7 V	109.8 V	109.7 V

9.9.3 Lamp history

Table 9-9 Lamp history for FEL BN 9101 258

Date period	Activity	Burn hours:minutes
June – November 2001	1st round measurements at NPL	6:22
November 2001	Air-freight to MSL-IRL	
May – June 2002	1st round measurements at MSL-IRL	13:59
July 2002	Air-freight to NPL	
January – May 2003	2nd round measurements at NPL	14:20
June 2003	Air-freight to MSL-IRL	
July – August 2003	2nd round measurements at MSL-IRL	9:54

Table 9-10 Lamp history for FEL BN 9101 214

Date period	Activity	Burn hours:minutes
June – November 2001	1st round measurements at NPL	11:23
November 2001	Air-freight to MSL-IRL	
May – June 2002	1st round measurements at MSL-IRL	13:16
July 2002	Air-freight to NPL	
January – May 2003	2nd round measurements at NPL	11:37
June 2003	Air-freight to MSL-IRL	
July – August 2003	2nd round measurements at MSL-IRL	12:12

Table 9-11 Lamp history for FEL BN 9101 215

Date period	Activity	Burn hours:minutes
June – November 2001	1st round measurements at NPL	11:22
November 2001	Air-freight to MSL-IRL	
May – June 2002	1st round measurements at MSL-IRL	12:32
July 2002	Air-freight to NPL	
January – May 2003	2nd round measurements at NPL	10:09
June 2003	Air-freight to MSL-IRL	
July – August 2003	2nd round measurements at MSL-IRL	10:54

9.9.4 Other lamp changes

MSL-IRL made the following comments on the lamps for the first round:

1) The white ceramic from the base of each lamp had loosened and was spread within the lamp cover and on the glass envelope of each lamp
2) Lamp 214. Spotting on the glass envelope – some within the field of view of the filament. These spots worsened with burn time.
3) Lamp 215. Spotting on front and rear of the glass envelope. Some small scratches on the glass envelope on the rear top left.
4) Lamp 258. Some minor spotting
5) Given the observed variability in the operating voltages of two of the lamps there may be increased likelihood of some instability in these transfer standards.
6) From our [MSL-IRL's] measurements we have observed indications of possible emission lines between 260-280 nm and around 310 nm in lamp 215.

MSL-IRL made the following comments on the lamps for the second round:

1) The alignment plate for lamp BN 9101 214 is approximately 2° misaligned about the horizontal axis. This was not observed in 2002.
2) BN 9101 215 appears to have changed in irradiance since 2002, it also continued to change during the calibration process. This was not consistent with the behaviour of the other two lamps in the comparison set.

9.9.5 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the MSL-IRL lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

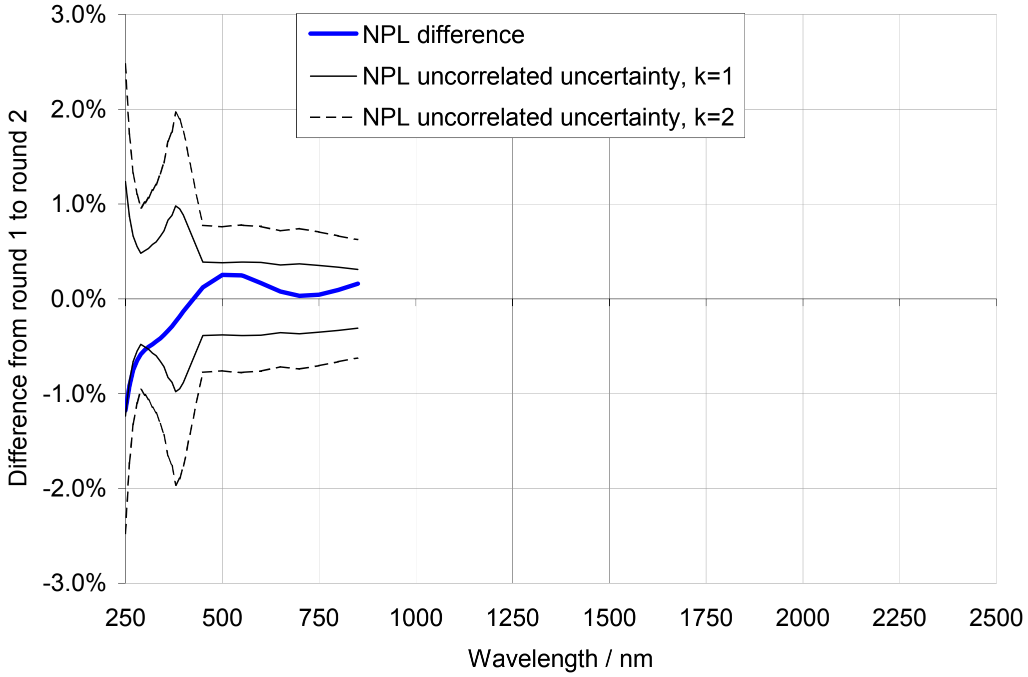

Figure 9-2 Difference between first and second round measurements of FEL BN 9101 258 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

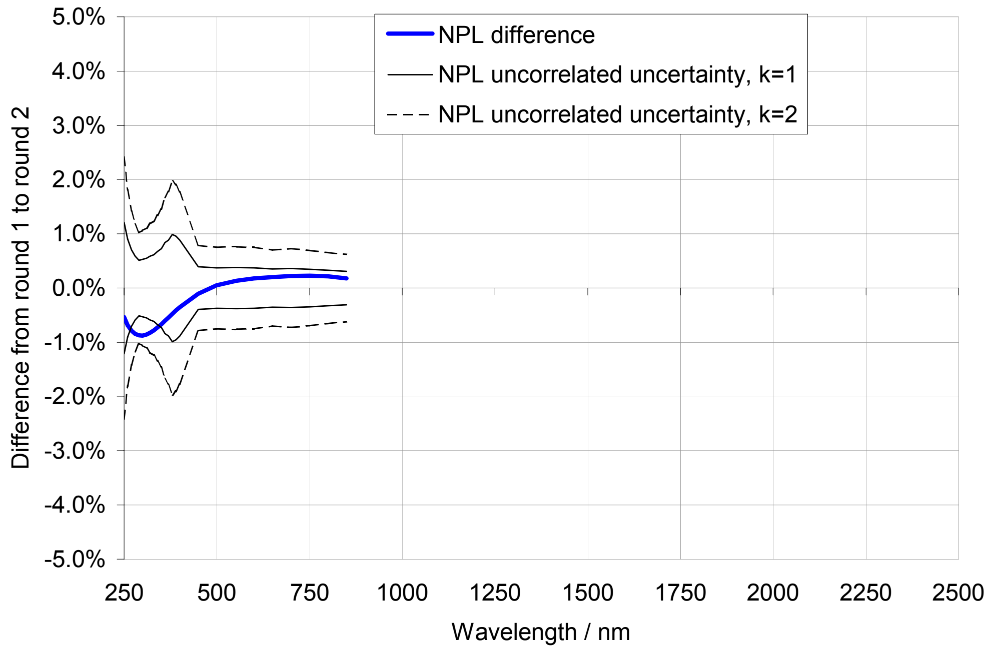

Figure 9-3 Difference between first and second round measurements of FEL BN 9101 214 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

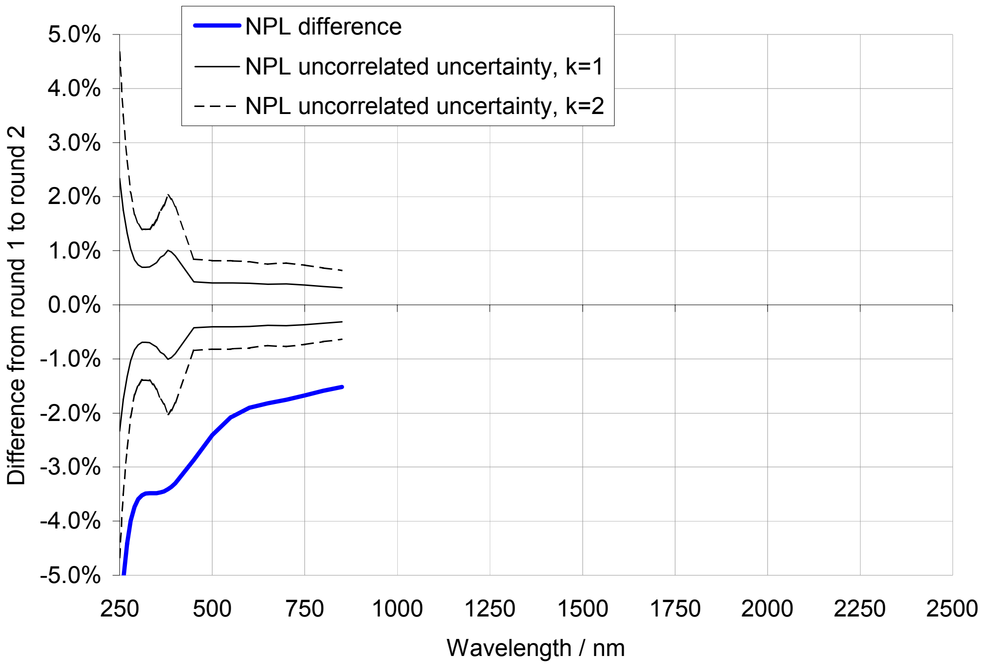

Figure 9-4 Difference between first and second round measurements of FEL BN 9101 215 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

9.9.6 Lamp stability from MSL-IRL measurements

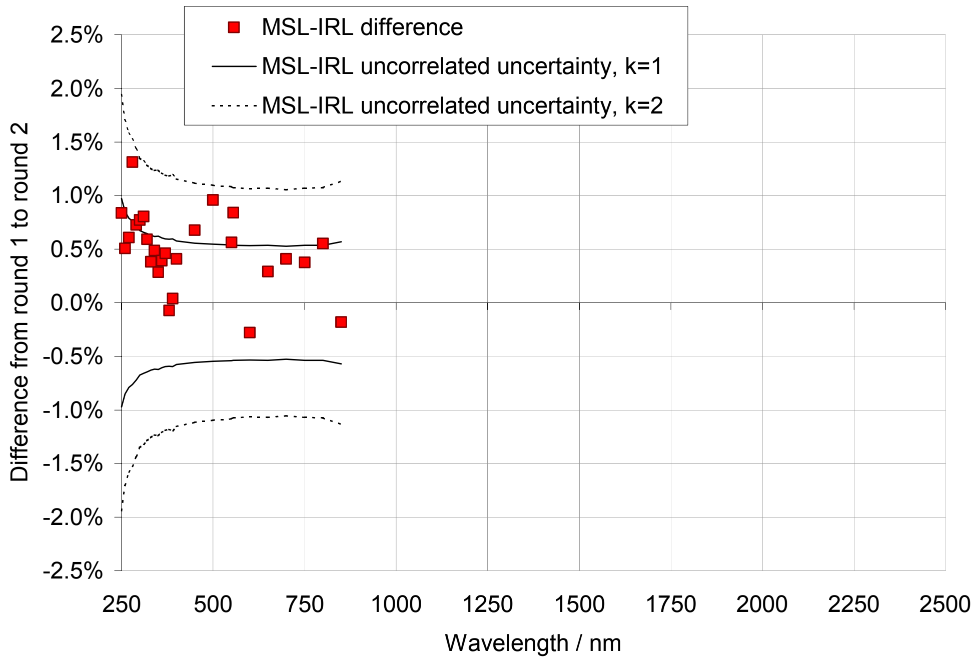

Figure 9-5 Difference between first and second round measurements of FEL BN 9101 258 by MSL-IRL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the MSL-IRL measurements

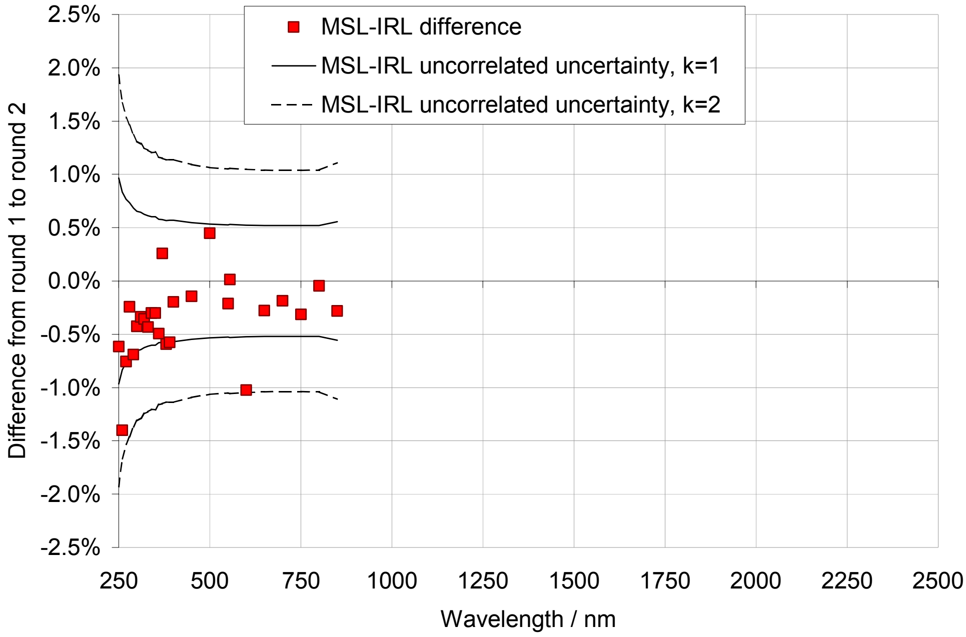

Figure 9-6 Difference between first and second round measurements of FEL BN 9101 214 by MSL-IRL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the MSL-IRL measurements

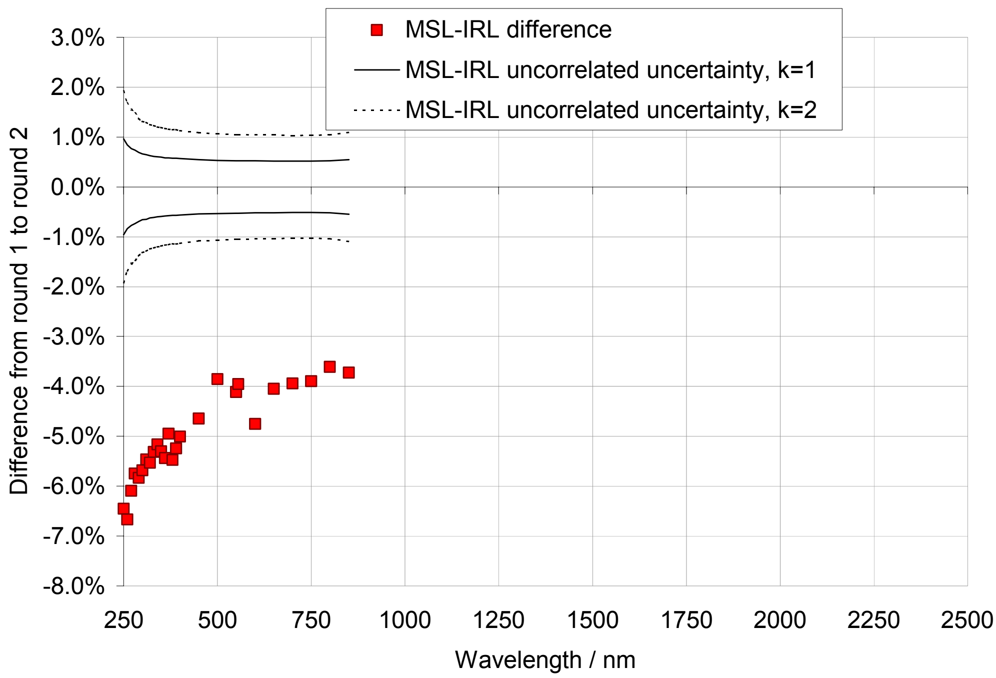

Figure 9-7 Difference between first and second round measurements of FEL BN 9101 215 by MSL-IRL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the MSL-IRL measurements

9.10 Bilateral comparison between MSL-IRL and the comparison scale

This graph shows the difference between the MSL-IRL and NPL measurements of the MSL-IRL lamps. A version of this graph normalised to show the relative difference between the lamps, but not the absolute difference between the measurements was used to assist in choosing which lamp measurements to use.

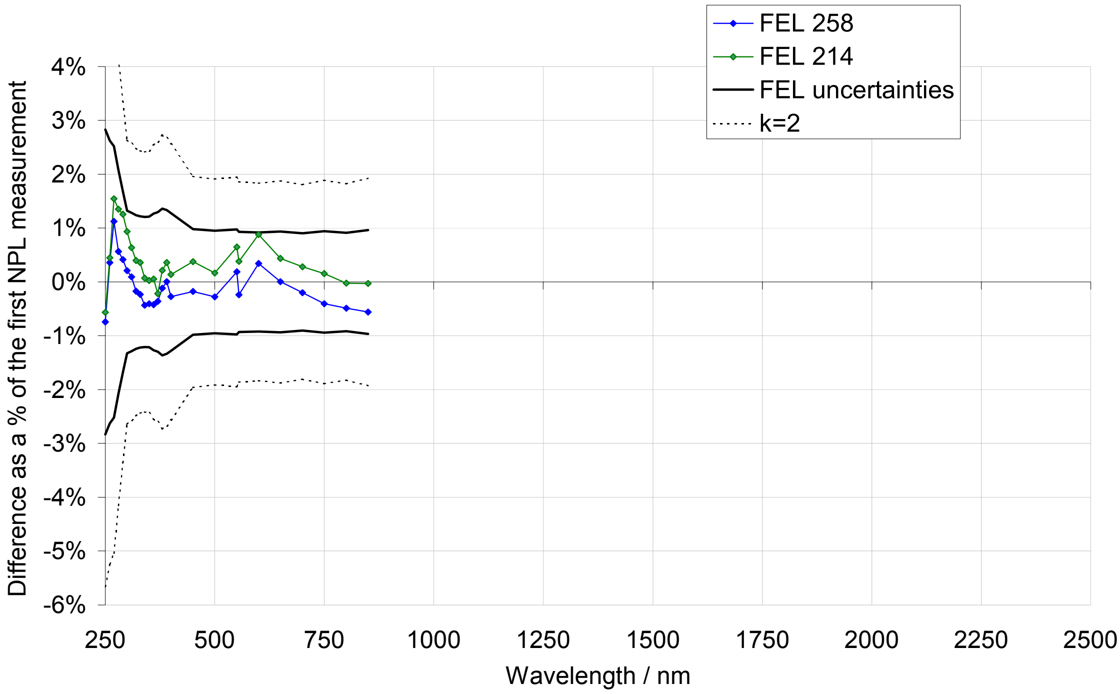

Figure 9-8 Bilateral comparisons of the MSL-IRL lamps

9.11 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to MSL-IRL the information in the graphs Figure 9-2 to Figure 9-8. It was decided that both participant measurements and both pilot measurements would be used for both FEL BN 9101 258 and for FEL BN 9101 214, but that lamp FEL BN 9101 215 would be entirely ignored for this comparison, since both laboratories noticed changes far in excess of their uncertainties.

10 Measurements at NIM

10.1 Primary scale realization

The NIM primary scale for spectral irradiance is realized using a black body source, the temperature of which is measured traceably to ITS-90 by using a pyrometer as a comparator and a temperature standard lamp G99-01 with uncertainty of 0.387 K at 2473 K ($k = 1$), which was calibrated on 20 June 2001 before the first round measurements, and 15 September 2003 before the second round measurements.

The length measurement of distance can be traced to the latest realization of the meter. A special micrometer, calibrated on 28 June 2001 and 15 September 2003 with uncertainty of 0.01 mm ($k = 1$), was used to measure the distance. The area of the water-cooled aperture was calibrated on 28 June 2001 and 2 June 2003 with uncertainty of 0.10% ($k = 1$). The electrical measurements of the digital voltmeter (uncertainty of 0.011% ($k = 1$), calibrated on 23 March, 2003) and the 0.01 Ω standard resistor (uncertainty of 1.1×10^{-5}, ($k = 1$), calibrated on 16 July 2003) are traceable to the latest realization of the ampere and volt.

10.2 Description of the measurement facility

10.2.1 Make and type of spectroradiometer

The main components of the spectroradiometer include input optics, a double-grating monochromator (GDS50-2 made in China), a reference tungsten halogen lamp for the substitution method, detectors for different wavelengths (photomultiplier R3896 made in Hamamatsu, Japan; thermoelectrically cooled PbS detector made in China) and a two-phase lock in amplifier.

The measurement system is shown in Figure 10-1.

10.3 Description of calibration laboratory conditions

Temperature range: 20 °C-26 °C, humidity: 60% RH maximum.

10.4 Laboratory transfer standards used

The laboratory transfer standard was a temperature standard lamp traceable to NIM (ITS-90).

10.5 Measurement procedure

First, the temperature of black body BB3200pg was measured with a pyrometer as a comparison instrument and with a standard temperature lamp traced to NIM (ITS-90). Next, the area of the water-cooled aperture of the black body was measured, along with the distance between the water-cooled aperture and the diffuser. Following this, the irradiance signal ratio of the black body and a reference lamp was measured throughout the specified wavelength range. The optical platform was moved to a specific position to measure the signal ratio of the reference lamp and the test lamp after the above measurement. For the spectroradiometer, the position of the test lamp and the water-cooled aperture of black body were similar. Thus the irradiance of the test lamp can be calculated according to Planck’s law by using the substitution method.

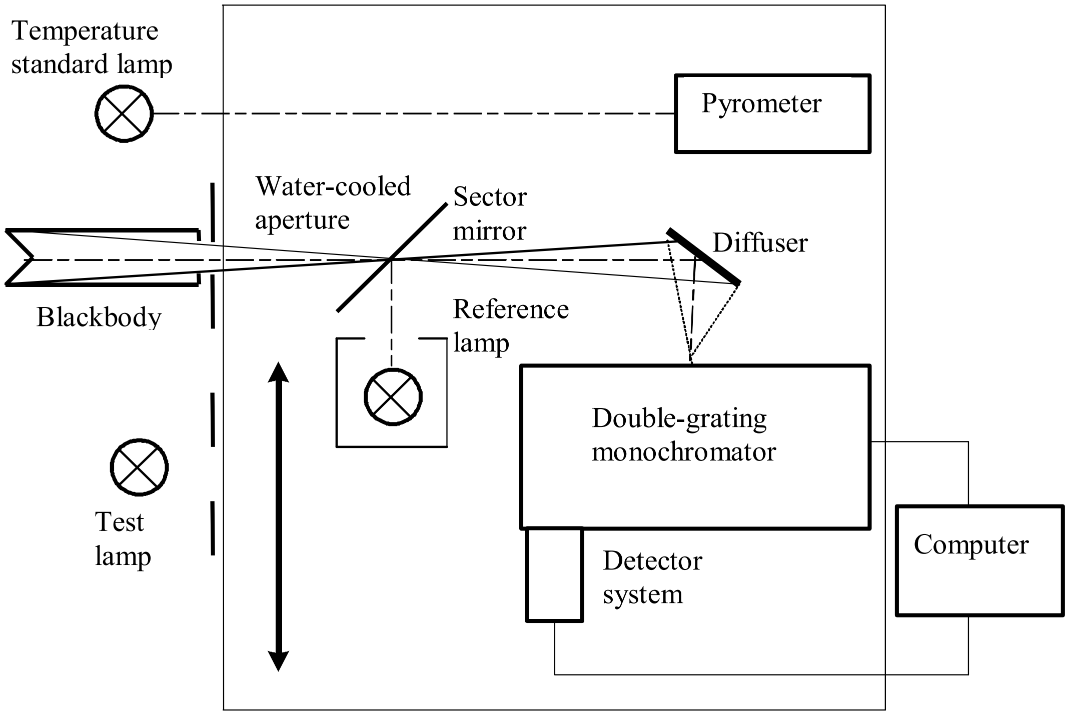

Figure 10-1 Measurement system for spectral irradiance

10.6 Uncertainty determination

10.6.1 Primary scale uncertainty

The spectral irradiance of the black body can be calculated according to the equation,

$$E_{\lambda b} = \varepsilon_{\lambda b} \cdot G \cdot C_1 \cdot \lambda^{-5} \frac{1}{e^{C_2/\lambda T} - 1} \qquad (10\text{-}1)$$

where,

$E_{\lambda b}$ spectral irradiance

$\varepsilon_{\lambda b}$ emissivity of the black body (HTBB)

G geometric factor

λ wavelength in air

$C_1 = 2\pi hc^2 = 3.7418 \times 10^{-16}$ W m^2, is the first radiation constant

$C_2 = hc/k = 1.4388 \times 10^4$ µm K, is the second radiation constant

T thermodynamic temperature

The sources of the uncertainty in the primary scale include:

- temperature measurement of the HTBB,
- non-uniformity of the HTBB source,
- instability of the HTBB source,
- correction of different size of source (HTBB & lamp),
- area of the water-cooled aperture,
- non-linearity of the measurement system.

10.6.1.1 Temperature Measurement of HTBB

For the temperature measurement of the High Temperature Black Body (HTBB), the pyrometer is used just as a comparison facility. For each measurement, a temperature standard lamp (from Heat Division of NIM) is used to calibrate the pyrometer at specified temperature, and then the pyrometer is used to measure the temperature of the HTBB.

The uncertainty of temperature measurement at 2473 K is $u_T = 0.58$ K ($k = 1$). The sources of uncertainty include the reproducibility for temperature measurement, collimating error, the temperature scale of NIM, the instability of the standard lamp, the non-linearity of pyrometer, the error of the size of the radiant source and the effect of ambient temperature.

The higher temperature of the HTBB is calculated according to the ratio of the monochromatic radiance at two different temperatures and Planck's law. The same spectral-radiometric measurement system used for spectral irradiance is used to extrapolate the temperature. When T = 2920 K, the uncertainty of temperature measurement of HTBB is $u_T = 0.81$ K ($k = 1$). The sources of uncertainty include the reproducibility for temperature measurement, the temperature scale of NIM, the instability of the standard lamp, the non-linearity of the pyrometer, the non-linearity of the spectral-radiometric measurement system, collimating fault, error of size of the radiant source etc.

The relative uncertainty of spectral irradiance contributed by temperature measurement of HTBB is calculated according to the equation $u = u_T c_2 / \left(\lambda T^2\right)$, see Table 10-1.

Table 10-1 Uncertainty of Temperature Measurement of HTBB

(250 nm – 400 nm, T = 2920 K, u_T = 0.81 K; 450 nm – 2500 nm, T = 2473 K, u_T = 0.58 K)

Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%
250	0.547	360	0.380	700	0.195	1500	0.091
260	0.526	370	0.370	750	0.182	1600	0.085
270	0.507	380	0.358	800	0.170	1700	0.080
280	0.489	390	0.349	850	0.160	1800	0.076
290	0.472	400	0.341	900	0.151	1900	0.072
300	0.456	450	0.303	950	0.143	2000	0.068
310	0.441	500	0.272	1000	0.136	2100	0.065
320	0.428	550	0.248	1100	0.124	2200	0.062
330	0.415	555	0.245	1200	0.114	2300	0.059
340	0.403	600	0.227	1300	0.105	2400	0.057
350	0.391	650	0.210	1400	0.097	2500	0.054

10.6.1.2 Non-uniformity of HTBB Source

The HTBB source non-uniformity has been measured at 2473 K and 2920 K.

At T = 2473 K, the HTBB non-uniformity is less than 0.3 K within the effective area of the aperture of diameter 7.2473 mm, therefore $u_T = 0.17$ K;

At T = 2920 K, the HTBB non-uniformity is less than 0.5 K within the effective area of the aperture of diameter 7.2473 mm, therefore $u_T = 0.29$ K.

The contribution to the relative uncertainty of spectral irradiance caused by the HTBB non-uniformity is calculated according to the equation $u = u_T c_2 / \left(\lambda T^2\right)$, see Table 10-2.

Table 10-2 The relative uncertainty of spectral irradiance caused by HTBB non-uniformity

(250 nm – 400 nm, T = 2920 K, u_T = 0.29 K; 450 nm – 2500 nm, T = 2473 K, u_T = 0.17 K)

Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%
250	0.195	360	0.135	700	0.058	1500	0.027
260	0.187	370	0.132	750	0.054	1600	0.025
270	0.180	380	0.128	800	0.051	1700	0.024
280	0.174	390	0.125	850	0.048	1800	0.023
290	0.168	400	0.122	900	0.045	1900	0.021
300	0.162	450	0.091	950	0.043	2000	0.020
310	0.157	500	0.081	1000	0.041	2100	0.019
320	0.152	550	0.074	1100	0.037	2200	0.019
330	0.148	555	0.073	1200	0.034	2300	0.018
340	0.143	600	0.068	1300	0.031	2400	0.017
350	0.139	650	0.063	1400	0.029	2500	0.016

10.6.1.3 Instability of HTBB Source

When the operating temperature of HTBB is 2920 K, the instability of HTBB is less than 0.3 K throughout each measurement, u_T = 0.17 K.

The relative uncertainty of spectral irradiance contributed by instability of HTBB source is calculated according to the equation $u = u_T c_2 / \left(\lambda T^2\right)$, see Table 10-3.

Table 10-3 The uncertainty of spectral irradiance caused by HTBB source instability

(250 nm – 400 nm, T = 2920 K, u_T = 0.17 K; 450 nm – 2500 nm, T = 2473 K, u_T = 0.17 K)

Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%
250	0.117	360	0.081	700	0.058	1500	0.027
260	0.112	370	0.079	750	0.054	1600	0.025
270	0.108	380	0.077	800	0.051	1700	0.024
280	0.104	390	0.075	850	0.048	1800	0.023
290	0.101	400	0.073	900	0.045	1900	0.021
300	0.097	450	0.091	950	0.043	2000	0.020
310	0.094	500	0.081	1000	0.041	2100	0.019
320	0.091	550	0.074	1100	0.037	2200	0.019
330	0.089	555	0.073	1200	0.034	2300	0.018
340	0.086	600	0.068	1300	0.031	2400	0.017
350	0.084	650	0.063	1400	0.029	2500	0.016

10.6.1.4 Correction for Different Size of Source (HTBB & lamp)

The effective diameter of the water-cooled aperture of the black body is 7.2473 mm, and the aiming area of strip of the tungsten lamp is ϕ 0.75 mm. When using the pyrometer to measure the temperature of the black body, a 2 mm × 1 mm aperture, similar to the strip lamp, is set up inside the bigger aperture, and this is removed when measuring spectral irradiance. This reduces the effect of size-of-source.

The temperature standard lamp's measured temperature will be higher than the true radiance temperature owing to the size of source effect: the correction is ΔT. The SSE coefficient is q = 0.000066, λ_e = 660.95 nm, the correction is $\Delta T = -q\lambda_e T_2/C_2$= -0.019 K.

The relative uncertainty of spectral irradiance contributed by correction of different size of source (HTBB & lamp) can be calculated according to the equation $u = u_T c_2 / (\lambda T^2)$, see Table 10-4.

Table 10-4 The uncertainty of spectral irradiance caused by correction of different size of source

(250 nm – 400 nm, T = 2920 K, u_T = 0.019 K; 450 nm – 2500 nm, T = 2473 K, u_T = 0.019 K)

Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%
250	0.013	360	0.009	700	0.006	1500	0.003
260	0.012	370	0.009	750	0.006	1600	0.003
270	0.012	380	0.008	800	0.006	1700	0.003
280	0.011	390	0.008	850	0.005	1800	0.002
290	0.011	400	0.008	900	0.005	1900	0.002
300	0.011	450	0.010	950	0.005	2000	0.002
310	0.010	500	0.009	1000	0.004	2100	0.002
320	0.010	550	0.008	1100	0.004	2200	0.002
330	0.010	555	0.008	1200	0.004	2300	0.002
340	0.009	600	0.007	1300	0.003	2400	0.002
350	0.009	650	0.007	1400	0.003	2500	0.002

10.6.1.5 Area of the Water-cooled Aperture

The relative uncertainty of spectral irradiance caused by the water-cooled aperture area is approximately 0.10 %.

The area of the water-cooled aperture is measured at the Length Division of NIM, using one hundred coordinate values to calculate the aperture area. The relative uncertainty due to the area of the water-cooled aperture is approximately u = 0.10 %. (The temperature of circulating water is less than 20 ºC)

10.6.2 Non-linearity of Measurement System for Spectral Irradiance

The measurement system non-linearity is less than 0.1 %, as tested by linearity system of NIM. The relative uncertainty of spectral irradiance due to the non-linearity of the measurement system is 0.1 %.

10.6.3 Distance to Transfer Standard

The relative uncertainty of spectral irradiance contributed by distance is 0.27 %.

The error of distance measurement using the special micrometer is u = 0.5 mm. Transfer standards are tested at 500 mm, and the relative uncertainty of spectral irradiance caused by this distance is u = 0.2 %. The distance between the water-cooled aperture and the diffuser is 560 mm, and the relative uncertainty of spectral irradiance contributed by this distance is u = 0.179 %. Therefore the overall relative uncertainty of spectral irradiance due to distance is 0.27 %.

10.6.4 Current Passed through Transfer Standard

The relative uncertainty of spectral irradiance from the current measurement is 0.10 %.

Sources of the uncertainty include the power supply (drift of the current with time is less than 5×10^{-5} / hour), the 6 and 1/2 digital multimeter (uncertainty: 0.011 %, k = 1), 0.01 Ω standard resistor (uncertainty: 1.1×10^{-5} Ω, k = 1) and other negligible terms.

10.6.5 Wavelength

A GDS50-2 double grating monochromator is adopted in the measurement system. A Hg spectrum lamp and He-Ne laser are used to calibrate the wavelength of the monochromator. The uncertainty of wavelength contributed by reproducibility and accuracy is:

$\Delta\lambda$ = 0.06 nm, u_λ = 0.035 nm (250 nm – 340 nm), T = 2920 K

$\Delta\lambda$ = 0.04 nm, u_λ = 0.023 nm (350 nm – 400 nm), T = 2920 K

$\Delta\lambda$ = 0.04 nm, u_λ = 0.023 nm (450 nm – 700 nm), T = 2473 K

$\Delta\lambda$ = 0.22 nm, u_λ = 0.127 nm (750 nm – 2500 nm), T = 2473 K

The relative uncertainty of spectral irradiance contributed by wavelength is calculated by the following equation, the result is in Table 10-5.

$$u = \left(\frac{-5}{\lambda} + \frac{C_2}{\lambda^2 T} \right) u_\lambda \tag{10-2}$$

Table 10-5 The relative uncertainty of spectral irradiance caused by wavelength

(250 nm – 400 nm, T = 2920 K, u_λ = 0.035 nm; 450 nm – 700 nm: T = 2473 K, u_λ = 0.025 nm; 750 nm – 2500 nm, T = 2473 K, u_λ = 0.127 nm)

Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%
250	0.204	360	0.056	700	0.011	1500	0.009
260	0.186	370	0.052	750	0.047	1600	0.011
270	0.170	380	0.048	800	0.036	1700	0.012
280	0.156	390	0.045	850	0.028	1800	0.012
290	0.143	400	0.042	900	0.021	1900	0.013
300	0.132	450	0.041	950	0.015	2000	0.013
310	0.122	500	0.031	1000	0.010	2100	0.013
320	0.113	550	0.023	1100	0.003	2200	0.014
330	0.104	555	0.023	1200	0.002	2300	0.014
340	0.097	600	0.018	1300	0.005	2400	0.014
350	0.060	650	0.014	1400	0.008	2500	0.014

10.6.6 Type A Uncertainty—Repeatability of reference & transfer standard

The sources of Type A uncertainty include the instability of the standard, the reproducibility of realignment of the standard and the repeatability of the measurement system. Before each measurement, the lamps are realigned. The largest relative standard deviation is calculated as the Type A uncertainty, given in Table 10-6.

Table 10-6 Relative standard deviation of measurements

Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%	Wavelength /nm	u /%
250	0.52	360	0.17	700	0.17	1500	0.29
260	0.29	370	0.17	750	0.17	1600	0.29
270	0.23	380	0.17	800	0.23	1700	0.29
280	0.23	390	0.17	850	0.23	1800	0.29
290	0.23	400	0.17	900	0.23	1900	0.29
300	0.17	450	0.17	950	0.23	2000	0.29
310	0.17	500	0.17	1000	0.23	2100	0.29
320	0.17	550	0.17	1100	0.23	2200	0.29
330	0.17	555	0.17	1200	0.23	2300	0.29
340	0.17	600	0.17	1300	0.29	2400	0.35
350	0.17	650	0.17	1400	0.29	2500	0.52

10.6.7 Overall uncertainty and correlation

The uncertainty components are given in Table 10-7 for Type I lamps and Table 10-8 for Type II lamps. Because only one calibration round is considered for each lamp type, these effects are either entirely uncorrelated or round-correlated. In this budget the effects relating to Type A uncertainties are entirely uncorrelated, while those relating to Type B uncertainties are entirely correlated within the round.

Table 10-7 Uncertainty budget for Type I lamps

	Type A Uncertainty in Value/%	Type B Uncertainty in Value/%									RMS total
		Scale /%									
Wave-length /nm	Repeatability of ref. & trans /%	Temperature measurement of HTBB %	Non-uniformity of HTBB /%	Instability of HTBB/%	Correction of different size of source/%	Area of water-cooled aperture /%	Non-linearity of measurement system /%	Current /%	Wavelength /%	Distance /%	u_c (%)
250	0.52	0.55	0.19	0.12	0.01	0.10	0.10	0.10	0.20	0.27	0.88
260	0.29	0.53	0.19	0.11	0.01	0.10	0.10	0.10	0.19	0.27	0.74
270	0.23	0.51	0.18	0.11	0.01	0.10	0.10	0.10	0.17	0.27	0.70
280	0.23	0.49	0.17	0.10	0.01	0.10	0.10	0.10	0.16	0.27	0.68
290	0.23	0.47	0.17	0.10	0.01	0.10	0.10	0.10	0.14	0.27	0.66
300	0.17	0.46	0.16	0.10	0.01	0.10	0.10	0.10	0.13	0.27	0.63
310	0.17	0.44	0.16	0.09	0.01	0.10	0.10	0.10	0.12	0.27	0.61
320	0.17	0.43	0.15	0.09	0.01	0.10	0.10	0.10	0.11	0.27	0.60
330	0.17	0.42	0.15	0.09	0.01	0.10	0.10	0.10	0.10	0.27	0.59
340	0.17	0.40	0.14	0.09	0.01	0.10	0.10	0.10	0.10	0.27	0.58
350	0.17	0.39	0.14	0.08	0.01	0.10	0.10	0.10	0.06	0.27	0.56
360	0.17	0.38	0.14	0.08	0.01	0.10	0.10	0.10	0.06	0.27	0.55
370	0.17	0.37	0.13	0.08	0.01	0.10	0.10	0.10	0.05	0.27	0.54
380	0.17	0.36	0.13	0.08	0.01	0.10	0.10	0.10	0.05	0.27	0.53
390	0.17	0.35	0.12	0.07	0.01	0.10	0.10	0.10	0.05	0.27	0.53
400	0.17	0.34	0.12	0.07	0.01	0.10	0.10	0.10	0.04	0.27	0.52
450	0.17	0.30	0.09	0.09	0.01	0.10	0.10	0.10	0.04	0.27	0.49
500	0.17	0.27	0.08	0.08	0.01	0.10	0.10	0.10	0.03	0.27	0.47
550	0.17	0.25	0.07	0.07	0.01	0.10	0.10	0.10	0.02	0.27	0.45
555	0.17	0.25	0.07	0.07	0.01	0.10	0.10	0.10	0.02	0.27	0.45
600	0.17	0.23	0.07	0.07	0.01	0.10	0.10	0.10	0.02	0.27	0.44
650	0.17	0.21	0.06	0.06	0.01	0.10	0.10	0.10	0.01	0.27	0.43

700	0.17	0.20	0.06	0.06	0.01	0.10	0.10	0.10	0.01	0.27	0.42
750	0.17	0.18	0.05	0.05	0.01	0.10	0.10	0.10	0.05	0.27	0.42
800	0.23	0.17	0.05	0.05	0.01	0.10	0.10	0.10	0.04	0.27	0.44
850	0.23	0.16	0.05	0.05	0.01	0.10	0.10	0.10	0.03	0.27	0.43
900	0.23	0.15	0.05	0.05	0.00	0.10	0.10	0.10	0.02	0.27	0.43
950	0.23	0.14	0.04	0.04	0.00	0.10	0.10	0.10	0.02	0.27	0.42
1000	0.23	0.14	0.04	0.04	0.00	0.10	0.10	0.10	0.01	0.27	0.42
1100	0.23	0.12	0.04	0.04	0.00	0.10	0.10	0.10	0.00	0.27	0.42
1200	0.23	0.11	0.03	0.03	0.00	0.10	0.10	0.10	0.00	0.27	0.41
1300	0.23	0.11	0.03	0.03	0.00	0.10	0.10	0.10	0.01	0.27	0.41
1400	0.29	0.10	0.03	0.03	0.00	0.10	0.10	0.10	0.01	0.27	0.45
1500	0.29	0.09	0.03	0.03	0.00	0.10	0.10	0.10	0.01	0.27	0.44
1600	0.29	0.09	0.03	0.03	0.00	0.10	0.10	0.10	0.01	0.27	0.44
1700	0.29	0.08	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	0.44
1800	0.29	0.08	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	0.44
1900	0.29	0.07	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	0.44
2000	0.29	0.07	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	0.44
2100	0.29	0.07	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	0.44
2200	0.29	0.06	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	0.44
2300	0.29	0.06	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	0.44
2400	0.35	0.06	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	0.48
2500	0.52	0.05	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	0.61

Table 10-8 Uncertainty budget for Type II lamps

Wave length /nm	Type A Uncertainty in Value/%	Type B Uncertainty in Value/%									RMS total
		Scale /%									
	Repeatability of ref. & trans /%	Temperature measurement of HTBB %	Non-uniformity of HTBB /%	Instability of HTBB/%	Correction of different size of source/%	Area of water-cooled aperture /%	Non-linearity of measurement system /%	Current /%	Wavelength /%	Distance /%	u_c (%)
250	0.78	0.55	0.19	0.12	0.01	0.10	0.10	0.10	0.20	0.27	**1.05**
260	0.49	0.53	0.19	0.11	0.01	0.10	0.10	0.10	0.19	0.27	**0.84**
270	0.43	0.51	0.18	0.11	0.01	0.10	0.10	0.10	0.17	0.27	**0.79**
280	0.40	0.49	0.17	0.10	0.01	0.10	0.10	0.10	0.16	0.27	**0.75**
290	0.38	0.47	0.17	0.10	0.01	0.10	0.10	0.10	0.14	0.27	**0.73**
300	0.37	0.46	0.16	0.10	0.01	0.10	0.10	0.10	0.13	0.27	**0.71**
310	0.37	0.44	0.16	0.09	0.01	0.10	0.10	0.10	0.12	0.27	**0.69**
320	0.35	0.43	0.15	0.09	0.01	0.10	0.10	0.10	0.11	0.27	**0.67**
330	0.32	0.42	0.15	0.09	0.01	0.10	0.10	0.10	0.10	0.27	**0.65**
340	0.3	0.4	0.14	0.09	0.01	0.10	0.10	0.10	0.10	0.27	**0.63**
350	0.28	0.39	0.14	0.08	0.01	0.10	0.10	0.10	0.06	0.27	**0.6**
360	0.28	0.38	0.14	0.08	0.01	0.10	0.10	0.10	0.06	0.27	**0.59**
370	0.28	0.37	0.13	0.08	0.01	0.10	0.10	0.10	0.05	0.27	**0.59**
380	0.26	0.36	0.13	0.08	0.01	0.10	0.10	0.10	0.05	0.27	**0.57**
390	0.26	0.35	0.12	0.07	0.01	0.10	0.10	0.10	0.05	0.27	**0.56**
400	0.26	0.34	0.12	0.07	0.01	0.10	0.10	0.10	0.04	0.27	**0.56**
450	0.26	0.3	0.09	0.09	0.01	0.10	0.10	0.10	0.04	0.27	**0.53**
500	0.26	0.27	0.08	0.08	0.01	0.10	0.10	0.10	0.03	0.27	**0.51**
550	0.26	0.25	0.07	0.07	0.01	0.10	0.10	0.10	0.02	0.27	**0.49**

555	0.25	0.25	0.07	0.07	0.01	0.10	0.10	0.10	0.02	0.27	**0.49**
600	0.25	0.23	0.07	0.07	0.01	0.10	0.10	0.10	0.02	0.27	**0.48**
650	0.25	0.21	0.06	0.06	0.01	0.10	0.10	0.10	0.01	0.27	**0.47**
700	0.24	0.2	0.06	0.06	0.01	0.10	0.10	0.10	0.01	0.27	**0.45**
750	0.24	0.18	0.05	0.05	0.01	0.10	0.10	0.10	0.05	0.27	**0.45**
800	0.26	0.17	0.05	0.05	0.01	0.10	0.10	0.10	0.04	0.27	**0.45**
850	0.26	0.16	0.05	0.05	0.01	0.10	0.10	0.10	0.03	0.27	**0.45**
900	0.26	0.15	0.05	0.05	0.00	0.10	0.10	0.10	0.02	0.27	**0.44**
950	0.28	0.14	0.04	0.04	0.00	0.10	0.10	0.10	0.02	0.27	**0.45**
1000	0.28	0.14	0.04	0.04	0.00	0.10	0.10	0.10	0.01	0.27	**0.45**
1100	0.28	0.12	0.04	0.04	0.00	0.10	0.10	0.10	0.00	0.27	**0.45**
1200	0.29	0.11	0.03	0.03	0.00	0.10	0.10	0.10	0.00	0.27	**0.45**
1300	0.30	0.11	0.03	0.03	0.00	0.10	0.10	0.10	0.01	0.27	**0.45**
1400	0.33	0.10	0.03	0.03	0.00	0.10	0.10	0.10	0.01	0.27	**0.47**
1500	0.33	0.09	0.03	0.03	0.00	0.10	0.10	0.10	0.01	0.27	**0.47**
1600	0.33	0.09	0.03	0.03	0.00	0.10	0.10	0.10	0.01	0.27	**0.47**
1700	0.35	0.08	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	**0.48**
1800	0.35	0.08	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	**0.48**
1900	0.35	0.07	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	**0.48**
2000	0.37	0.07	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	**0.50**
2100	0.37	0.07	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	**0.49**
2200	0.38	0.06	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	**0.50**
2300	0.38	0.06	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	**0.50**
2400	0.43	0.06	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	**0.54**
2500	0.61	0.05	0.02	0.02	0.00	0.10	0.10	0.10	0.01	0.27	**0.69**

10.7 NIM Results

NIM measured three Type I lamps and three Type II lamps. See section 10.9 for a further discussion of which lamps were measured. The results for FEL BN 9101 235 are given in Table 10-9 and the results for FEL BN 9101 208 are given in Table 10-10 and the results for FEL BN 9101 216 are given in Table 10-11. The results for PA848 are given in Table 10-12, the results for P249c are given in Table 10-13 and the results for PA847 are given in Table 10-14.

Table 10-9 NIM Results for FEL BN 9101 235. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

FEL 235	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.299E-04	0.52 %	0.70 %	0.00 %	0.88 %					
260	2.192E-04	0.29 %	0.68 %	0.00 %	0.74 %					
270	3.657E-04	0.23 %	0.66 %	0.00 %	0.70 %					
280	5.834E-04	0.23 %	0.64 %	0.00 %	0.68 %					
290	8.854E-04	0.23 %	0.62 %	0.00 %	0.66 %					
300	1.295E-03	0.17 %	0.61 %	0.00 %	0.63 %					
310	1.847E-03	0.17 %	0.59 %	0.00 %	0.61 %					
320	2.544E-03	0.17 %	0.57 %	0.00 %	0.60 %					
330	3.436E-03	0.17 %	0.57 %	0.00 %	0.59 %					
340	4.527E-03	0.17 %	0.55 %	0.00 %	0.57 %					
350	5.836E-03	0.17 %	0.53 %	0.00 %	0.56 %					
360	7.395E-03	0.17 %	0.53 %	0.00 %	0.55 %					
370	9.211E-03	0.17 %	0.52 %	0.00 %	0.54 %					
380	1.130E-02	0.17 %	0.51 %	0.00 %	0.54 %					
390	1.367E-02	0.17 %	0.50 %	0.00 %	0.53 %					
400	1.632E-02	0.17 %	0.49 %	0.00 %	0.52 %					
450	3.429E-02	0.17 %	0.46 %	0.00 %	0.49 %					
500	5.731E-02	0.17 %	0.44 %	0.00 %	0.47 %					
550	8.356E-02	0.17 %	0.42 %	0.00 %	0.45 %					
555	8.653E-02	0.17 %	0.42 %	0.00 %	0.45 %					
600	1.110E-01	0.17 %	0.41 %	0.00 %	0.44 %					
650	1.350E-01	0.17 %	0.39 %	0.00 %	0.43 %					
700	1.561E-01	0.17 %	0.39 %	0.00 %	0.42 %					
750										
800										
850										
900										
950										
1000										
1100										
1200	1.628E-01	0.23 %	0.34 %	0.00 %	0.41 %					
1300	1.458E-01	0.23 %	0.34 %	0.00 %	0.41 %					
1400	1.277E-01	0.29 %	0.34 %	0.00 %	0.45 %					
1500	1.133E-01	0.29 %	0.34 %	0.00 %	0.44 %					
1600	9.912E-02	0.29 %	0.34 %	0.00 %	0.44 %					
1700	8.662E-02	0.29 %	0.33 %	0.00 %	0.44 %					
1800	7.538E-02	0.29 %	0.33 %	0.00 %	0.44 %					
1900	6.604E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2000	5.782E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2100	5.085E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2200	4.483E-02	0.29 %	0.33 %	0.00 %	0.44 %					

2300	3.891E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2400	3.400E-02	0.35 %	0.33 %	0.00 %	0.48 %					
2500	2.982E-02	0.52 %	0.33 %	0.00 %	0.61 %					

Table 10-10 NIM Results for FEL BN 9101 208. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

FEL 208	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.505E-04	0.52 %	0.70 %	0.00 %	0.88 %					
260	2.632E-04	0.29 %	0.68 %	0.00 %	0.74 %					
270	4.439E-04	0.23 %	0.66 %	0.00 %	0.70 %					
280	7.005E-04	0.23 %	0.64 %	0.00 %	0.68 %					
290	1.062E-03	0.23 %	0.62 %	0.00 %	0.66 %					
300	1.542E-03	0.17 %	0.61 %	0.00 %	0.63 %					
310	2.182E-03	0.17 %	0.59 %	0.00 %	0.61 %					
320	2.997E-03	0.17 %	0.57 %	0.00 %	0.60 %					
330	4.028E-03	0.17 %	0.57 %	0.00 %	0.59 %					
340	5.281E-03	0.17 %	0.55 %	0.00 %	0.57 %					
350	6.781E-03	0.17 %	0.53 %	0.00 %	0.56 %					
360	8.565E-03	0.17 %	0.53 %	0.00 %	0.55 %					
370	1.063E-02	0.17 %	0.52 %	0.00 %	0.54 %					
380	1.298E-02	0.17 %	0.51 %	0.00 %	0.54 %					
390	1.566E-02	0.17 %	0.50 %	0.00 %	0.53 %					
400	1.857E-02	0.17 %	0.49 %	0.00 %	0.52 %					
450	3.818E-02	0.17 %	0.46 %	0.00 %	0.49 %					
500	6.325E-02	0.17 %	0.44 %	0.00 %	0.47 %					
550	9.133E-02	0.17 %	0.42 %	0.00 %	0.45 %					
555	9.422E-02	0.17 %	0.42 %	0.00 %	0.45 %					
600	1.201E-01	0.17 %	0.41 %	0.00 %	0.44 %					
650	1.457E-01	0.17 %	0.39 %	0.00 %	0.43 %					
700	1.677E-01	0.17 %	0.39 %	0.00 %	0.42 %					
750										
800										
850										
900										
950										
1000										
1100										
1200	1.684E-01	0.23 %	0.34 %	0.00 %	0.41 %					
1300	1.502E-01	0.23 %	0.34 %	0.00 %	0.41 %					
1400	1.316E-01	0.29 %	0.34 %	0.00 %	0.45 %					
1500	1.164E-01	0.29 %	0.34 %	0.00 %	0.44 %					
1600	1.015E-01	0.29 %	0.34 %	0.00 %	0.44 %					
1700	8.862E-02	0.29 %	0.33 %	0.00 %	0.44 %					
1800	7.696E-02	0.29 %	0.33 %	0.00 %	0.44 %					
1900	6.759E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2000	5.900E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2100	5.183E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2200	4.570E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2300	3.967E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2400	3.457E-02	0.35 %	0.33 %	0.00 %	0.48 %					
2500	3.037E-02	0.52 %	0.33 %	0.00 %	0.61 %					

Table 10-11 NIM Results for FEL BN 9101 216. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

FEL 216	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.297E-04	0.52 %	0.70 %	0.00 %	0.88 %					
260	2.214E-04	0.29 %	0.68 %	0.00 %	0.74 %					
270	3.737E-04	0.23 %	0.66 %	0.00 %	0.70 %					
280	5.873E-04	0.23 %	0.64 %	0.00 %	0.68 %					
290	9.037E-04	0.23 %	0.62 %	0.00 %	0.66 %					
300	1.321E-03	0.17 %	0.61 %	0.00 %	0.63 %					
310	1.884E-03	0.17 %	0.59 %	0.00 %	0.61 %					
320	2.584E-03	0.17 %	0.57 %	0.00 %	0.60 %					
330	3.489E-03	0.17 %	0.57 %	0.00 %	0.59 %					
340	4.597E-03	0.17 %	0.55 %	0.00 %	0.57 %					
350	5.924E-03	0.17 %	0.53 %	0.00 %	0.56 %					
360	7.515E-03	0.17 %	0.53 %	0.00 %	0.55 %					
370	9.348E-03	0.17 %	0.52 %	0.00 %	0.54 %					
380	1.144E-02	0.17 %	0.51 %	0.00 %	0.54 %					
390	1.393E-02	0.17 %	0.50 %	0.00 %	0.53 %					
400	1.664E-02	0.17 %	0.49 %	0.00 %	0.52 %					
450	3.455E-02	0.17 %	0.46 %	0.00 %	0.49 %					
500	5.821E-02	0.17 %	0.44 %	0.00 %	0.47 %					
550	8.483E-02	0.17 %	0.42 %	0.00 %	0.45 %					
555	8.780E-02	0.17 %	0.42 %	0.00 %	0.45 %					
600	1.128E-01	0.17 %	0.41 %	0.00 %	0.44 %					
650	1.377E-01	0.17 %	0.39 %	0.00 %	0.43 %					
700	1.591E-01	0.17 %	0.39 %	0.00 %	0.42 %					
750										
800										
850										
900										
950										
1000										
1100										
1200	1.666E-01	0.23 %	0.34 %	0.00 %	0.41 %					
1300	1.504E-01	0.23 %	0.34 %	0.00 %	0.41 %					
1400	1.319E-01	0.29 %	0.34 %	0.00 %	0.45 %					
1500	1.170E-01	0.29 %	0.34 %	0.00 %	0.44 %					
1600	1.025E-01	0.29 %	0.34 %	0.00 %	0.44 %					
1700	8.974E-02	0.29 %	0.33 %	0.00 %	0.44 %					
1800	7.794E-02	0.29 %	0.33 %	0.00 %	0.44 %					
1900	6.841E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2000	6.000E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2100	5.262E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2200	4.642E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2300	4.028E-02	0.29 %	0.33 %	0.00 %	0.44 %					
2400	3.518E-02	0.35 %	0.33 %	0.00 %	0.48 %					
2500	3.089E-02	0.52 %	0.33 %	0.00 %	0.61 %					

Table 10-12 NIM Results for Polaron PA848. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

PA 848	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.782E-05	0.78 %	0.70 %	0.00 %	1.05 %					
260	3.176E-05	0.49 %	0.68 %	0.00 %	0.84 %					
270	5.393E-05	0.43 %	0.66 %	0.00 %	0.79 %					
280	8.655E-05	0.40 %	0.64 %	0.00 %	0.75 %					
290	1.343E-04	0.38 %	0.62 %	0.00 %	0.73 %					
300	2.003E-04	0.37 %	0.61 %	0.00 %	0.71 %					
310	2.910E-04	0.37 %	0.59 %	0.00 %	0.69 %					
320	4.079E-04	0.35 %	0.57 %	0.00 %	0.67 %					
330	5.618E-04	0.32 %	0.57 %	0.00 %	0.65 %					
340	7.506E-04	0.30 %	0.55 %	0.00 %	0.63 %					
350	9.814E-04	0.28 %	0.53 %	0.00 %	0.60 %					
360	1.258E-03	0.28 %	0.53 %	0.00 %	0.60 %					
370	1.586E-03	0.28 %	0.52 %	0.00 %	0.59 %					
380	1.958E-03	0.26 %	0.51 %	0.00 %	0.57 %					
390	2.389E-03	0.26 %	0.50 %	0.00 %	0.56 %					
400	2.891E-03	0.26 %	0.49 %	0.00 %	0.55 %					
450	6.188E-03	0.26 %	0.46 %	0.00 %	0.53 %					
500	1.071E-02	0.26 %	0.44 %	0.00 %	0.51 %					
550	1.606E-02	0.26 %	0.42 %	0.00 %	0.49 %					
555	1.661E-02	0.25 %	0.42 %	0.00 %	0.49 %					
600	2.154E-02	0.25 %	0.41 %	0.00 %	0.48 %					
650	2.669E-02	0.25 %	0.39 %	0.00 %	0.47 %					
700	3.105E-02	0.24 %	0.39 %	0.00 %	0.46 %					
750	3.453E-02	0.24 %	0.38 %	0.00 %	0.45 %					
800	3.720E-02	0.26 %	0.37 %	0.00 %	0.45 %					
850	3.799E-02	0.26 %	0.37 %	0.00 %	0.45 %					
900	3.903E-02	0.26 %	0.36 %	0.00 %	0.45 %					
950	3.915E-02	0.28 %	0.36 %	0.00 %	0.45 %					
1000	3.860E-02	0.28 %	0.35 %	0.00 %	0.45 %					
1100	3.667E-02	0.28 %	0.35 %	0.00 %	0.45 %					
1200	3.341E-02	0.29 %	0.34 %	0.00 %	0.45 %					
1300	2.996E-02	0.30 %	0.34 %	0.00 %	0.45 %					
1400	2.648E-02	0.33 %	0.34 %	0.00 %	0.47 %					
1500	2.342E-02	0.33 %	0.34 %	0.00 %	0.47 %					
1600	2.057E-02	0.33 %	0.34 %	0.00 %	0.47 %					
1700	1.781E-02	0.35 %	0.33 %	0.00 %	0.48 %					
1800	1.546E-02	0.35 %	0.33 %	0.00 %	0.48 %					
1900	1.358E-02	0.35 %	0.33 %	0.00 %	0.48 %					
2000	1.156E-02	0.37 %	0.33 %	0.00 %	0.50 %					
2100	1.015E-02	0.37 %	0.33 %	0.00 %	0.50 %					
2200	8.972E-03	0.38 %	0.33 %	0.00 %	0.50 %					
2300	7.786E-03	0.38 %	0.33 %	0.00 %	0.50 %					
2400	6.797E-03	0.43 %	0.33 %	0.00 %	0.54 %					
2500	5.876E-03	0.61 %	0.33 %	0.00 %	0.69 %					

Table 10-13 NIM Results for Polaron P249c. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

P249c	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	2.129E-05	0.78 %	0.70 %	0.00 %	1.05 %					
260	3.717E-05	0.49 %	0.68 %	0.00 %	0.84 %					
270	6.273E-05	0.43 %	0.66 %	0.00 %	0.79 %					
280	1.003E-04	0.40 %	0.64 %	0.00 %	0.75 %					
290	1.545E-04	0.38 %	0.62 %	0.00 %	0.73 %					
300	2.291E-04	0.37 %	0.61 %	0.00 %	0.71 %					
310	3.309E-04	0.37 %	0.59 %	0.00 %	0.69 %					
320	4.608E-04	0.35 %	0.57 %	0.00 %	0.67 %					
330	6.310E-04	0.32 %	0.57 %	0.00 %	0.65 %					
340	8.419E-04	0.30 %	0.55 %	0.00 %	0.63 %					
350	1.094E-03	0.28 %	0.53 %	0.00 %	0.60 %					
360	1.396E-03	0.28 %	0.53 %	0.00 %	0.60 %					
370	1.753E-03	0.28 %	0.52 %	0.00 %	0.59 %					
380	2.173E-03	0.26 %	0.51 %	0.00 %	0.57 %					
390	2.641E-03	0.26 %	0.50 %	0.00 %	0.56 %					
400	3.184E-03	0.26 %	0.49 %	0.00 %	0.55 %					
450	6.749E-03	0.26 %	0.46 %	0.00 %	0.53 %					
500	1.159E-02	0.26 %	0.44 %	0.00 %	0.51 %					
550	1.718E-02	0.26 %	0.42 %	0.00 %	0.49 %					
555	1.773E-02	0.25 %	0.42 %	0.00 %	0.49 %					
600	2.287E-02	0.25 %	0.41 %	0.00 %	0.48 %					
650	2.816E-02	0.25 %	0.39 %	0.00 %	0.47 %					
700	3.263E-02	0.24 %	0.39 %	0.00 %	0.46 %					
750	3.616E-02	0.24 %	0.38 %	0.00 %	0.45 %					
800	3.853E-02	0.26 %	0.37 %	0.00 %	0.45 %					
850	3.961E-02	0.26 %	0.37 %	0.00 %	0.45 %					
900	4.028E-02	0.26 %	0.36 %	0.00 %	0.45 %					
950	4.003E-02	0.28 %	0.36 %	0.00 %	0.45 %					
1000	3.935E-02	0.28 %	0.35 %	0.00 %	0.45 %					
1100	3.698E-02	0.28 %	0.35 %	0.00 %	0.45 %					
1200	3.356E-02	0.29 %	0.34 %	0.00 %	0.45 %					
1300	3.009E-02	0.30 %	0.34 %	0.00 %	0.45 %					
1400	2.660E-02	0.33 %	0.34 %	0.00 %	0.47 %					
1500	2.331E-02	0.33 %	0.34 %	0.00 %	0.47 %					
1600	2.038E-02	0.33 %	0.34 %	0.00 %	0.47 %					
1700	1.775E-02	0.35 %	0.33 %	0.00 %	0.48 %					
1800	1.527E-02	0.35 %	0.33 %	0.00 %	0.48 %					
1900	1.337E-02	0.35 %	0.33 %	0.00 %	0.48 %					
2000	1.143E-02	0.37 %	0.33 %	0.00 %	0.50 %					
2100	1.009E-02	0.37 %	0.33 %	0.00 %	0.50 %					
2200	8.846E-03	0.38 %	0.33 %	0.00 %	0.50 %					
2300	7.612E-03	0.38 %	0.33 %	0.00 %	0.50 %					
2400	6.557E-03	0.43 %	0.33 %	0.00 %	0.54 %					
2500	5.798E-03	0.61 %	0.33 %	0.00 %	0.69 %					

Table 10-14 NIM Results for Polaron PA847. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

PA847	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	2.242E-05	0.78 %	0.70 %	0.00 %	1.05 %					
260	3.912E-05	0.49 %	0.68 %	0.00 %	0.84 %					
270	6.565E-05	0.43 %	0.66 %	0.00 %	0.79 %					
280	1.049E-04	0.40 %	0.64 %	0.00 %	0.75 %					
290	1.614E-04	0.38 %	0.62 %	0.00 %	0.73 %					
300	2.394E-04	0.37 %	0.61 %	0.00 %	0.71 %					
310	3.455E-04	0.37 %	0.59 %	0.00 %	0.69 %					
320	4.822E-04	0.35 %	0.57 %	0.00 %	0.67 %					
330	6.574E-04	0.32 %	0.57 %	0.00 %	0.65 %					
340	8.812E-04	0.30 %	0.55 %	0.00 %	0.63 %					
350	1.144E-03	0.28 %	0.53 %	0.00 %	0.60 %					
360	1.460E-03	0.28 %	0.53 %	0.00 %	0.60 %					
370	1.831E-03	0.28 %	0.52 %	0.00 %	0.59 %					
380	2.255E-03	0.26 %	0.51 %	0.00 %	0.57 %					
390	2.742E-03	0.26 %	0.50 %	0.00 %	0.56 %					
400	3.299E-03	0.26 %	0.49 %	0.00 %	0.55 %					
450	6.944E-03	0.26 %	0.46 %	0.00 %	0.53 %					
500	1.190E-02	0.26 %	0.44 %	0.00 %	0.51 %					
550	1.767E-02	0.26 %	0.42 %	0.00 %	0.49 %					
555	1.825E-02	0.25 %	0.42 %	0.00 %	0.49 %					
600	2.350E-02	0.25 %	0.41 %	0.00 %	0.48 %					
650	2.894E-02	0.25 %	0.39 %	0.00 %	0.47 %					
700	3.351E-02	0.24 %	0.39 %	0.00 %	0.46 %					
750	3.713E-02	0.24 %	0.38 %	0.00 %	0.45 %					
800	3.968E-02	0.26 %	0.37 %	0.00 %	0.45 %					
850	4.113E-02	0.26 %	0.37 %	0.00 %	0.45 %					
900	4.116E-02	0.26 %	0.36 %	0.00 %	0.45 %					
950	4.159E-02	0.28 %	0.36 %	0.00 %	0.45 %					
1000	4.083E-02	0.28 %	0.35 %	0.00 %	0.45 %					
1100	3.830E-02	0.28 %	0.35 %	0.00 %	0.45 %					
1200	3.482E-02	0.29 %	0.34 %	0.00 %	0.45 %					
1300	3.109E-02	0.30 %	0.34 %	0.00 %	0.45 %					
1400	2.751E-02	0.33 %	0.34 %	0.00 %	0.47 %					
1500	2.421E-02	0.33 %	0.34 %	0.00 %	0.47 %					
1600	2.106E-02	0.33 %	0.34 %	0.00 %	0.47 %					
1700	1.836E-02	0.35 %	0.33 %	0.00 %	0.48 %					
1800	1.584E-02	0.35 %	0.33 %	0.00 %	0.48 %					
1900	1.367E-02	0.35 %	0.33 %	0.00 %	0.48 %					
2000	1.205E-02	0.37 %	0.33 %	0.00 %	0.50 %					
2100	1.039E-02	0.37 %	0.33 %	0.00 %	0.50 %					
2200	9.314E-03	0.38 %	0.33 %	0.00 %	0.50 %					
2300	7.935E-03	0.38 %	0.33 %	0.00 %	0.50 %					
2400	6.848E-03	0.43 %	0.33 %	0.00 %	0.54 %					
2500	5.907E-03	0.61 %	0.33 %	0.00 %	0.69 %					

10.8 Pilot Results

NPL's results for FEL BN 9101 235 are given in Table 10-15 and the results for FEL BN 9101 208 are given in Table 10-16 and the results for FEL BN 9101 216 are given in Table 10-17. NPL's results for PA848 are given in Table 10-18, the results for P249c are given in Table 10-19, and the results for PA847 are given in Table 10-20.

Table 10-15 NPL Results for FEL BN 9101 235. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

FEL 235	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.250E-04	0.32 %	0.48 %	2.00 %	2.08 %	1.249E-04	1.15 %	0.45 %	2.00 %	2.35 %
260	2.189E-04	0.26 %	0.46 %	2.00 %	2.07 %	2.191E-04	0.89 %	0.43 %	2.00 %	2.23 %
270	3.640E-04	0.22 %	0.44 %	2.00 %	2.06 %	3.645E-04	0.73 %	0.41 %	2.00 %	2.17 %
280	5.783E-04	0.19 %	0.43 %	1.50 %	1.57 %	5.792E-04	0.62 %	0.40 %	1.50 %	1.67 %
290	8.824E-04	0.18 %	0.41 %	1.00 %	1.10 %	8.836E-04	0.56 %	0.38 %	1.00 %	1.21 %
300	1.299E-03	0.17 %	0.40 %	0.25 %	0.50 %	1.300E-03	0.52 %	0.37 %	0.25 %	0.68 %
310	1.852E-03	0.16 %	0.39 %	0.28 %	0.51 %	1.853E-03	0.49 %	0.36 %	0.28 %	0.67 %
320	2.567E-03	0.16 %	0.37 %	0.25 %	0.48 %	2.566E-03	0.46 %	0.35 %	0.25 %	0.63 %
330	3.466E-03	0.15 %	0.36 %	0.28 %	0.48 %	3.462E-03	0.44 %	0.34 %	0.28 %	0.62 %
340	4.573E-03	0.14 %	0.35 %	0.33 %	0.50 %	4.565E-03	0.42 %	0.33 %	0.33 %	0.63 %
350	5.909E-03	0.14 %	0.34 %	0.36 %	0.52 %	5.893E-03	0.40 %	0.32 %	0.36 %	0.63 %
360	7.491E-03	0.13 %	0.33 %	0.43 %	0.56 %	7.466E-03	0.39 %	0.31 %	0.43 %	0.66 %
370	9.333E-03	0.13 %	0.32 %	0.46 %	0.58 %	9.296E-03	0.38 %	0.30 %	0.46 %	0.67 %
380	1.145E-02	0.13 %	0.31 %	0.52 %	0.62 %	1.140E-02	0.37 %	0.29 %	0.52 %	0.70 %
390	1.384E-02	0.12 %	0.31 %	0.50 %	0.60 %	1.377E-02	0.37 %	0.29 %	0.50 %	0.68 %
400	1.652E-02	0.12 %	0.30 %	0.46 %	0.56 %	1.642E-02	0.37 %	0.28 %	0.46 %	0.65 %
450	3.398E-02	0.12 %	0.27 %	0.10 %	0.31 %	3.374E-02	0.38 %	0.25 %	0.10 %	0.46 %
500	5.704E-02	0.11 %	0.24 %	0.01 %	0.26 %	5.665E-02	0.37 %	0.22 %	0.01 %	0.44 %
550	8.317E-02	0.10 %	0.22 %	0.00 %	0.24 %	8.267E-02	0.36 %	0.20 %	0.00 %	0.42 %
555	8.585E-02	0.10 %	0.22 %	0.00 %	0.24 %	8.534E-02	0.36 %	0.20 %	0.00 %	0.42 %
600	1.096E-01	0.09 %	0.20 %	0.00 %	0.22 %	1.090E-01	0.36 %	0.19 %	0.00 %	0.40 %
650	1.340E-01	0.09 %	0.18 %	0.00 %	0.20 %	1.333E-01	0.36 %	0.17 %	0.00 %	0.40 %
700	1.546E-01	0.09 %	0.17 %	0.00 %	0.19 %	1.540E-01	0.35 %	0.16 %	0.00 %	0.39 %
750	1.708E-01	0.08 %	0.16 %	0.01 %	0.18 %	1.700E-01	0.35 %	0.15 %	0.01 %	0.38 %
800	1.822E-01	0.08 %	0.15 %	0.00 %	0.17 %	1.814E-01	0.34 %	0.14 %	0.00 %	0.37 %
850	1.892E-01	0.07 %	0.14 %	0.00 %	0.16 %	1.883E-01	0.34 %	0.13 %	0.00 %	0.36 %
900	1.923E-01	0.07 %	0.13 %	0.00 %	0.15 %	1.914E-01	0.34 %	0.12 %	0.00 %	0.36 %
950	1.922E-01	0.07 %	0.13 %	0.01 %	0.14 %	1.913E-01	0.33 %	0.12 %	0.01 %	0.36 %
1000	1.895E-01	0.07 %	0.12 %	0.01 %	0.14 %	1.887E-01	0.34 %	0.11 %	0.01 %	0.35 %
1100	1.787E-01	0.07 %	0.11 %	0.01 %	0.13 %	1.784E-01	0.34 %	0.10 %	0.01 %	0.36 %
1200	1.638E-01	0.08 %	0.10 %	0.02 %	0.13 %	1.639E-01	0.34 %	0.09 %	0.02 %	0.36 %
1300	1.472E-01	0.09 %	0.09 %	0.00 %	0.13 %	1.475E-01	0.34 %	0.09 %	0.00 %	0.35 %
1400	1.307E-01	0.10 %	0.09 %	0.01 %	0.13 %	1.308E-01	0.35 %	0.08 %	0.01 %	0.36 %
1500	1.150E-01	0.09 %	0.08 %	0.01 %	0.13 %	1.150E-01	0.35 %	0.08 %	0.01 %	0.35 %
1600	1.008E-01	0.09 %	0.08 %	0.01 %	0.12 %	1.008E-01	0.38 %	0.07 %	0.01 %	0.39 %
1700	8.823E-02	0.12 %	0.07 %	0.01 %	0.14 %	8.843E-02	0.49 %	0.07 %	0.01 %	0.49 %
1800	7.720E-02	0.15 %	0.07 %	0.02 %	0.17 %	7.761E-02	0.60 %	0.07 %	0.02 %	0.61 %
1900	6.753E-02	0.18 %	0.07 %	0.02 %	0.19 %	6.807E-02	0.70 %	0.06 %	0.02 %	0.70 %
2000	5.906E-02	0.20 %	0.07 %	0.05 %	0.22 %	5.956E-02	0.76 %	0.06 %	0.05 %	0.77 %
2100	5.170E-02	0.20 %	0.06 %	0.02 %	0.21 %	5.199E-02	0.77 %	0.06 %	0.02 %	0.77 %
2200	4.537E-02	0.21 %	0.06 %	0.00 %	0.22 %	4.542E-02	0.83 %	0.06 %	0.00 %	0.83 %
2300	3.991E-02	0.24 %	0.06 %	0.01 %	0.25 %	3.985E-02	0.90 %	0.06 %	0.01 %	0.90 %
2400	3.511E-02	0.36 %	0.06 %	0.07 %	0.37 %	3.512E-02	1.06 %	0.05 %	0.07 %	1.06 %

2500	3.105E-02	0.37 %	0.06 %	0.05 %	0.38 %	3.120E-02	1.60 %	0.05 %	0.05 %	1.60 %

Table 10-16 NPL Results for FEL BN 9101 208. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

FEL 208	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.550E-04	0.40 %	0.48 %	2.00 %	2.10 %	1.544E-04	0.84 %	0.45 %	2.00 %	2.21 %
260	2.689E-04	0.31 %	0.46 %	2.00 %	2.08 %	2.681E-04	0.67 %	0.43 %	2.00 %	2.15 %
270	4.433E-04	0.25 %	0.44 %	2.00 %	2.06 %	4.421E-04	0.57 %	0.41 %	2.00 %	2.12 %
280	6.986E-04	0.22 %	0.43 %	1.50 %	1.57 %	6.970E-04	0.51 %	0.40 %	1.50 %	1.63 %
290	1.058E-03	0.20 %	0.41 %	1.00 %	1.10 %	1.056E-03	0.47 %	0.38 %	1.00 %	1.17 %
300	1.547E-03	0.18 %	0.40 %	0.25 %	0.50 %	1.544E-03	0.45 %	0.37 %	0.25 %	0.63 %
310	2.192E-03	0.17 %	0.39 %	0.28 %	0.51 %	2.187E-03	0.43 %	0.36 %	0.28 %	0.63 %
320	3.019E-03	0.16 %	0.37 %	0.25 %	0.48 %	3.012E-03	0.41 %	0.35 %	0.25 %	0.59 %
330	4.054E-03	0.16 %	0.36 %	0.28 %	0.48 %	4.045E-03	0.40 %	0.34 %	0.28 %	0.59 %
340	5.321E-03	0.15 %	0.35 %	0.33 %	0.50 %	5.309E-03	0.39 %	0.33 %	0.33 %	0.60 %
350	6.842E-03	0.14 %	0.34 %	0.36 %	0.52 %	6.825E-03	0.38 %	0.32 %	0.36 %	0.61 %
360	8.634E-03	0.14 %	0.33 %	0.43 %	0.56 %	8.613E-03	0.37 %	0.31 %	0.43 %	0.65 %
370	1.071E-02	0.13 %	0.32 %	0.46 %	0.58 %	1.069E-02	0.36 %	0.30 %	0.46 %	0.66 %
380	1.309E-02	0.13 %	0.31 %	0.52 %	0.62 %	1.305E-02	0.36 %	0.29 %	0.52 %	0.70 %
390	1.576E-02	0.13 %	0.31 %	0.50 %	0.60 %	1.572E-02	0.36 %	0.29 %	0.50 %	0.68 %
400	1.874E-02	0.13 %	0.30 %	0.46 %	0.56 %	1.870E-02	0.35 %	0.28 %	0.46 %	0.64 %
450	3.797E-02	0.12 %	0.27 %	0.10 %	0.31 %	3.791E-02	0.36 %	0.25 %	0.10 %	0.44 %
500	6.298E-02	0.12 %	0.24 %	0.01 %	0.27 %	6.295E-02	0.35 %	0.22 %	0.01 %	0.42 %
550	9.095E-02	0.11 %	0.22 %	0.00 %	0.24 %	9.099E-02	0.35 %	0.20 %	0.00 %	0.40 %
555	9.379E-02	0.10 %	0.22 %	0.00 %	0.24 %	9.384E-02	0.35 %	0.20 %	0.00 %	0.40 %
600	1.189E-01	0.10 %	0.20 %	0.00 %	0.22 %	1.190E-01	0.34 %	0.19 %	0.00 %	0.39 %
650	1.443E-01	0.10 %	0.18 %	0.00 %	0.21 %	1.445E-01	0.34 %	0.17 %	0.00 %	0.38 %
700	1.656E-01	0.09 %	0.17 %	0.00 %	0.19 %	1.657E-01	0.34 %	0.16 %	0.00 %	0.37 %
750	1.819E-01	0.09 %	0.16 %	0.01 %	0.18 %	1.820E-01	0.33 %	0.15 %	0.01 %	0.36 %
800	1.932E-01	0.08 %	0.15 %	0.00 %	0.17 %	1.932E-01	0.33 %	0.14 %	0.00 %	0.36 %
850	1.998E-01	0.08 %	0.14 %	0.00 %	0.16 %	1.997E-01	0.33 %	0.13 %	0.00 %	0.35 %
900	2.023E-01	0.07 %	0.13 %	0.00 %	0.15 %	2.022E-01	0.33 %	0.12 %	0.00 %	0.35 %
950	2.015E-01	0.07 %	0.13 %	0.01 %	0.15 %	2.015E-01	0.33 %	0.12 %	0.01 %	0.35 %
1000	1.980E-01	0.07 %	0.12 %	0.01 %	0.14 %	1.982E-01	0.33 %	0.11 %	0.01 %	0.34 %
1100	1.858E-01	0.08 %	0.11 %	0.01 %	0.13 %	1.862E-01	0.33 %	0.10 %	0.01 %	0.34 %
1200	1.695E-01	0.09 %	0.10 %	0.02 %	0.14 %	1.703E-01	0.33 %	0.09 %	0.02 %	0.34 %
1300	1.518E-01	0.10 %	0.09 %	0.00 %	0.14 %	1.527E-01	0.33 %	0.09 %	0.00 %	0.34 %
1400	1.343E-01	0.11 %	0.09 %	0.01 %	0.14 %	1.351E-01	0.33 %	0.08 %	0.01 %	0.34 %
1500	1.180E-01	0.11 %	0.08 %	0.01 %	0.14 %	1.187E-01	0.34 %	0.08 %	0.01 %	0.35 %
1600	1.033E-01	0.11 %	0.08 %	0.01 %	0.13 %	1.038E-01	0.40 %	0.07 %	0.01 %	0.40 %
1700	9.030E-02	0.15 %	0.07 %	0.01 %	0.16 %	9.083E-02	0.48 %	0.07 %	0.01 %	0.49 %
1800	7.887E-02	0.19 %	0.07 %	0.02 %	0.20 %	7.939E-02	0.53 %	0.07 %	0.02 %	0.53 %
1900	6.879E-02	0.23 %	0.07 %	0.02 %	0.24 %	6.927E-02	0.54 %	0.06 %	0.02 %	0.55 %
2000	5.996E-02	0.26 %	0.07 %	0.05 %	0.28 %	6.031E-02	0.58 %	0.06 %	0.05 %	0.58 %
2100	5.233E-02	0.26 %	0.06 %	0.02 %	0.27 %	5.251E-02	0.59 %	0.06 %	0.02 %	0.59 %
2200	4.586E-02	0.29 %	0.06 %	0.00 %	0.29 %	4.590E-02	0.62 %	0.06 %	0.00 %	0.62 %
2300	4.035E-02	0.32 %	0.06 %	0.01 %	0.32 %	4.037E-02	0.67 %	0.06 %	0.01 %	0.67 %
2400	3.549E-02	0.47 %	0.06 %	0.07 %	0.48 %	3.559E-02	0.77 %	0.05 %	0.07 %	0.77 %
2500	3.145E-02	0.40 %	0.06 %	0.05 %	0.41 %	3.147E-02	1.13 %	0.05 %	0.05 %	1.14 %

Table 10-17 NPL Results for FEL BN 9101 216. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

FEL 216	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250						1.301E-04	2.52 %	0.45 %	2.00 %	3.25 %
260						2.271E-04	1.90 %	0.43 %	2.00 %	2.80 %
270						3.768E-04	1.49 %	0.41 %	2.00 %	2.53 %
280						5.973E-04	1.22 %	0.40 %	1.50 %	1.98 %
290						9.096E-04	1.05 %	0.38 %	1.00 %	1.50 %
300	1.339E-03	1.74 %	0.40 %	0.25 %	1.80 %	1.337E-03	0.93 %	0.37 %	0.25 %	1.03 %
310	1.902E-03	1.05 %	0.39 %	0.28 %	1.15 %	1.903E-03	0.84 %	0.36 %	0.28 %	0.96 %
320	2.628E-03	0.68 %	0.37 %	0.25 %	0.82 %	2.633E-03	0.76 %	0.35 %	0.25 %	0.88 %
330	3.541E-03	0.53 %	0.36 %	0.28 %	0.70 %	3.551E-03	0.69 %	0.34 %	0.28 %	0.82 %
340	4.665E-03	0.47 %	0.35 %	0.33 %	0.67 %	4.680E-03	0.63 %	0.33 %	0.33 %	0.78 %
350	6.021E-03	0.43 %	0.34 %	0.36 %	0.65 %	6.042E-03	0.57 %	0.32 %	0.36 %	0.75 %
360	7.627E-03	0.38 %	0.33 %	0.43 %	0.66 %	7.654E-03	0.53 %	0.31 %	0.43 %	0.75 %
370	9.498E-03	0.34 %	0.32 %	0.46 %	0.66 %	9.531E-03	0.49 %	0.30 %	0.46 %	0.74 %
380	1.165E-02	0.33 %	0.31 %	0.52 %	0.69 %	1.168E-02	0.47 %	0.29 %	0.52 %	0.76 %
390	1.408E-02	0.34 %	0.31 %	0.50 %	0.68 %	1.412E-02	0.46 %	0.29 %	0.50 %	0.74 %
400	1.680E-02	0.36 %	0.30 %	0.46 %	0.66 %	1.685E-02	0.46 %	0.28 %	0.46 %	0.71 %
450	3.460E-02	0.46 %	0.27 %	0.10 %	0.54 %	3.466E-02	0.52 %	0.25 %	0.10 %	0.58 %
500	5.819E-02	0.39 %	0.24 %	0.01 %	0.46 %	5.826E-02	0.52 %	0.22 %	0.01 %	0.57 %
550	8.499E-02	0.29 %	0.22 %	0.00 %	0.36 %	8.508E-02	0.50 %	0.20 %	0.00 %	0.54 %
555	8.773E-02	0.28 %	0.22 %	0.00 %	0.35 %	8.783E-02	0.49 %	0.20 %	0.00 %	0.53 %
600	1.121E-01	0.23 %	0.20 %	0.00 %	0.31 %	1.123E-01	0.48 %	0.19 %	0.00 %	0.52 %
650	1.372E-01	0.23 %	0.18 %	0.00 %	0.30 %	1.373E-01	0.48 %	0.17 %	0.00 %	0.51 %
700	1.585E-01	0.24 %	0.17 %	0.00 %	0.30 %	1.586E-01	0.47 %	0.16 %	0.00 %	0.49 %
750	1.751E-01	0.23 %	0.16 %	0.01 %	0.28 %	1.752E-01	0.44 %	0.15 %	0.01 %	0.47 %
800	1.868E-01	0.20 %	0.15 %	0.00 %	0.25 %	1.869E-01	0.42 %	0.14 %	0.00 %	0.44 %
850	1.940E-01	0.18 %	0.14 %	0.00 %	0.23 %	1.942E-01	0.41 %	0.13 %	0.00 %	0.43 %
900	1.972E-01	0.17 %	0.13 %	0.00 %	0.22 %	1.974E-01	0.41 %	0.12 %	0.00 %	0.43 %
950	1.970E-01	0.16 %	0.13 %	0.01 %	0.20 %	1.974E-01	0.41 %	0.12 %	0.01 %	0.42 %
1000	1.942E-01	0.16 %	0.12 %	0.01 %	0.20 %	1.949E-01	0.41 %	0.11 %	0.01 %	0.43 %
1100	1.830E-01	0.23 %	0.11 %	0.01 %	0.25 %	1.842E-01	0.44 %	0.10 %	0.01 %	0.45 %
1200	1.676E-01	0.33 %	0.10 %	0.02 %	0.35 %	1.692E-01	0.45 %	0.09 %	0.02 %	0.46 %
1300	1.508E-01	0.45 %	0.09 %	0.00 %	0.46 %	1.522E-01	0.45 %	0.09 %	0.00 %	0.46 %
1400	1.340E-01	0.50 %	0.09 %	0.01 %	0.51 %	1.351E-01	0.46 %	0.08 %	0.01 %	0.47 %
1500	1.181E-01	0.49 %	0.08 %	0.01 %	0.50 %	1.189E-01	0.46 %	0.08 %	0.01 %	0.47 %
1600	1.036E-01	0.46 %	0.08 %	0.01 %	0.46 %	1.044E-01	0.59 %	0.07 %	0.01 %	0.59 %
1700	9.053E-02	0.66 %	0.07 %	0.01 %	0.66 %	9.168E-02	0.92 %	0.07 %	0.01 %	0.92 %
1800	7.906E-02	0.92 %	0.07 %	0.02 %	0.93 %	8.050E-02	1.24 %	0.07 %	0.02 %	1.24 %
1900	6.899E-02	0.05 %	0.07 %	0.02 %	0.09 %	7.059E-02	1.48 %	0.06 %	0.02 %	1.48 %
2000	6.014E-02	0.05 %	0.07 %	0.05 %	0.10 %	6.174E-02	1.64 %	0.06 %	0.05 %	1.64 %
2100	5.248E-02	0.05 %	0.06 %	0.02 %	0.08 %	5.392E-02	1.65 %	0.06 %	0.02 %	1.66 %
2200	4.615E-02	0.05 %	0.06 %	0.00 %	0.08 %	4.715E-02	1.81 %	0.06 %	0.00 %	1.81 %
2300	4.096E-02	0.05 %	0.06 %	0.01 %	0.08 %	4.135E-02	1.98 %	0.06 %	0.01 %	1.98 %
2400	3.587E-02	0.05 %	0.06 %	0.07 %	0.10 %	3.634E-02	2.37 %	0.05 %	0.07 %	2.37 %
2500	3.165E-02	0.05 %	0.06 %	0.05 %	0.09 %	3.232E-02	3.66 %	0.05 %	0.05 %	3.66 %

Table 10-18 NPL Results for PA848. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1

PA848	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	1.988E-04	1.18 %	0.33 %	0.42 %	1.29 %	2.001E-04	1.18 %	0.15 %	0.42 %	1.26 %
310	2.879E-04	0.84 %	0.38 %	0.41 %	1.01 %	2.904E-04	0.84 %	0.20 %	0.41 %	0.96 %
320	4.050E-04	0.61 %	0.43 %	0.35 %	0.83 %	4.090E-04	0.61 %	0.25 %	0.35 %	0.75 %
330	5.547E-04	0.46 %	0.47 %	0.34 %	0.74 %	5.608E-04	0.46 %	0.28 %	0.34 %	0.64 %
340	7.419E-04	0.38 %	0.53 %	0.33 %	0.73 %	7.504E-04	0.38 %	0.33 %	0.33 %	0.60 %
350	9.709E-04	0.34 %	0.58 %	0.32 %	0.74 %	9.825E-04	0.34 %	0.36 %	0.32 %	0.59 %
360	1.246E-03	0.32 %	0.67 %	0.31 %	0.81 %	1.261E-03	0.32 %	0.43 %	0.31 %	0.62 %
370	1.570E-03	0.31 %	0.72 %	0.30 %	0.84 %	1.589E-03	0.31 %	0.46 %	0.30 %	0.63 %
380	1.947E-03	0.30 %	0.81 %	0.30 %	0.91 %	1.971E-03	0.30 %	0.52 %	0.30 %	0.67 %
390	2.379E-03	0.29 %	0.78 %	0.29 %	0.88 %	2.407E-03	0.29 %	0.50 %	0.29 %	0.64 %
400	2.867E-03	0.27 %	0.72 %	0.28 %	0.82 %	2.900E-03	0.27 %	0.46 %	0.28 %	0.60 %
450	6.155E-03	0.21 %	0.31 %	0.26 %	0.46 %	6.208E-03	0.21 %	0.10 %	0.26 %	0.35 %
500	1.068E-02	0.18 %	0.31 %	0.23 %	0.43 %	1.074E-02	0.18 %	0.00 %	0.23 %	0.29 %
550	1.598E-02	0.16 %	0.33 %	0.20 %	0.42 %	1.603E-02	0.16 %	0.00 %	0.20 %	0.26 %
555	1.653E-02	0.16 %	0.33 %	0.20 %	0.42 %	1.658E-02	0.16 %	0.00 %	0.20 %	0.26 %
600	2.149E-02	0.15 %	0.33 %	0.19 %	0.41 %	2.153E-02	0.15 %	0.00 %	0.19 %	0.24 %
650	2.670E-02	0.16 %	0.32 %	0.17 %	0.40 %	2.671E-02	0.16 %	0.00 %	0.17 %	0.23 %
700	3.123E-02	0.16 %	0.31 %	0.16 %	0.39 %	3.120E-02	0.16 %	0.00 %	0.16 %	0.23 %
750	3.485E-02	0.15 %	0.30 %	0.15 %	0.37 %	3.478E-02	0.15 %	0.00 %	0.15 %	0.21 %
800	3.748E-02	0.14 %	0.29 %	0.14 %	0.35 %	3.737E-02	0.14 %	0.00 %	0.14 %	0.20 %
850	3.916E-02	0.13 %	0.28 %	0.13 %	0.33 %	3.901E-02	0.13 %	0.00 %	0.13 %	0.18 %
900	3.997E-02	0.12 %	0.26 %	0.13 %	0.32 %	3.979E-02	0.12 %	0.00 %	0.13 %	0.17 %
950	4.006E-02	0.12 %	0.25 %	0.12 %	0.30 %	3.987E-02	0.12 %	0.00 %	0.12 %	0.17 %
1000	3.956E-02	0.12 %	0.25 %	0.11 %	0.30 %	3.939E-02	0.12 %	0.00 %	0.11 %	0.16 %
1100	3.733E-02	0.14 %	0.25 %	0.12 %	0.31 %	3.726E-02	0.14 %	0.00 %	0.12 %	0.18 %
1200	3.417E-02	0.17 %	0.28 %	0.10 %	0.34 %	3.420E-02	0.17 %	0.00 %	0.10 %	0.19 %
1300	3.067E-02	0.19 %	0.32 %	0.09 %	0.38 %	3.076E-02	0.19 %	0.00 %	0.09 %	0.21 %
1400	2.717E-02	0.20 %	0.33 %	0.09 %	0.40 %	2.728E-02	0.20 %	0.00 %	0.09 %	0.22 %
1500	2.385E-02	0.19 %	0.30 %	0.12 %	0.37 %	2.396E-02	0.19 %	0.00 %	0.12 %	0.23 %
1600	2.080E-02	0.17 %	0.26 %	0.07 %	0.32 %	2.092E-02	0.17 %	0.00 %	0.07 %	0.19 %
1700	1.807E-02	0.25 %	0.23 %	0.10 %	0.35 %	1.820E-02	0.25 %	0.00 %	0.10 %	0.27 %
1800	1.569E-02	0.51 %	0.21 %	0.10 %	0.56 %	1.582E-02	0.51 %	0.00 %	0.10 %	0.52 %
1900	1.366E-02	0.87 %	0.23 %	0.07 %	0.91 %	1.375E-02	0.87 %	0.00 %	0.07 %	0.88 %
2000	1.194E-02	1.11 %	0.29 %	0.11 %	1.15 %	1.196E-02	1.11 %	0.00 %	0.11 %	1.12 %
2100	1.048E-02	1.27 %	0.38 %	0.09 %	1.33 %	1.044E-02	1.27 %	0.00 %	0.09 %	1.27 %
2200	9.226E-03	1.75 %	0.45 %	0.06 %	1.81 %	9.141E-03	1.75 %	0.00 %	0.06 %	1.75 %
2300	8.135E-03	2.02 %	0.45 %	0.06 %	2.07 %	8.045E-03	2.02 %	0.00 %	0.06 %	2.02 %
2400	7.168E-03	3.00 %	0.76 %	0.08 %	3.10 %	7.104E-03	3.00 %	0.00 %	0.08 %	3.00 %
2500	6.419E-03	3.84 %	1.46 %	0.08 %	4.11 %	6.334E-03	3.84 %	0.00 %	0.08 %	3.84 %

Table 10-19 NPL Results for P249c. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

P249c	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	2.319E-04	0.72 %	0.33 %	0.42 %	0.90 %	2.255E-04	0.70 %	0.15 %	0.42 %	0.83 %
310	3.333E-04	0.44 %	0.38 %	0.41 %	0.71 %	3.261E-04	0.50 %	0.20 %	0.41 %	0.68 %
320	4.656E-04	0.30 %	0.43 %	0.35 %	0.63 %	4.576E-04	0.36 %	0.25 %	0.35 %	0.56 %
330	6.342E-04	0.24 %	0.47 %	0.34 %	0.63 %	6.250E-04	0.27 %	0.28 %	0.34 %	0.52 %
340	8.441E-04	0.23 %	0.53 %	0.33 %	0.67 %	8.333E-04	0.23 %	0.33 %	0.33 %	0.52 %
350	1.100E-03	0.22 %	0.58 %	0.32 %	0.69 %	1.087E-03	0.20 %	0.36 %	0.32 %	0.52 %
360	1.406E-03	0.21 %	0.67 %	0.31 %	0.77 %	1.390E-03	0.19 %	0.43 %	0.31 %	0.57 %
370	1.765E-03	0.19 %	0.72 %	0.30 %	0.80 %	1.747E-03	0.19 %	0.46 %	0.30 %	0.58 %
380	2.182E-03	0.18 %	0.81 %	0.30 %	0.88 %	2.159E-03	0.19 %	0.52 %	0.30 %	0.63 %
390	2.657E-03	0.17 %	0.78 %	0.29 %	0.85 %	2.629E-03	0.19 %	0.50 %	0.29 %	0.61 %
400	3.192E-03	0.17 %	0.72 %	0.28 %	0.79 %	3.158E-03	0.18 %	0.46 %	0.28 %	0.57 %
450	6.753E-03	0.15 %	0.31 %	0.26 %	0.43 %	6.677E-03	0.18 %	0.10 %	0.26 %	0.34 %
500	1.158E-02	0.13 %	0.31 %	0.23 %	0.41 %	1.144E-02	0.17 %	0.00 %	0.23 %	0.29 %
550	1.716E-02	0.12 %	0.33 %	0.20 %	0.41 %	1.695E-02	0.15 %	0.00 %	0.20 %	0.25 %
555	1.774E-02	0.12 %	0.33 %	0.20 %	0.41 %	1.752E-02	0.15 %	0.00 %	0.20 %	0.25 %
600	2.291E-02	0.12 %	0.33 %	0.19 %	0.40 %	2.261E-02	0.14 %	0.00 %	0.19 %	0.23 %
650	2.827E-02	0.12 %	0.32 %	0.17 %	0.38 %	2.789E-02	0.14 %	0.00 %	0.17 %	0.22 %
700	3.287E-02	0.12 %	0.31 %	0.16 %	0.37 %	3.241E-02	0.14 %	0.00 %	0.16 %	0.21 %
750	3.647E-02	0.12 %	0.30 %	0.15 %	0.36 %	3.597E-02	0.13 %	0.00 %	0.15 %	0.20 %
800	3.903E-02	0.11 %	0.29 %	0.14 %	0.34 %	3.849E-02	0.12 %	0.00 %	0.14 %	0.19 %
850	4.058E-02	0.10 %	0.28 %	0.13 %	0.32 %	4.003E-02	0.12 %	0.00 %	0.13 %	0.18 %
900	4.127E-02	0.10 %	0.26 %	0.13 %	0.31 %	4.070E-02	0.12 %	0.00 %	0.13 %	0.17 %
950	4.122E-02	0.10 %	0.25 %	0.12 %	0.30 %	4.065E-02	0.11 %	0.00 %	0.12 %	0.17 %
1000	4.058E-02	0.10 %	0.25 %	0.11 %	0.29 %	4.004E-02	0.12 %	0.00 %	0.11 %	0.16 %
1100	3.806E-02	0.10 %	0.25 %	0.12 %	0.30 %	3.765E-02	0.14 %	0.00 %	0.12 %	0.18 %
1200	3.461E-02	0.11 %	0.28 %	0.10 %	0.32 %	3.440E-02	0.18 %	0.00 %	0.10 %	0.20 %
1300	3.090E-02	0.12 %	0.32 %	0.09 %	0.36 %	3.082E-02	0.22 %	0.00 %	0.09 %	0.24 %
1400	2.728E-02	0.13 %	0.33 %	0.09 %	0.36 %	2.725E-02	0.25 %	0.00 %	0.09 %	0.26 %
1500	2.387E-02	0.12 %	0.30 %	0.12 %	0.34 %	2.387E-02	0.24 %	0.00 %	0.12 %	0.27 %
1600	2.070E-02	0.12 %	0.26 %	0.07 %	0.29 %	2.081E-02	0.24 %	0.00 %	0.07 %	0.25 %
1700	1.784E-02	0.20 %	0.23 %	0.10 %	0.32 %	1.810E-02	0.32 %	0.00 %	0.10 %	0.33 %
1800	1.542E-02	0.37 %	0.21 %	0.10 %	0.44 %	1.574E-02	0.42 %	0.00 %	0.10 %	0.43 %
1900	1.347E-02	0.53 %	0.23 %	0.07 %	0.58 %	1.368E-02	0.50 %	0.00 %	0.07 %	0.50 %
2000	1.186E-02	0.57 %	0.29 %	0.11 %	0.65 %	1.189E-02	0.58 %	0.00 %	0.11 %	0.59 %
2100	1.039E-02	0.71 %	0.38 %	0.09 %	0.81 %	1.033E-02	0.59 %	0.00 %	0.09 %	0.59 %
2200	9.018E-03	0.88 %	0.45 %	0.06 %	0.99 %	9.011E-03	0.63 %	0.00 %	0.06 %	0.64 %
2300	7.913E-03	1.26 %	0.45 %	0.06 %	1.35 %	7.920E-03	0.72 %	0.00 %	0.06 %	0.72 %
2400	7.092E-03	1.48 %	0.76 %	0.08 %	1.66 %	6.996E-03	1.02 %	0.00 %	0.08 %	1.03 %
2500	6.205E-03	1.77 %	1.46 %	0.08 %	2.30 %	6.077E-03	0.92 %	0.00 %	0.08 %	0.92 %

Table 10-20 NPL Results for PA847. Uncertainties have been split according to correlation between lamps and between rounds and are k = 1.

PA847	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	2.366E-04	0.48 %	0.33 %	0.42 %	0.73 %	2.363E-04	0.49 %	0.15 %	0.42 %	0.67 %
310	3.404E-04	0.35 %	0.38 %	0.41 %	0.66 %	3.416E-04	0.35 %	0.20 %	0.41 %	0.58 %
320	4.758E-04	0.26 %	0.43 %	0.35 %	0.62 %	4.790E-04	0.26 %	0.25 %	0.35 %	0.50 %
330	6.482E-04	0.21 %	0.47 %	0.34 %	0.61 %	6.538E-04	0.20 %	0.28 %	0.34 %	0.48 %
340	8.625E-04	0.18 %	0.53 %	0.33 %	0.65 %	8.711E-04	0.16 %	0.33 %	0.33 %	0.49 %
350	1.124E-03	0.16 %	0.58 %	0.32 %	0.68 %	1.135E-03	0.15 %	0.36 %	0.32 %	0.50 %
360	1.436E-03	0.16 %	0.67 %	0.31 %	0.76 %	1.451E-03	0.14 %	0.43 %	0.31 %	0.55 %
370	1.803E-03	0.15 %	0.72 %	0.30 %	0.79 %	1.821E-03	0.14 %	0.46 %	0.30 %	0.57 %
380	2.227E-03	0.15 %	0.81 %	0.30 %	0.87 %	2.250E-03	0.14 %	0.52 %	0.30 %	0.61 %
390	2.712E-03	0.14 %	0.78 %	0.29 %	0.84 %	2.737E-03	0.14 %	0.50 %	0.29 %	0.59 %
400	3.257E-03	0.14 %	0.72 %	0.28 %	0.79 %	3.286E-03	0.14 %	0.46 %	0.28 %	0.56 %
450	6.896E-03	0.12 %	0.31 %	0.26 %	0.42 %	6.927E-03	0.14 %	0.10 %	0.26 %	0.31 %
500	1.183E-02	0.11 %	0.31 %	0.23 %	0.40 %	1.185E-02	0.13 %	0.00 %	0.23 %	0.26 %
550	1.753E-02	0.10 %	0.33 %	0.20 %	0.40 %	1.753E-02	0.12 %	0.00 %	0.20 %	0.24 %
555	1.812E-02	0.10 %	0.33 %	0.20 %	0.40 %	1.811E-02	0.12 %	0.00 %	0.20 %	0.23 %
600	2.339E-02	0.10 %	0.33 %	0.19 %	0.39 %	2.336E-02	0.11 %	0.00 %	0.19 %	0.22 %
650	2.886E-02	0.10 %	0.32 %	0.17 %	0.38 %	2.880E-02	0.11 %	0.00 %	0.17 %	0.20 %
700	3.356E-02	0.10 %	0.31 %	0.16 %	0.37 %	3.345E-02	0.11 %	0.00 %	0.16 %	0.19 %
750	3.727E-02	0.10 %	0.30 %	0.15 %	0.35 %	3.710E-02	0.11 %	0.00 %	0.15 %	0.18 %
800	3.992E-02	0.10 %	0.29 %	0.14 %	0.34 %	3.969E-02	0.10 %	0.00 %	0.14 %	0.17 %
850	4.157E-02	0.09 %	0.28 %	0.13 %	0.32 %	4.127E-02	0.10 %	0.00 %	0.13 %	0.17 %
900	4.231E-02	0.09 %	0.26 %	0.13 %	0.31 %	4.197E-02	0.10 %	0.00 %	0.13 %	0.16 %
950	4.229E-02	0.09 %	0.25 %	0.12 %	0.29 %	4.193E-02	0.10 %	0.00 %	0.12 %	0.15 %
1000	4.166E-02	0.09 %	0.25 %	0.11 %	0.29 %	4.131E-02	0.10 %	0.00 %	0.11 %	0.15 %
1100	3.912E-02	0.09 %	0.25 %	0.12 %	0.29 %	3.887E-02	0.11 %	0.00 %	0.12 %	0.16 %
1200	3.564E-02	0.10 %	0.28 %	0.10 %	0.32 %	3.551E-02	0.13 %	0.00 %	0.10 %	0.16 %
1300	3.186E-02	0.11 %	0.32 %	0.09 %	0.35 %	3.180E-02	0.16 %	0.00 %	0.09 %	0.18 %
1400	2.814E-02	0.11 %	0.33 %	0.09 %	0.36 %	2.810E-02	0.18 %	0.00 %	0.09 %	0.20 %
1500	2.463E-02	0.11 %	0.30 %	0.12 %	0.34 %	2.463E-02	0.17 %	0.00 %	0.12 %	0.21 %
1600	2.143E-02	0.12 %	0.26 %	0.07 %	0.29 %	2.151E-02	0.18 %	0.00 %	0.07 %	0.19 %
1700	1.856E-02	0.20 %	0.23 %	0.10 %	0.32 %	1.876E-02	0.27 %	0.00 %	0.10 %	0.29 %
1800	1.605E-02	0.32 %	0.21 %	0.10 %	0.40 %	1.636E-02	0.41 %	0.00 %	0.10 %	0.43 %
1900	1.391E-02	0.45 %	0.23 %	0.07 %	0.51 %	1.426E-02	0.57 %	0.00 %	0.07 %	0.57 %
2000	1.213E-02	0.53 %	0.29 %	0.11 %	0.61 %	1.243E-02	0.67 %	0.00 %	0.11 %	0.68 %
2100	1.065E-02	0.56 %	0.38 %	0.09 %	0.68 %	1.085E-02	0.66 %	0.00 %	0.09 %	0.67 %
2200	9.433E-03	0.70 %	0.45 %	0.06 %	0.83 %	9.506E-03	0.74 %	0.00 %	0.06 %	0.75 %
2300	8.409E-03	0.79 %	0.45 %	0.06 %	0.91 %	8.339E-03	0.80 %	0.00 %	0.06 %	0.80 %
2400	7.434E-03	1.19 %	0.76 %	0.08 %	1.41 %	7.300E-03	1.03 %	0.00 %	0.08 %	1.03 %
2500	6.374E-03	1.57 %	1.46 %	0.08 %	2.15 %	6.537E-03	1.08 %	0.00 %	0.08 %	1.08 %

10.9 Lamp Behaviour

10.9.1 NIM lamps

The following Type I lamps were supplied to NIM by NPL:

FEL BN 9101 235 FEL BN 9101 208 FEL BN 9101 216

The following Type II lamps were supplied to NIM by NPL:

PA848 P249c PA847

10.9.1.1 Measurement sequence

For the Type II lamps, NIM has supplied the pilot with data for the first calibration round only. This data will be analysed in the sequence NPL (2001) – NIM (2001) – NPL (2002).

However, NIM did not receive the second protocol. This means that the first and second round NIM measurements cannot be analysed for the Type I lamps. NIM therefore performed an additional measurement in a short time period and subsequently NPL repeated an additional calibration of all these lamps. Therefore for the Type I lamps, for the purposes of the analysis of the comparison, the measurement sequence is NPL (2002) – NIM (2003) – NPL (2004). Earlier measurements by both NPL and NIM have been ignored.

10.9.1.2 Calibration Wavelengths

NIM calibrated the Type II lamps at all intercomparison wavelengths, although NPL only made measurements at wavelengths above 300 nm (as indicated in the protocol). The measurements of the Type I lamps that were made at the correct current did not cover the region from 750 to 1100 nm. The comparison in this region will only be made against Type II lamps.

In the first useable measurement round, FEL 216 was not measured below 300 nm at NPL.

10.9.2 Lamp history

Table 10-21 Lamp history for FEL BN 9101 235

Date period	Activity	Burn hours:minutes
March – June 2001	0th round measurements at NPL	9:21
May 2001	Hand-carried to NIM	
Sept. – Nov. 2001	0th round measurements at NIM at 8.3 A	10:12
December 2001	Air-freight to NPL	
May – October 2002	1st round measurements at NPL	11:28
October 2002	Hand-carried to NIM	
Sept. – Nov. 2003	Measurements at NIM at 8.3 A	3:30
December 2003	1st round measurements at NIM at 8.1 A	7:36
January 2004	Air-freight to NPL	
March – April 2004	2nd round measurements at NPL	6:45

Table 10-22 Lamp history for FEL BN 9101 208

Date period	Activity	Burn hours:minutes
March – June 2001	0th round measurements at NPL	6:52
May 2001	Hand-carried to NIM	
Sept. – Nov. 2001	0th round measurements at NIM at 8.3 A	14:39
December 2001	Air-freight to NPL	
May – October 2002	1st round measurements at NPL	10:29
October 2002	Hand-carried to NIM	
Sept. – Nov. 2003	Measurements at NIM at 8.3 A	9:32
December 2003	1st round measurements at NIM at 8.1 A	10:04
January 2004	Air-freight to NPL	
March – April 2004	2nd round measurements at NPL	6:45

Table 10-23 Lamp history for FEL BN 9101 216. This lamp replaced FEL BN 9101 241 that was damaged on transit to NIM

Date period	Activity	Burn hours:minutes
March – June 2001	Measurements at NPL	16:08
May – October 2002	1st round measurements at NPL	10:42
October 2002	Hand-carried to NIM	
Sept. – Nov. 2003	Measurements at NIM at 8.3 A	4:20
December 2003	1st round measurements at NIM at 8.1 A	6:58
January 2004	Air-freight to NPL	
March – April 2004	2nd round measurements at NPL	6:45

Table 10-24 Lamp history for PA848

Date period	Activity	Burn hours:minutes
May 2001	1st round measurements at NPL	12:06
June 2001	Air-freight to NIM	
Sept.– Nov. 2001	1st round measurements at NIM	12:48
December 2001	Air-freight to NPL	
July – December 2002	2nd round measurements at NPL	13:11
January 2003	Air-freight to NIM	

Table 10-25 Lamp history for P249c

Date period	Activity	Burn hours:minutes
May 2001	1st round measurements at NPL	12:18
June 2001	Air-freight to NIM	
Sept.– Nov. 2001	1st round measurements at NIM	12:54
December 2001	Air-freight to NPL	
July – December 2002	2nd round measurements at NPL	12:57
January 2003	Air-freight to NIM	

Table 10-26 Lamp history for PA847

Date period	Activity	Burn hours:minutes
May 2001	1st round measurements at NPL	6:52
June 2001	Air-freight to NIM	
Sept.– Nov. 2001	1st round measurements at NIM	13:48
December 2001	Air-freight to NPL	
July – December 2002	2nd round measurements at NPL	13:45
January 2003	Air-freight to NIM	

10.9.3 Lamp electrical stability

The Type I lamps were operated at 8.100 A, the lamp voltage measured was:

Lamp	Potential first NPL measurement	Potential first NIM measurement	Potential second NPL measurement
FEL BN 9101 235	106.2 V	106.3 V	106.4 V
FEL BN 9101 208	105.4 V	105.5 V	105.5 V
FEL BN 9101 216	105.8 V	106.0 V	105.1 – 106.2 V

The Type II lamps were operated at 27.200 A, the lamp voltage measured was:

Lamp	Potential first NPL measurement	Potential first NIM measurement	Potential second NPL measurement
PA848	15.1 V	15.4 V	15.4 V
P249c	15.5 V	15.6 V	15.6 V
PA847	15.9 V	16.0 V	15.9 V

10.9.4 Other lamp issues

NIM noticed during the comparison that white spots on the envelope of the Type I lamps increased in size on all lamps during the comparison.

10.9.5 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the NIM lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

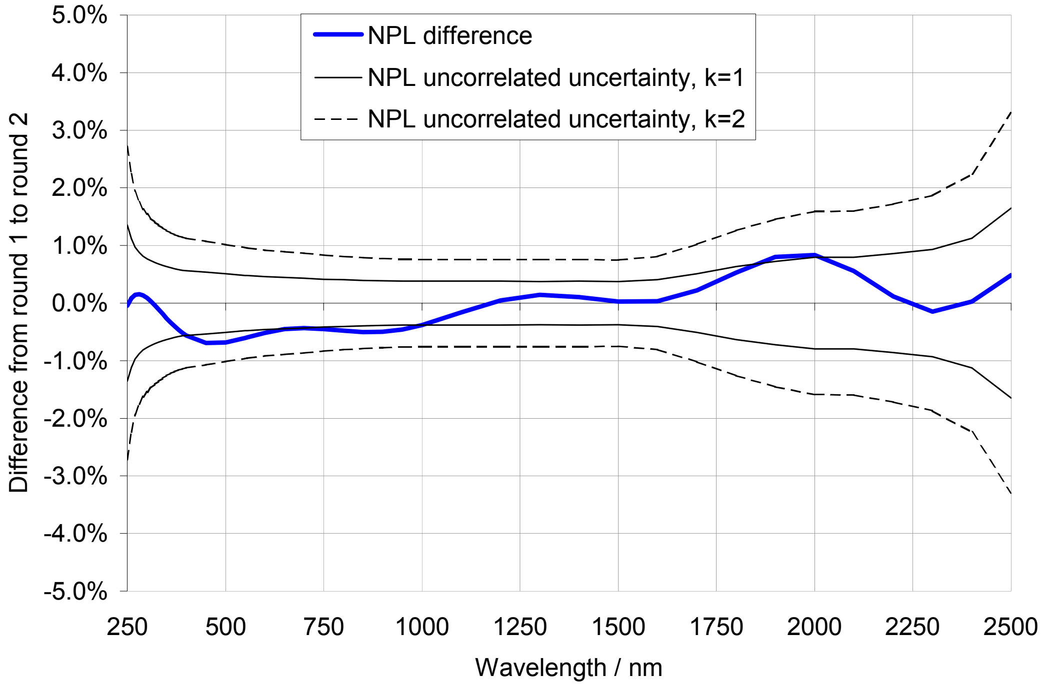

Figure 10-2 Difference between first and second round measurements of FEL BN 9101 235 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

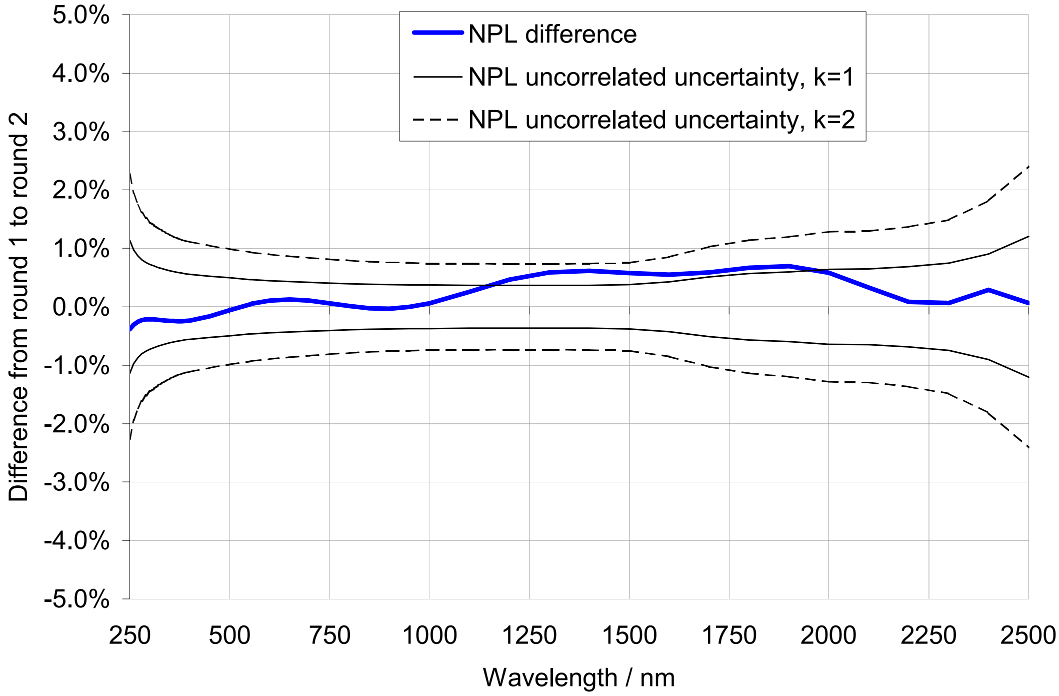

Figure 10-3 Difference between first and second round measurements of FEL BN 9101 208 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

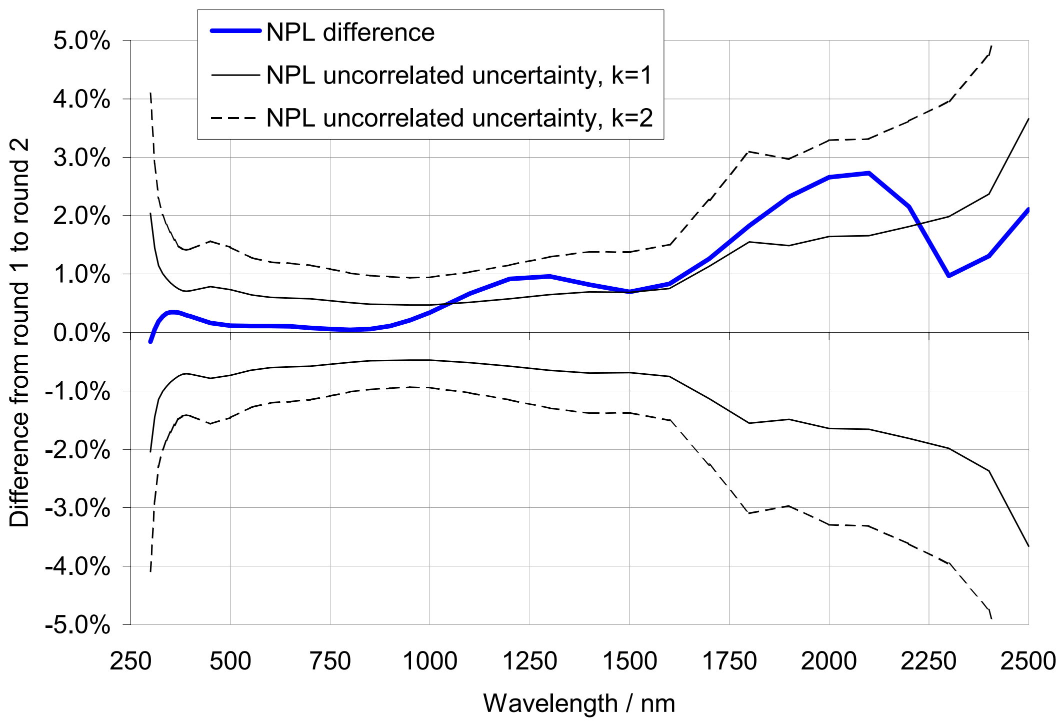

Figure 10-4 Difference between first and second round measurements of FEL BN 9101 216 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

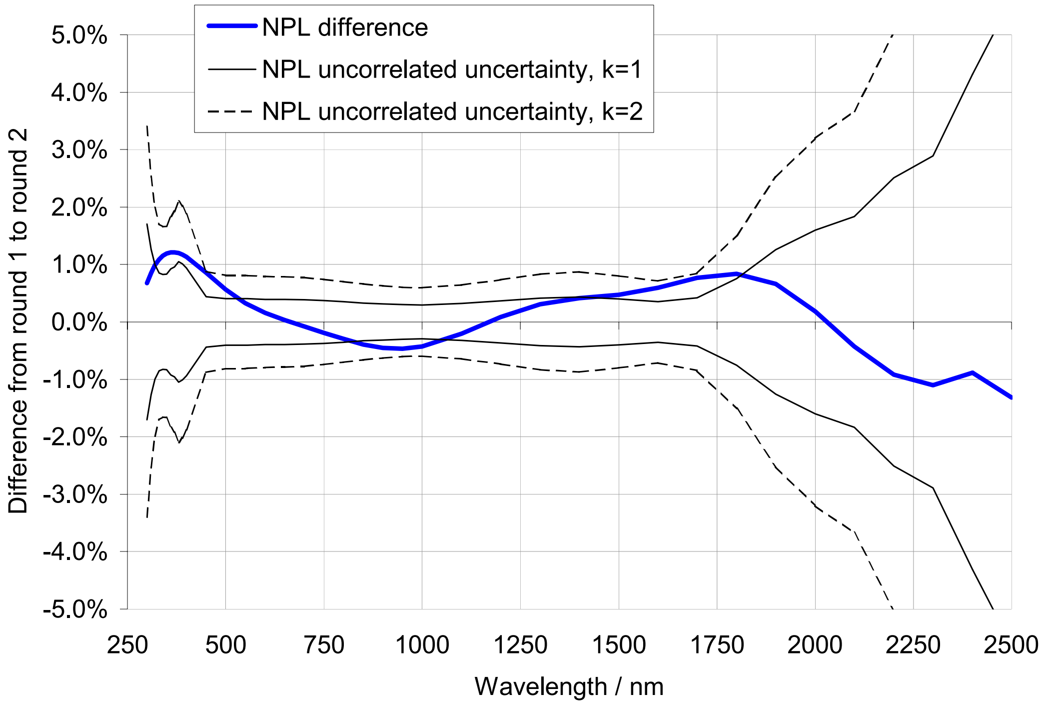

Figure 10-5 Difference between first and second round measurements of PA848 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

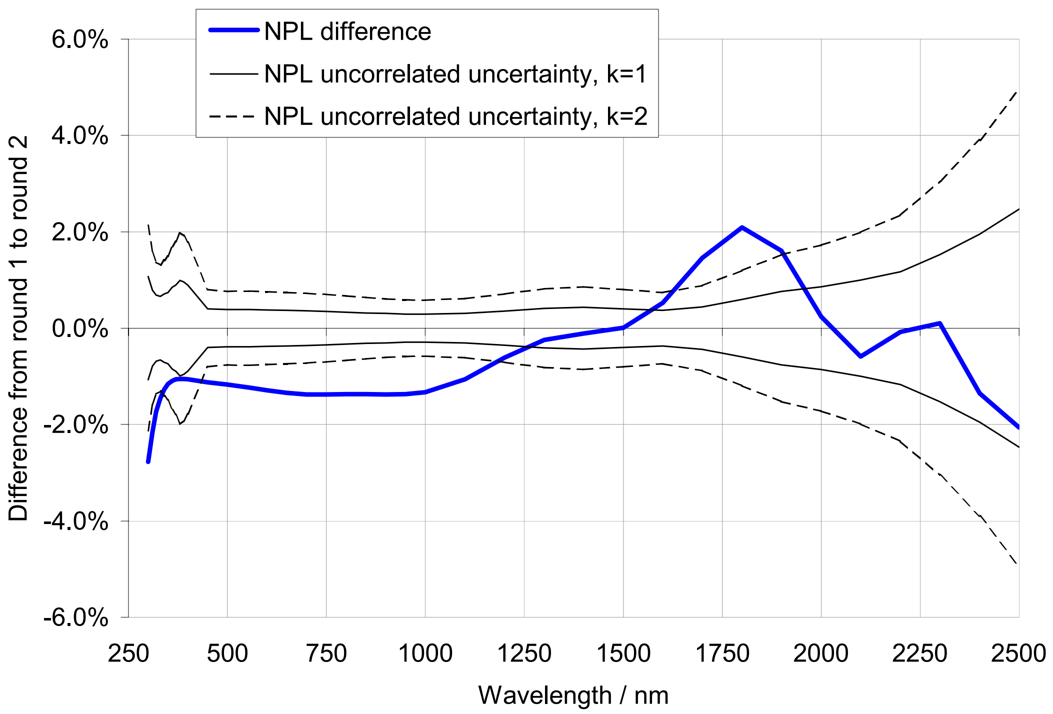

Figure 10-6 Difference between first and second round measurements of P249c by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

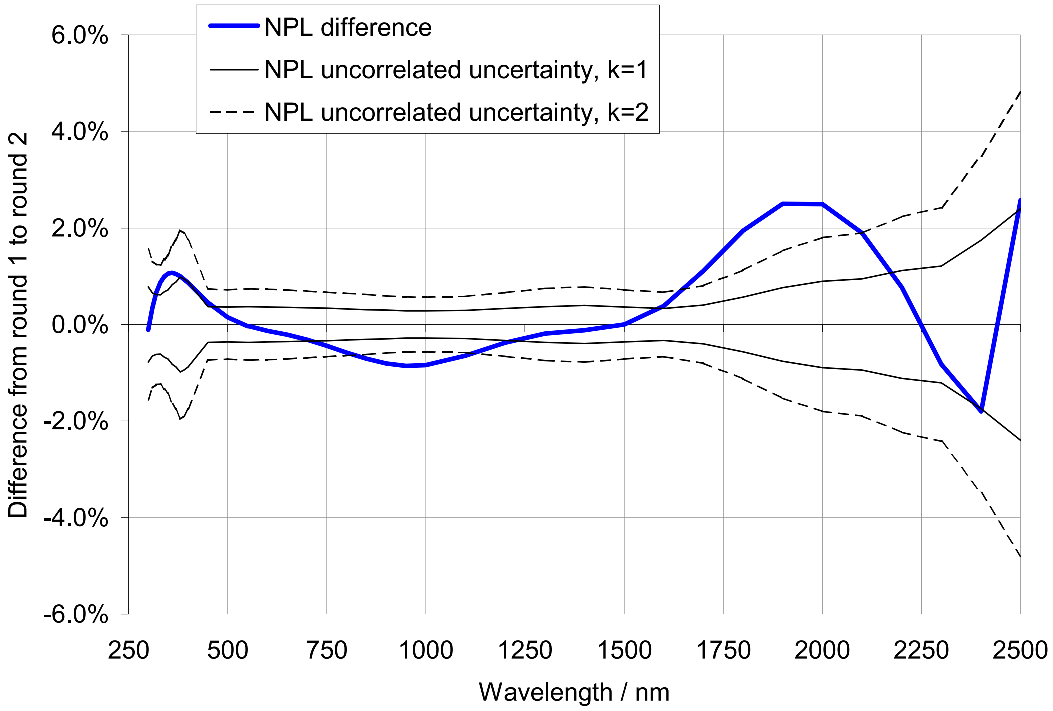

Figure 10-7 Difference between first and second round measurements of PA847 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

10.9.6 Lamp stability from NIM measurements

Because only one measurement of each lamp by NIM can be considered part of this comparison, it is not possible to comment on the stability of these lamps from the NIM measurements.

10.10 Bilateral comparison between NIM and the comparison scale

These graphs show the difference between the NIM and NPL measurements of the NIM lamps. Versions of these graphs normalised to show the relative difference between the lamps, but not the absolute difference between the measurements were used to assist in choosing which lamp measurements to use.

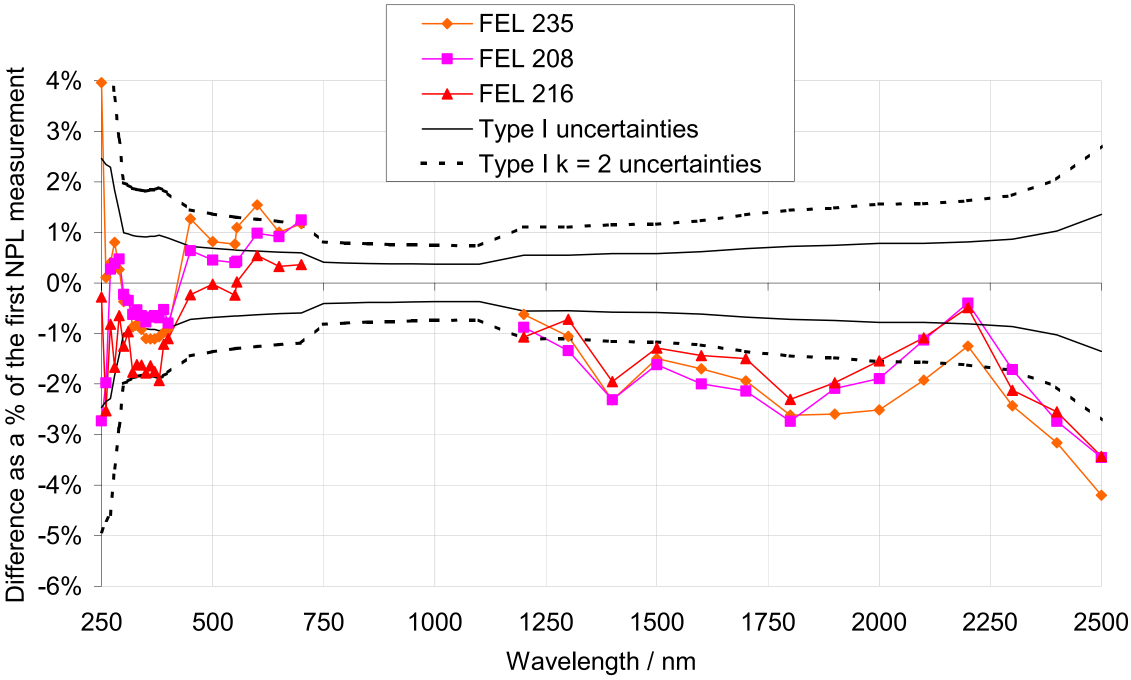

Figure 10-8 Bilateral comparisons of the NIM Type I lamps

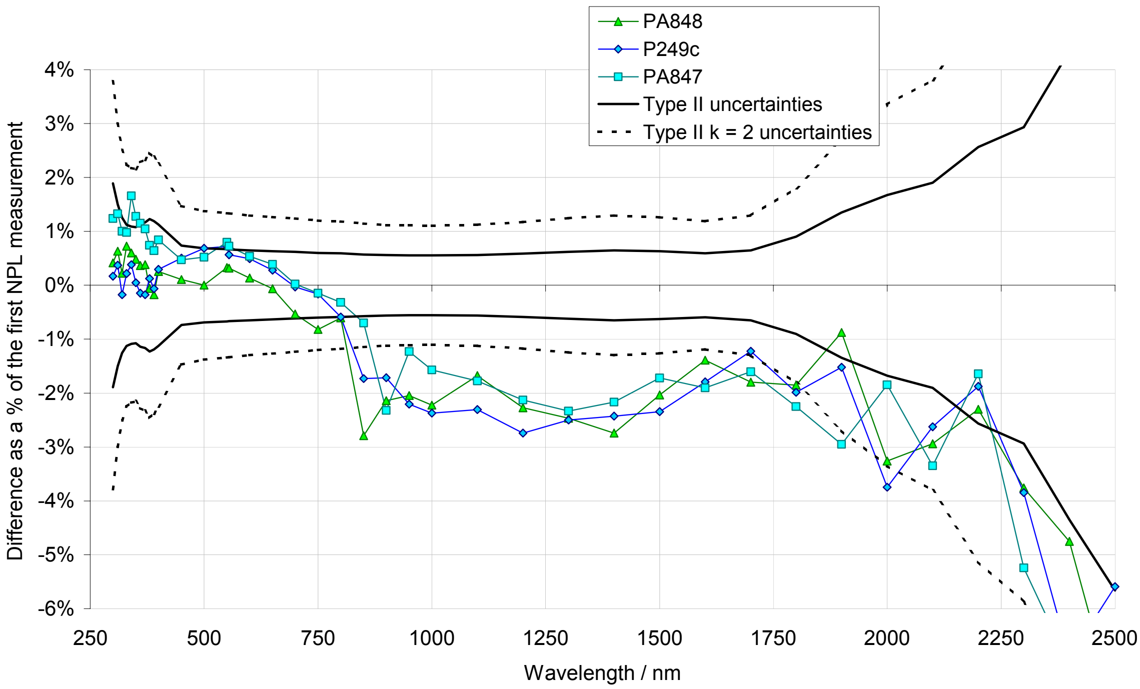

Figure 10-9 Bilateral comparisons of the NIM Type II lamps

10.11 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to NIM the information in the graphs Figure 10-2 to Figure 10-9. The decision was made to use all the data for FEL BN 9101 235 and FEL BN 9101 208, but for FEL BN 9101 216 to ignore wavelengths above 1700 nm because of the pilot's repeatability. For the Type II lamps, all the data for PA848 will be used. The other lamps performed less well, but the decision was made to use PA847 but not P249c.

11 Measurements at NIST

11.1 Primary scale realization

The date of the last realization was Oct. 31, 2003. The spectral irradiance scale National Institute of Standards and Technology is detector-based. The NIST High Accuracy Cryogenic Radiometer (HACR) is the primary standard and the scale is maintained on six FEL-type tungsten quartz halogen lamps and three check standard lamps. The details of realization are listed below and shown in Figure 11-1.

1) The spectral response of the trap detector (TRAP) is determined by comparison to the HACR.
2) The spectral response of the standard photodiode (STD DIODE) is determined by comparison with the trap detector in the Spectral Comparator Facility (SCF).
3) The spectral response of the filter radiometers (FR) is determined by comparison with the standard photodiode in the SCF.
4) The radiance temperature of the high temperature blackbody (HTBB) is determined by the filter radiometers.
5) The spectral irradiance of a high-temperature blackbody is determined using the Planck's Law, the radiance temperature of the HTBB, and a geometrical factor.
6) The spectral irradiance of comparison lamps is determined by comparison to the high temperature blackbody using the FASCAL spectroradiometer.

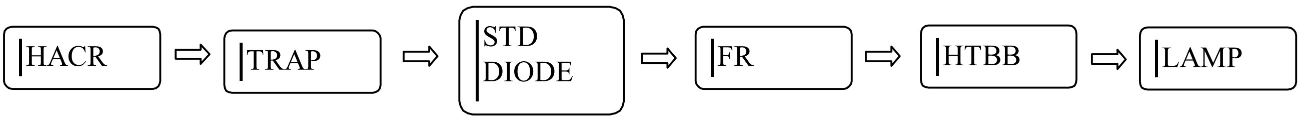

Figure 11-1 Flow chart of NIST irradiance scale realization

11.2 Description of the calibration facility

The lamp was measured in the NIST Facility for Automated Spectroradiometric Calibrations (FASCAL) using the equipment and procedures described in Ref [1]. The spectroradiometer is a NIST design which uses a Cary 14 prism/grating double monochromator*. The monochromator and the detector compartments are continuously purged with dry air. The monochromator specifications are listed in Table 11-1. The detector specifications are listed in Table 11-1. A drawing of the measurement facility is shown in Figure 11-2. The room temperature and humidity are monitored but not controlled.

Table 11-1 Monochromator specifications

Monochromator	Double
Make	CARY 14
Type	Prism/grating
Slit width	2.0 mm
Focal length	0.4 m
f - number	8

* Any mention of commercial products within this document is for information only; it does not imply recommendation or endorsement by NIST.

Table 11-2 Detector specifications

Detector	PMT (S-20)	InGaAs photodiode
Manufacturer	EMI	EG&G Judson
Model	9659Q	J18TE4-3GN-R02M-2.6
Spectral range	250 to 900 nm	800 to 2500 nm
Operating temperature	-15 °C	-60 °C for 800 to 2400 nm -20 °C for 2300 to 2500 nm
Frequency	DC	290 Hz
Integration time	0.8 s to 6.7 s	1.7 s for 800 to 2400 nm 1.7 to 8.3 s for 2300 to 2500 nm

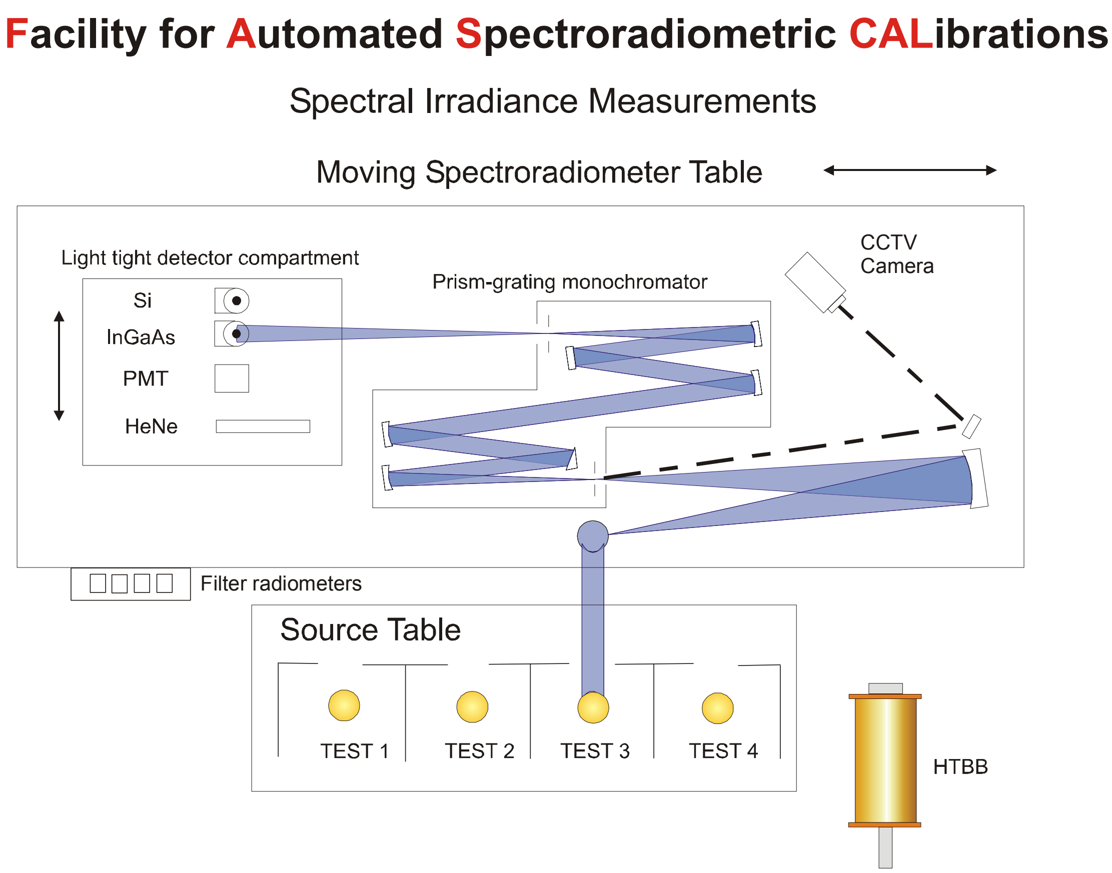

Figure 11-2 Diagram of the FASCAL calibration facility

11.3 Laboratory conditions

The room temperature was 23 °C ± 1 °C and the relative humidity varied between 40 % and 50 %.

11.4 Laboratory transfer standard

The laboratory transfer standard is a high temperature blackbody (HTBB). The HTBB is a type BB3200cc manufactured by VNIIOFI. The HTBB, which has an estimated emissivity of 0.999 [2], was operated at approximately 2950 K.

11.5 Measurement procedure

NIST performed scale realizations before the first NIST measurement (NIST1) of the comparison lamps in Oct. 00 and the second NIST measurement (NIST2) in Nov. 03. The measurements were conducted according to the instructions listed in the document "CIPM Spectral Irradiance comparison protocol" (CCPR IRRAD proto.doc dated Aug. 16, 2000).

The lamp was measured at a distance of 50 cm from the entrance aperture of the integrating sphere with an aperture area of 1.0027 cm^2. The sphere viewed approximately a 9 cm diameter target in the plane of the lamp reference surface. With this geometry, the entire lamp was viewed from the top of the lamp envelope down to the top half of the lamp holder. Light baffling was used between the lamp and the spectroradiometer integrating sphere to minimize effects of scattered light. The alignment of the lamp is described in the next paragraph.

The lamp was mounted vertically, base down with the lamp serial number facing away from the spectroradiometer. The lamp alignment was accomplished by placing a spirit level on top of the lamp protection cap and then by adjusting the angle about the optical axis until the level was balanced. The cap was removed and an alignment jig, glass plate with target, was placed in the lamp holder between the lamp and the spectroradiometer with the label 'Please remove jig before switching on!' facing the spectroradiometer. The alignment jig target area, which is indicated by cross hairs, was centered vertically and horizontally onto the optical axis. The jig was set perpendicular to the optical axis by reflecting the spectroradiometer laser beam back onto itself. The distance along the optical axis from the lamp reference surface to the plane of the sphere aperture was set at 50 cm as shown in Figure 11-3. The lamp reference surface is located on the front surface of the lamp holder at the bottom edge of the bevel and centered horizontally. The jig was removed before operating the lamp.

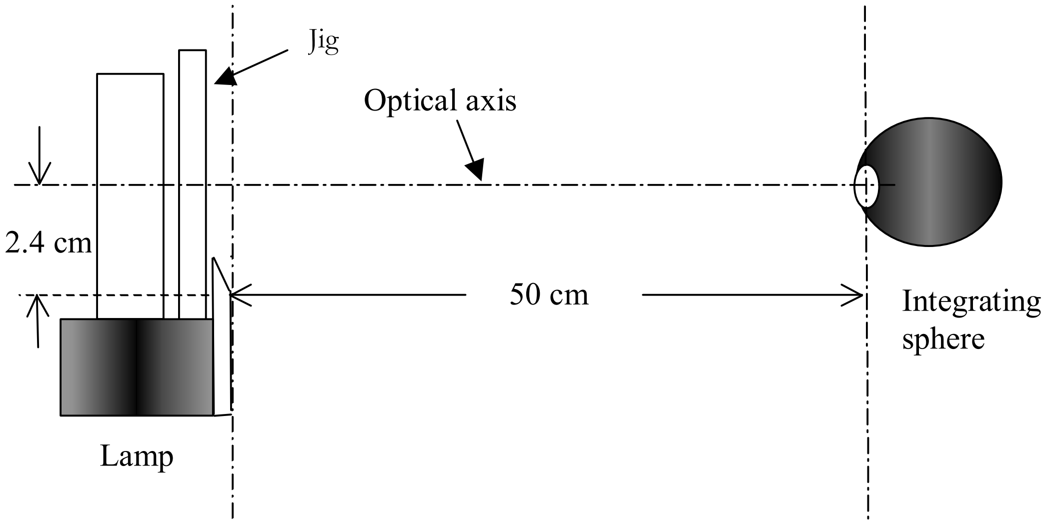

Figure 11-3 This drawing shows the distance measurement between the integrating sphere plane and the lamp reference surface

Details of the first NIST measurement are listed below:

1) Four comparison lamps and four check standard lamps were spectrally compared to the HTBB using the FASCAL spectroradiometer.
2) The comparison lamps were BN-9101-234, BN-9101-244, BN-9101-251, BN-9101-260
3) Lamp BN-9101-234 remained at NIST as a comparison check standard.
4) The check standard lamps were F-272, F-273, F-302, F-433
5) All the lamps were measured 3 times in 3 different test positions.
6) First, all the lamps were measured in the IR region (800 to 2400 nm).
7) Next, the UV-VIS region (250 to 900 nm) and FIR region (2300 to 2500 nm) were measured.

8) The filter radiometers (FR2, FR3, FR4) were used to measure the spectral irradiance of the HTBB at the beginning of the measurements and repeated after each set of four lamps was measured.
9) Due to a misunderstanding of the distance reference, the lamps were measured at a distance of 49.94 cm and corrected to 50 cm using Equation (11-1).

$$E_{\lambda,50} = E_{\lambda}\left(\frac{d}{d_{50}}\right)^2 \qquad (11\text{-}1)$$

where $E_{\lambda,50}$ is the irradiance calculated at 50 cm, E_{λ} is the irradiance measured at 49.94 cm, d is the distance between the integrating sphere and the distance reference plane (d = 49.94 cm), and d_{50} = 50 cm.

Details of the second NIST measurement are listed below:

1) Four comparison lamps were spectrally compared to the HTBB using the FASCAL spectroradiometer.
2) The comparison lamps were BN-9101-234, BN-9101-244, BN-9101-251, BN-9101-260
3) Lamp BN-9101-234 remained at NIST as a comparison check standard.
4) All the lamps were measured 3 times in 3 different test positions.
5) First, all the lamps were measured in the IR region (800 to 2400 nm) and UV-VIS region (250 to 900 nm).
6) Next, the FIR region (2300 to 2500 nm) was measured.
7) The filter radiometers (FR1, FR2, FR4) were used to measure the spectral irradiance of the HTBB at the beginning of the measurements and repeated after each set of four lamps was measured. The absolute pyrometer (AP1) was used to measure the temperature of the HTBB as an additional check of the temperature assigned by the group of filter radiometers.
8) The lamps were measured at a distance of 49.94 cm and corrected to 50 cm using Equation (11-1).

11.6 Uncertainty determination

Table 11-3 lists the sources of uncertainty in the spectral irradiance measurement. This table also distinguishes those uncertainties that are correlated for all measurements of the lamp and those uncertainties that are entirely uncorrelated. For these measurements there were no sources of uncertainty that were correlated within a round but not between rounds.

Table 11-3 NIST Spectral Irradiance Scale Uncertainty (k = 1) [%]

Source of uncertainty				Wavelength [nm]										
Type	Correlated	Uncorrelated		250	350	450	550	650	900	1600	2000	2300	2400	2500
B	X		B1) HTBB Temperature Uncertainty (0.43 K at 2950 K)	0.284	0.203	0.158	0.129	0.109	0.079	0.047	0.039	0.034	0.034	0.034
B	X		B2) HTBB spectral emissivity	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
B	X		B3) HTBB spatial uniformity	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
B	X		B4) Geometric Factors in Irradiance Transfer	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
B		X	B5) Lamp Current Stability	0.033	0.024	0.020	0.015	0.015	0.010	0.010	0.005	0.005	0.005	0.005
B	X		B6) Wavelength accuracy (0.05 nm)	0.290	0.128	0.065	0.035	0.019	0.003	0.006	0.007	0.006	0.006	0.006
B		X	B7) Long-term stability of working standards	0.655	0.468	0.364	0.298	0.252	0.182	0.102	0.082	0.071	0.068	0.066
			Total Type B	**0.78**	**0.53**	**0.41**	**0.34**	**0.29**	**0.22**	**0.14**	**0.13**	**0.12**	**0.12**	**0.11**
A		X	A1) HTBB temporal stability (0.05 K / hour)	0.033	0.024	0.018	0.015	0.013	0.009	0.005	0.005	0.004	0.004	0.004
A		X	A2) Lamp / Spectroradiometer transfer	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
A		X	A3) Spectroradiometer Responsivity Stability	0.155	0.095	0.085	0.085	0.085	0.065	0.060	0.105	0.215	0.270	0.510
			Total type A	**0.17**	**0.11**	**0.10**	**0.10**	**0.10**	**0.08**	**0.08**	**0.12**	**0.22**	**0.27**	**0.51**
			Total (A+B) (*k* =1)	**0.79**	**0.54**	**0.42**	**0.35**	**0.31**	**0.23**	**0.16**	**0.17**	**0.25**	**0.30**	**0.52**
			Uncertainty of the issued standards Total (A+B) (*k* = 2)	1.59	1.09	0.85	0.71	0.61	0.46	0.33	0.34	0.50	0.60	1.05

11.7 NIST Results

NIST measured three lamps for the comparison. The results for FEL BN 9101 244 are given in Table 11-4 and the results for FEL BN 9101 251 are given in Table 11-5 and the results for FEL BN 9101 260 are given in Table 11-6.

Table 11-4 NIST Results for FEL BN 9101 244. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1. The first round measurements of this lamp have been ignored, as described in Section 11.9.

FEL 244	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250						1.345E-04	0.68 %	0.00 %	0.42 %	0.80 %
260						2.377E-04	0.67 %	0.00 %	0.36 %	0.77 %
270						3.993E-04	0.67 %	0.00 %	0.32 %	0.75 %
280						6.328E-04	0.67 %	0.00 %	0.24 %	0.72 %
290						9.647E-04	0.67 %	0.00 %	0.18 %	0.69 %
300						1.410E-03	0.49 %	0.00 %	0.46 %	0.67 %
310						2.010E-03	0.49 %	0.00 %	0.42 %	0.64 %
320						2.764E-03	0.49 %	0.00 %	0.39 %	0.62 %
330						3.723E-03	0.48 %	0.00 %	0.34 %	0.59 %
340						4.907E-03	0.48 %	0.00 %	0.31 %	0.57 %
350						6.306E-03	0.48 %	0.00 %	0.27 %	0.55 %
360						7.996E-03	0.48 %	0.00 %	0.23 %	0.53 %
370						9.960E-03	0.48 %	0.00 %	0.20 %	0.52 %
380						1.220E-02	0.48 %	0.00 %	0.17 %	0.51 %
390						1.477E-02	0.48 %	0.00 %	0.10 %	0.49 %
400						1.764E-02	0.48 %	0.00 %	0.04 %	0.48 %
450						3.600E-02	0.38 %	0.00 %	0.19 %	0.42 %
500						6.050E-02	0.38 %	0.00 %	0.11 %	0.39 %
550						8.744E-02	0.31 %	0.00 %	0.16 %	0.35 %
555						9.065E-02	0.31 %	0.00 %	0.16 %	0.35 %
600						1.153E-01	0.31 %	0.00 %	0.09 %	0.33 %
650						1.402E-01	0.27 %	0.00 %	0.14 %	0.31 %
700						1.611E-01	0.27 %	0.00 %	0.10 %	0.29 %
750						1.769E-01	0.27 %	0.00 %	0.06 %	0.28 %
800						1.890E-01	0.22 %	0.00 %	0.13 %	0.26 %
850						1.950E-01	0.22 %	0.00 %	0.11 %	0.25 %
900						1.977E-01	0.20 %	0.00 %	0.12 %	0.24 %
950						1.974E-01	0.20 %	0.00 %	0.10 %	0.23 %
1000						1.942E-01	0.20 %	0.00 %	0.08 %	0.22 %
1100						1.823E-01	0.20 %	0.00 %	0.05 %	0.21 %
1200						1.665E-01	0.18 %	0.00 %	0.08 %	0.20 %
1300						1.494E-01	0.17 %	0.00 %	0.08 %	0.19 %
1400						1.322E-01	0.16 %	0.00 %	0.08 %	0.18 %
1500						1.165E-01	0.15 %	0.00 %	0.07 %	0.17 %
1600						1.018E-01	0.13 %	0.00 %	0.10 %	0.16 %
1700						8.911E-02	0.14 %	0.00 %	0.10 %	0.17 %
1800						7.781E-02	0.14 %	0.00 %	0.08 %	0.16 %
1900						6.797E-02	0.15 %	0.00 %	0.08 %	0.17 %
2000						5.929E-02	0.14 %	0.00 %	0.10 %	0.17 %
2100						5.160E-02	0.17 %	0.00 %	0.09 %	0.19 %
2200						4.597E-02	0.20 %	0.00 %	0.09 %	0.22 %
2300						4.034E-02	0.23 %	0.00 %	0.10 %	0.25 %

2400						3.491E-02	0.28 %	0.00 %	0.10 %	0.30 %
2500						3.104E-02	0.51 %	0.00 %	0.10 %	0.52 %

Table 11-5 NIST Results for FEL BN 9101 251. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 251	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.222E-04	0.68 %	0.00 %	0.42 %	0.80 %	1.204E-04	0.68 %	0.00 %	0.42 %	0.80 %
260	2.187E-04	0.67 %	0.00 %	0.36 %	0.77 %	2.136E-04	0.67 %	0.00 %	0.36 %	0.77 %
270	3.662E-04	0.67 %	0.00 %	0.32 %	0.75 %	3.609E-04	0.67 %	0.00 %	0.32 %	0.75 %
280	5.840E-04	0.67 %	0.00 %	0.24 %	0.72 %	5.760E-04	0.67 %	0.00 %	0.24 %	0.72 %
290	8.909E-04	0.67 %	0.00 %	0.18 %	0.69 %	8.787E-04	0.67 %	0.00 %	0.18 %	0.69 %
300	1.307E-03	0.49 %	0.00 %	0.46 %	0.67 %	1.293E-03	0.49 %	0.00 %	0.46 %	0.67 %
310	1.862E-03	0.49 %	0.00 %	0.42 %	0.64 %	1.849E-03	0.49 %	0.00 %	0.42 %	0.64 %
320	2.581E-03	0.49 %	0.00 %	0.39 %	0.62 %	2.552E-03	0.49 %	0.00 %	0.39 %	0.62 %
330	3.489E-03	0.48 %	0.00 %	0.34 %	0.59 %	3.438E-03	0.48 %	0.00 %	0.34 %	0.59 %
340	4.580E-03	0.48 %	0.00 %	0.31 %	0.57 %	4.540E-03	0.48 %	0.00 %	0.31 %	0.57 %
350	5.936E-03	0.48 %	0.00 %	0.27 %	0.55 %	5.850E-03	0.48 %	0.00 %	0.27 %	0.55 %
360	7.512E-03	0.48 %	0.00 %	0.23 %	0.53 %	7.432E-03	0.48 %	0.00 %	0.23 %	0.53 %
370	9.380E-03	0.48 %	0.00 %	0.20 %	0.52 %	9.290E-03	0.48 %	0.00 %	0.20 %	0.52 %
380	1.146E-02	0.48 %	0.00 %	0.17 %	0.51 %	1.140E-02	0.48 %	0.00 %	0.17 %	0.51 %
390	1.391E-02	0.48 %	0.00 %	0.10 %	0.49 %	1.385E-02	0.48 %	0.00 %	0.10 %	0.49 %
400	1.663E-02	0.48 %	0.00 %	0.04 %	0.48 %	1.653E-02	0.48 %	0.00 %	0.04 %	0.48 %
450	3.466E-02	0.38 %	0.00 %	0.19 %	0.42 %	3.418E-02	0.38 %	0.00 %	0.19 %	0.42 %
500	5.810E-02	0.38 %	0.00 %	0.11 %	0.39 %	5.771E-02	0.38 %	0.00 %	0.11 %	0.39 %
550	8.466E-02	0.31 %	0.00 %	0.16 %	0.35 %	8.422E-02	0.31 %	0.00 %	0.16 %	0.35 %
555	8.772E-02	0.31 %	0.00 %	0.16 %	0.35 %	8.716E-02	0.31 %	0.00 %	0.16 %	0.35 %
600	1.116E-01	0.31 %	0.00 %	0.09 %	0.33 %	1.112E-01	0.31 %	0.00 %	0.09 %	0.33 %
650	1.366E-01	0.27 %	0.00 %	0.14 %	0.31 %	1.361E-01	0.27 %	0.00 %	0.14 %	0.31 %
700	1.573E-01	0.27 %	0.00 %	0.10 %	0.29 %	1.566E-01	0.27 %	0.00 %	0.10 %	0.29 %
750	1.734E-01	0.27 %	0.00 %	0.06 %	0.28 %	1.730E-01	0.27 %	0.00 %	0.06 %	0.28 %
800	1.852E-01	0.22 %	0.00 %	0.13 %	0.26 %	1.849E-01	0.22 %	0.00 %	0.13 %	0.26 %
850	1.917E-01	0.22 %	0.00 %	0.11 %	0.25 %	1.912E-01	0.22 %	0.00 %	0.11 %	0.25 %
900	1.951E-01	0.20 %	0.00 %	0.12 %	0.24 %	1.944E-01	0.20 %	0.00 %	0.12 %	0.24 %
950	1.948E-01	0.20 %	0.00 %	0.10 %	0.23 %	1.943E-01	0.20 %	0.00 %	0.10 %	0.23 %
1000	1.919E-01	0.20 %	0.00 %	0.08 %	0.22 %	1.913E-01	0.20 %	0.00 %	0.08 %	0.22 %
1100	1.805E-01	0.20 %	0.00 %	0.05 %	0.21 %	1.802E-01	0.20 %	0.00 %	0.05 %	0.21 %
1200	1.650E-01	0.18 %	0.00 %	0.08 %	0.20 %	1.648E-01	0.18 %	0.00 %	0.08 %	0.20 %
1300	1.481E-01	0.17 %	0.00 %	0.08 %	0.19 %	1.479E-01	0.17 %	0.00 %	0.08 %	0.19 %
1400	1.309E-01	0.16 %	0.00 %	0.08 %	0.18 %	1.312E-01	0.16 %	0.00 %	0.08 %	0.18 %
1500	1.155E-01	0.15 %	0.00 %	0.07 %	0.17 %	1.154E-01	0.15 %	0.00 %	0.07 %	0.17 %
1600	1.011E-01	0.13 %	0.00 %	0.10 %	0.16 %	1.011E-01	0.13 %	0.00 %	0.10 %	0.16 %
1700	8.847E-02	0.14 %	0.00 %	0.10 %	0.17 %	8.839E-02	0.14 %	0.00 %	0.10 %	0.17 %
1800	7.717E-02	0.14 %	0.00 %	0.08 %	0.16 %	7.714E-02	0.14 %	0.00 %	0.08 %	0.16 %
1900	6.746E-02	0.15 %	0.00 %	0.08 %	0.17 %	6.765E-02	0.15 %	0.00 %	0.08 %	0.17 %
2000	5.895E-02	0.14 %	0.00 %	0.10 %	0.17 %	5.890E-02	0.14 %	0.00 %	0.10 %	0.17 %
2100	5.146E-02	0.17 %	0.00 %	0.09 %	0.19 %	5.150E-02	0.17 %	0.00 %	0.09 %	0.19 %
2200	4.518E-02	0.20 %	0.00 %	0.09 %	0.22 %	4.555E-02	0.20 %	0.00 %	0.09 %	0.22 %
2300	3.970E-02	0.23 %	0.00 %	0.10 %	0.25 %	3.993E-02	0.23 %	0.00 %	0.10 %	0.25 %
2400	3.511E-02	0.28 %	0.00 %	0.10 %	0.30 %	3.501E-02	0.28 %	0.00 %	0.10 %	0.30 %
2500	3.004E-02	0.51 %	0.00 %	0.10 %	0.52 %	3.011E-02	0.51 %	0.00 %	0.10 %	0.52 %

Table 11-6 NIST Results for FEL BN 9101 260. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 260	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.419E-04	0.68 %	0.00 %	0.42 %	0.80 %	1.388E-04	0.68 %	0.00 %	0.42 %	0.80 %
260	2.509E-04	0.67 %	0.00 %	0.36 %	0.77 %	2.453E-04	0.67 %	0.00 %	0.36 %	0.77 %
270	4.182E-04	0.67 %	0.00 %	0.32 %	0.75 %	4.094E-04	0.67 %	0.00 %	0.32 %	0.75 %
280	6.496E-04	0.67 %	0.00 %	0.24 %	0.72 %	6.379E-04	0.67 %	0.00 %	0.24 %	0.72 %
290	1.002E-03	0.67 %	0.00 %	0.18 %	0.69 %	9.874E-04	0.67 %	0.00 %	0.18 %	0.69 %
300	1.466E-03	0.49 %	0.00 %	0.46 %	0.67 %	1.447E-03	0.49 %	0.00 %	0.46 %	0.67 %
310	2.091E-03	0.49 %	0.00 %	0.42 %	0.64 %	2.060E-03	0.49 %	0.00 %	0.42 %	0.64 %
320	2.862E-03	0.49 %	0.00 %	0.39 %	0.62 %	2.831E-03	0.49 %	0.00 %	0.39 %	0.62 %
330	3.844E-03	0.48 %	0.00 %	0.34 %	0.59 %	3.803E-03	0.48 %	0.00 %	0.34 %	0.59 %
340	5.064E-03	0.48 %	0.00 %	0.31 %	0.57 %	5.002E-03	0.48 %	0.00 %	0.31 %	0.57 %
350	6.523E-03	0.48 %	0.00 %	0.27 %	0.55 %	6.448E-03	0.48 %	0.00 %	0.27 %	0.55 %
360	8.226E-03	0.48 %	0.00 %	0.23 %	0.53 %	8.172E-03	0.48 %	0.00 %	0.23 %	0.53 %
370	1.026E-02	0.48 %	0.00 %	0.20 %	0.52 %	1.015E-02	0.48 %	0.00 %	0.20 %	0.52 %
380	1.252E-02	0.48 %	0.00 %	0.17 %	0.51 %	1.243E-02	0.48 %	0.00 %	0.17 %	0.51 %
390	1.518E-02	0.48 %	0.00 %	0.10 %	0.49 %	1.509E-02	0.48 %	0.00 %	0.10 %	0.49 %
400	1.814E-02	0.48 %	0.00 %	0.04 %	0.48 %	1.800E-02	0.48 %	0.00 %	0.04 %	0.48 %
450	3.716E-02	0.38 %	0.00 %	0.19 %	0.42 %	3.673E-02	0.38 %	0.00 %	0.19 %	0.42 %
500	6.222E-02	0.38 %	0.00 %	0.11 %	0.39 %	6.168E-02	0.38 %	0.00 %	0.11 %	0.39 %
550	9.010E-02	0.31 %	0.00 %	0.16 %	0.35 %	8.954E-02	0.31 %	0.00 %	0.16 %	0.35 %
555	9.327E-02	0.31 %	0.00 %	0.16 %	0.35 %	9.261E-02	0.31 %	0.00 %	0.16 %	0.35 %
600	1.185E-01	0.31 %	0.00 %	0.09 %	0.33 %	1.177E-01	0.31 %	0.00 %	0.09 %	0.33 %
650	1.442E-01	0.27 %	0.00 %	0.14 %	0.31 %	1.437E-01	0.27 %	0.00 %	0.14 %	0.31 %
700	1.662E-01	0.27 %	0.00 %	0.10 %	0.29 %	1.649E-01	0.27 %	0.00 %	0.10 %	0.29 %
750	1.822E-01	0.27 %	0.00 %	0.06 %	0.28 %	1.814E-01	0.27 %	0.00 %	0.06 %	0.28 %
800	1.938E-01	0.22 %	0.00 %	0.13 %	0.26 %	1.936E-01	0.22 %	0.00 %	0.13 %	0.26 %
850	2.009E-01	0.22 %	0.00 %	0.11 %	0.25 %	2.000E-01	0.22 %	0.00 %	0.11 %	0.25 %
900	2.035E-01	0.20 %	0.00 %	0.12 %	0.24 %	2.030E-01	0.20 %	0.00 %	0.12 %	0.24 %
950	2.030E-01	0.20 %	0.00 %	0.10 %	0.23 %	2.026E-01	0.20 %	0.00 %	0.10 %	0.23 %
1000	1.997E-01	0.20 %	0.00 %	0.08 %	0.22 %	1.992E-01	0.20 %	0.00 %	0.08 %	0.22 %
1100	1.877E-01	0.20 %	0.00 %	0.05 %	0.21 %	1.872E-01	0.20 %	0.00 %	0.05 %	0.21 %
1200	1.712E-01	0.18 %	0.00 %	0.08 %	0.20 %	1.710E-01	0.18 %	0.00 %	0.08 %	0.20 %
1300	1.534E-01	0.17 %	0.00 %	0.08 %	0.19 %	1.533E-01	0.17 %	0.00 %	0.08 %	0.19 %
1400	1.357E-01	0.16 %	0.00 %	0.08 %	0.18 %	1.360E-01	0.16 %	0.00 %	0.08 %	0.18 %
1500	1.196E-01	0.15 %	0.00 %	0.07 %	0.17 %	1.195E-01	0.15 %	0.00 %	0.07 %	0.17 %
1600	1.046E-01	0.13 %	0.00 %	0.10 %	0.16 %	1.046E-01	0.13 %	0.00 %	0.10 %	0.16 %
1700	9.149E-02	0.14 %	0.00 %	0.10 %	0.17 %	9.147E-02	0.14 %	0.00 %	0.10 %	0.17 %
1800	7.983E-02	0.14 %	0.00 %	0.08 %	0.16 %	7.985E-02	0.14 %	0.00 %	0.08 %	0.16 %
1900	6.957E-02	0.15 %	0.00 %	0.08 %	0.17 %	7.000E-02	0.15 %	0.00 %	0.08 %	0.17 %
2000	6.092E-02	0.14 %	0.00 %	0.10 %	0.17 %	6.083E-02	0.14 %	0.00 %	0.10 %	0.17 %
2100	5.301E-02	0.17 %	0.00 %	0.09 %	0.19 %	5.322E-02	0.17 %	0.00 %	0.09 %	0.19 %
2200	4.677E-02	0.20 %	0.00 %	0.09 %	0.22 %	4.692E-02	0.20 %	0.00 %	0.09 %	0.22 %
2300	4.122E-02	0.23 %	0.00 %	0.10 %	0.25 %	4.118E-02	0.23 %	0.00 %	0.10 %	0.25 %
2400	3.629E-02	0.28 %	0.00 %	0.10 %	0.30 %	3.605E-02	0.28 %	0.00 %	0.10 %	0.30 %
2500	3.190E-02	0.51 %	0.00 %	0.10 %	0.52 %	3.232E-02	0.51 %	0.00 %	0.10 %	0.52 %

11.8 Pilot Results

NPL's results for FEL BN 9101 244 are given in Table 11-7 and the results for FEL BN 9101 251 are given in Table 11-8 and the results for FEL BN 9101 260 are given in Table 11-9.

Table 11-7 NPL Results for FEL BN 9101 244. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 244	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.355E-04	0.38 %	0.48 %	2.00 %	2.09 %	1.363E-04	0.65 %	0.45 %	2.00 %	2.15 %
260	2.376E-04	0.30 %	0.46 %	2.00 %	2.07 %	2.386E-04	0.49 %	0.43 %	2.00 %	2.10 %
270	3.955E-04	0.24 %	0.44 %	2.00 %	2.06 %	3.965E-04	0.38 %	0.41 %	2.00 %	2.08 %
280	6.284E-04	0.21 %	0.43 %	1.50 %	1.57 %	6.294E-04	0.30 %	0.40 %	1.50 %	1.58 %
290	9.587E-04	0.18 %	0.41 %	1.00 %	1.10 %	9.592E-04	0.25 %	0.38 %	1.00 %	1.10 %
300	1.411E-03	0.17 %	0.40 %	0.25 %	0.50 %	1.410E-03	0.22 %	0.37 %	0.25 %	0.50 %
310	2.010E-03	0.16 %	0.39 %	0.28 %	0.50 %	2.008E-03	0.20 %	0.36 %	0.28 %	0.50 %
320	2.782E-03	0.15 %	0.37 %	0.25 %	0.47 %	2.778E-03	0.18 %	0.35 %	0.25 %	0.47 %
330	3.752E-03	0.14 %	0.36 %	0.28 %	0.48 %	3.746E-03	0.17 %	0.34 %	0.28 %	0.47 %
340	4.945E-03	0.14 %	0.35 %	0.33 %	0.50 %	4.936E-03	0.16 %	0.33 %	0.33 %	0.49 %
350	6.381E-03	0.13 %	0.34 %	0.36 %	0.51 %	6.369E-03	0.16 %	0.32 %	0.36 %	0.51 %
360	8.080E-03	0.13 %	0.33 %	0.43 %	0.56 %	8.063E-03	0.15 %	0.31 %	0.43 %	0.55 %
370	1.005E-02	0.13 %	0.32 %	0.46 %	0.58 %	1.003E-02	0.15 %	0.30 %	0.46 %	0.57 %
380	1.232E-02	0.12 %	0.31 %	0.52 %	0.62 %	1.229E-02	0.14 %	0.29 %	0.52 %	0.61 %
390	1.487E-02	0.12 %	0.31 %	0.50 %	0.60 %	1.485E-02	0.14 %	0.29 %	0.50 %	0.59 %
400	1.773E-02	0.12 %	0.30 %	0.46 %	0.56 %	1.770E-02	0.14 %	0.28 %	0.46 %	0.56 %
450	3.626E-02	0.11 %	0.27 %	0.10 %	0.30 %	3.624E-02	0.13 %	0.25 %	0.10 %	0.30 %
500	6.055E-02	0.10 %	0.24 %	0.01 %	0.26 %	6.058E-02	0.12 %	0.22 %	0.01 %	0.25 %
550	8.790E-02	0.09 %	0.22 %	0.00 %	0.24 %	8.797E-02	0.11 %	0.20 %	0.00 %	0.23 %
555	9.068E-02	0.09 %	0.22 %	0.00 %	0.23 %	9.076E-02	0.11 %	0.20 %	0.00 %	0.23 %
600	1.153E-01	0.09 %	0.20 %	0.00 %	0.22 %	1.155E-01	0.10 %	0.19 %	0.00 %	0.21 %
650	1.405E-01	0.08 %	0.18 %	0.00 %	0.20 %	1.406E-01	0.10 %	0.17 %	0.00 %	0.20 %
700	1.616E-01	0.08 %	0.17 %	0.00 %	0.19 %	1.617E-01	0.09 %	0.16 %	0.00 %	0.18 %
750	1.779E-01	0.08 %	0.16 %	0.01 %	0.18 %	1.780E-01	0.09 %	0.15 %	0.01 %	0.17 %
800	1.893E-01	0.07 %	0.15 %	0.00 %	0.17 %	1.894E-01	0.08 %	0.14 %	0.00 %	0.16 %
850	1.960E-01	0.07 %	0.14 %	0.00 %	0.16 %	1.963E-01	0.08 %	0.13 %	0.00 %	0.15 %
900	1.988E-01	0.07 %	0.13 %	0.00 %	0.15 %	1.992E-01	0.08 %	0.12 %	0.00 %	0.15 %
950	1.983E-01	0.07 %	0.13 %	0.01 %	0.14 %	1.989E-01	0.08 %	0.12 %	0.01 %	0.14 %
1000	1.951E-01	0.06 %	0.12 %	0.01 %	0.14 %	1.959E-01	0.08 %	0.11 %	0.01 %	0.14 %
1100	1.834E-01	0.07 %	0.11 %	0.01 %	0.13 %	1.845E-01	0.09 %	0.10 %	0.01 %	0.14 %
1200	1.676E-01	0.07 %	0.10 %	0.02 %	0.13 %	1.688E-01	0.10 %	0.09 %	0.02 %	0.14 %
1300	1.503E-01	0.08 %	0.09 %	0.00 %	0.13 %	1.514E-01	0.10 %	0.09 %	0.00 %	0.13 %
1400	1.331E-01	0.09 %	0.09 %	0.01 %	0.13 %	1.341E-01	0.10 %	0.08 %	0.01 %	0.13 %
1500	1.171E-01	0.09 %	0.08 %	0.01 %	0.12 %	1.179E-01	0.10 %	0.08 %	0.01 %	0.13 %
1600	1.027E-01	0.09 %	0.08 %	0.01 %	0.12 %	1.033E-01	0.10 %	0.07 %	0.01 %	0.12 %
1700	8.995E-02	0.11 %	0.07 %	0.01 %	0.13 %	9.034E-02	0.12 %	0.07 %	0.01 %	0.14 %
1800	7.872E-02	0.14 %	0.07 %	0.02 %	0.16 %	7.891E-02	0.15 %	0.07 %	0.02 %	0.17 %
1900	6.875E-02	0.17 %	0.07 %	0.02 %	0.18 %	6.880E-02	0.17 %	0.06 %	0.02 %	0.19 %
2000	5.996E-02	0.19 %	0.07 %	0.05 %	0.21 %	5.994E-02	0.19 %	0.06 %	0.05 %	0.21 %
2100	5.236E-02	0.18 %	0.06 %	0.02 %	0.20 %	5.236E-02	0.17 %	0.06 %	0.02 %	0.18 %
2200	4.593E-02	0.20 %	0.06 %	0.00 %	0.21 %	4.601E-02	0.15 %	0.06 %	0.00 %	0.16 %
2300	4.041E-02	0.22 %	0.06 %	0.01 %	0.23 %	4.060E-02	0.19 %	0.06 %	0.01 %	0.20 %
2400	3.547E-02	0.34 %	0.06 %	0.07 %	0.35 %	3.570E-02	0.20 %	0.05 %	0.07 %	0.22 %
2500	3.145E-02	0.43 %	0.06 %	0.05 %	0.43 %	3.158E-02	0.20 %	0.05 %	0.05 %	0.21 %

Table 11-8 NPL Results for FEL BN 9101 251. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 251	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.225E-04	0.65 %	0.48 %	2.00 %	2.16 %	1.239E-04	0.64 %	0.45 %	2.00 %	2.15 %
260	2.155E-04	0.49 %	0.46 %	2.00 %	2.11 %	2.170E-04	0.49 %	0.43 %	2.00 %	2.10 %
270	3.598E-04	0.38 %	0.44 %	2.00 %	2.08 %	3.612E-04	0.37 %	0.41 %	2.00 %	2.08 %
280	5.735E-04	0.31 %	0.43 %	1.50 %	1.59 %	5.743E-04	0.30 %	0.40 %	1.50 %	1.58 %
290	8.775E-04	0.26 %	0.41 %	1.00 %	1.11 %	8.773E-04	0.25 %	0.38 %	1.00 %	1.10 %
300	1.295E-03	0.23 %	0.40 %	0.25 %	0.53 %	1.293E-03	0.22 %	0.37 %	0.25 %	0.50 %
310	1.849E-03	0.22 %	0.39 %	0.28 %	0.52 %	1.846E-03	0.20 %	0.36 %	0.28 %	0.50 %
320	2.566E-03	0.20 %	0.37 %	0.25 %	0.49 %	2.561E-03	0.18 %	0.35 %	0.25 %	0.47 %
330	3.470E-03	0.19 %	0.36 %	0.28 %	0.49 %	3.463E-03	0.17 %	0.34 %	0.28 %	0.47 %
340	4.583E-03	0.18 %	0.35 %	0.33 %	0.51 %	4.575E-03	0.16 %	0.33 %	0.33 %	0.49 %
350	5.927E-03	0.17 %	0.34 %	0.36 %	0.52 %	5.919E-03	0.15 %	0.32 %	0.36 %	0.50 %
360	7.519E-03	0.16 %	0.33 %	0.43 %	0.57 %	7.513E-03	0.15 %	0.31 %	0.43 %	0.55 %
370	9.376E-03	0.15 %	0.32 %	0.46 %	0.58 %	9.373E-03	0.14 %	0.30 %	0.46 %	0.57 %
380	1.151E-02	0.15 %	0.31 %	0.52 %	0.63 %	1.151E-02	0.14 %	0.29 %	0.52 %	0.61 %
390	1.392E-02	0.15 %	0.31 %	0.50 %	0.60 %	1.394E-02	0.14 %	0.29 %	0.50 %	0.59 %
400	1.662E-02	0.15 %	0.30 %	0.46 %	0.57 %	1.665E-02	0.14 %	0.28 %	0.46 %	0.56 %
450	3.428E-02	0.15 %	0.27 %	0.10 %	0.32 %	3.443E-02	0.13 %	0.25 %	0.10 %	0.30 %
500	5.766E-02	0.14 %	0.24 %	0.01 %	0.28 %	5.800E-02	0.12 %	0.22 %	0.01 %	0.25 %
550	8.424E-02	0.12 %	0.22 %	0.00 %	0.25 %	8.475E-02	0.11 %	0.20 %	0.00 %	0.23 %
555	8.696E-02	0.12 %	0.22 %	0.00 %	0.25 %	8.749E-02	0.11 %	0.20 %	0.00 %	0.23 %
600	1.112E-01	0.11 %	0.20 %	0.00 %	0.23 %	1.118E-01	0.10 %	0.19 %	0.00 %	0.21 %
650	1.360E-01	0.11 %	0.18 %	0.00 %	0.21 %	1.367E-01	0.10 %	0.17 %	0.00 %	0.20 %
700	1.571E-01	0.10 %	0.17 %	0.00 %	0.20 %	1.578E-01	0.09 %	0.16 %	0.00 %	0.18 %
750	1.736E-01	0.10 %	0.16 %	0.01 %	0.19 %	1.743E-01	0.09 %	0.15 %	0.01 %	0.17 %
800	1.852E-01	0.09 %	0.15 %	0.00 %	0.18 %	1.860E-01	0.09 %	0.14 %	0.00 %	0.16 %
850	1.923E-01	0.09 %	0.14 %	0.00 %	0.17 %	1.931E-01	0.08 %	0.13 %	0.00 %	0.16 %
900	1.953E-01	0.09 %	0.13 %	0.00 %	0.16 %	1.963E-01	0.08 %	0.12 %	0.00 %	0.15 %
950	1.950E-01	0.09 %	0.13 %	0.01 %	0.15 %	1.961E-01	0.08 %	0.12 %	0.01 %	0.14 %
1000	1.922E-01	0.09 %	0.12 %	0.01 %	0.15 %	1.933E-01	0.09 %	0.11 %	0.01 %	0.14 %
1100	1.810E-01	0.11 %	0.11 %	0.01 %	0.16 %	1.821E-01	0.09 %	0.10 %	0.01 %	0.14 %
1200	1.658E-01	0.13 %	0.10 %	0.02 %	0.17 %	1.667E-01	0.10 %	0.09 %	0.02 %	0.14 %
1300	1.489E-01	0.16 %	0.09 %	0.00 %	0.18 %	1.496E-01	0.11 %	0.09 %	0.00 %	0.14 %
1400	1.321E-01	0.17 %	0.09 %	0.01 %	0.20 %	1.327E-01	0.11 %	0.08 %	0.01 %	0.13 %
1500	1.163E-01	0.17 %	0.08 %	0.01 %	0.19 %	1.167E-01	0.10 %	0.08 %	0.01 %	0.13 %
1600	1.020E-01	0.17 %	0.08 %	0.01 %	0.18 %	1.022E-01	0.10 %	0.07 %	0.01 %	0.12 %
1700	8.933E-02	0.22 %	0.07 %	0.01 %	0.23 %	8.940E-02	0.11 %	0.07 %	0.01 %	0.13 %
1800	7.817E-02	0.29 %	0.07 %	0.02 %	0.30 %	7.810E-02	0.13 %	0.07 %	0.02 %	0.15 %
1900	6.832E-02	0.35 %	0.07 %	0.02 %	0.36 %	6.820E-02	0.14 %	0.06 %	0.02 %	0.16 %
2000	5.967E-02	0.40 %	0.07 %	0.05 %	0.41 %	5.954E-02	0.16 %	0.06 %	0.05 %	0.18 %
2100	5.218E-02	0.39 %	0.06 %	0.02 %	0.39 %	5.205E-02	0.16 %	0.06 %	0.02 %	0.17 %
2200	4.579E-02	0.42 %	0.06 %	0.00 %	0.42 %	4.569E-02	0.14 %	0.06 %	0.00 %	0.16 %
2300	4.026E-02	0.48 %	0.06 %	0.01 %	0.48 %	4.031E-02	0.19 %	0.06 %	0.01 %	0.20 %
2400	3.534E-02	0.76 %	0.06 %	0.07 %	0.77 %	3.562E-02	0.27 %	0.05 %	0.07 %	0.28 %
2500	3.140E-02	0.61 %	0.06 %	0.05 %	0.62 %	3.136E-02	0.16 %	0.05 %	0.05 %	0.18 %

Table 11-9 NPL Results for FEL BN 9101 260. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 260	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.409E-04	0.63 %	0.48 %	2.00 %	2.15 %	1.425E-04	0.59 %	0.45 %	2.00 %	2.13 %
260	2.460E-04	0.48 %	0.46 %	2.00 %	2.11 %	2.479E-04	0.45 %	0.43 %	2.00 %	2.09 %
270	4.079E-04	0.37 %	0.44 %	2.00 %	2.08 %	4.098E-04	0.35 %	0.41 %	2.00 %	2.07 %
280	6.462E-04	0.29 %	0.43 %	1.50 %	1.59 %	6.480E-04	0.28 %	0.40 %	1.50 %	1.58 %
290	9.836E-04	0.24 %	0.41 %	1.00 %	1.11 %	9.846E-04	0.24 %	0.38 %	1.00 %	1.10 %
300	1.445E-03	0.20 %	0.40 %	0.25 %	0.51 %	1.444E-03	0.21 %	0.37 %	0.25 %	0.49 %
310	2.055E-03	0.18 %	0.39 %	0.28 %	0.51 %	2.053E-03	0.19 %	0.36 %	0.28 %	0.50 %
320	2.842E-03	0.17 %	0.37 %	0.25 %	0.48 %	2.838E-03	0.18 %	0.35 %	0.25 %	0.46 %
330	3.830E-03	0.15 %	0.36 %	0.28 %	0.48 %	3.823E-03	0.17 %	0.34 %	0.28 %	0.47 %
340	5.044E-03	0.15 %	0.35 %	0.33 %	0.50 %	5.035E-03	0.16 %	0.33 %	0.33 %	0.49 %
350	6.506E-03	0.14 %	0.34 %	0.36 %	0.52 %	6.494E-03	0.15 %	0.32 %	0.36 %	0.50 %
360	8.234E-03	0.14 %	0.33 %	0.43 %	0.56 %	8.220E-03	0.15 %	0.31 %	0.43 %	0.55 %
370	1.024E-02	0.13 %	0.32 %	0.46 %	0.58 %	1.023E-02	0.14 %	0.30 %	0.46 %	0.57 %
380	1.255E-02	0.13 %	0.31 %	0.52 %	0.62 %	1.253E-02	0.14 %	0.29 %	0.52 %	0.61 %
390	1.515E-02	0.13 %	0.31 %	0.50 %	0.60 %	1.514E-02	0.14 %	0.29 %	0.50 %	0.59 %
400	1.805E-02	0.13 %	0.30 %	0.46 %	0.56 %	1.805E-02	0.13 %	0.28 %	0.46 %	0.55 %
450	3.693E-02	0.12 %	0.27 %	0.10 %	0.31 %	3.698E-02	0.13 %	0.25 %	0.10 %	0.30 %
500	6.171E-02	0.11 %	0.24 %	0.01 %	0.26 %	6.187E-02	0.12 %	0.22 %	0.01 %	0.25 %
550	8.963E-02	0.10 %	0.22 %	0.00 %	0.24 %	8.991E-02	0.11 %	0.20 %	0.00 %	0.23 %
555	9.247E-02	0.10 %	0.22 %	0.00 %	0.24 %	9.277E-02	0.10 %	0.20 %	0.00 %	0.23 %
600	1.177E-01	0.09 %	0.20 %	0.00 %	0.22 %	1.181E-01	0.10 %	0.19 %	0.00 %	0.21 %
650	1.434E-01	0.09 %	0.18 %	0.00 %	0.21 %	1.438E-01	0.09 %	0.17 %	0.00 %	0.20 %
700	1.652E-01	0.09 %	0.17 %	0.00 %	0.19 %	1.655E-01	0.09 %	0.16 %	0.00 %	0.18 %
750	1.820E-01	0.08 %	0.16 %	0.01 %	0.18 %	1.823E-01	0.08 %	0.15 %	0.01 %	0.17 %
800	1.938E-01	0.08 %	0.15 %	0.00 %	0.17 %	1.940E-01	0.08 %	0.14 %	0.00 %	0.16 %
850	2.009E-01	0.08 %	0.14 %	0.00 %	0.16 %	2.011E-01	0.08 %	0.13 %	0.00 %	0.15 %
900	2.039E-01	0.07 %	0.13 %	0.00 %	0.15 %	2.041E-01	0.08 %	0.12 %	0.00 %	0.15 %
950	2.034E-01	0.07 %	0.13 %	0.01 %	0.14 %	2.037E-01	0.08 %	0.12 %	0.01 %	0.14 %
1000	2.002E-01	0.07 %	0.12 %	0.01 %	0.14 %	2.006E-01	0.08 %	0.11 %	0.01 %	0.14 %
1100	1.883E-01	0.08 %	0.11 %	0.01 %	0.13 %	1.887E-01	0.09 %	0.10 %	0.01 %	0.13 %
1200	1.721E-01	0.09 %	0.10 %	0.02 %	0.14 %	1.727E-01	0.09 %	0.09 %	0.02 %	0.13 %
1300	1.544E-01	0.11 %	0.09 %	0.00 %	0.14 %	1.550E-01	0.09 %	0.09 %	0.00 %	0.13 %
1400	1.368E-01	0.12 %	0.09 %	0.01 %	0.15 %	1.374E-01	0.10 %	0.08 %	0.01 %	0.13 %
1500	1.203E-01	0.12 %	0.08 %	0.01 %	0.14 %	1.208E-01	0.09 %	0.08 %	0.01 %	0.12 %
1600	1.053E-01	0.12 %	0.08 %	0.01 %	0.14 %	1.057E-01	0.09 %	0.07 %	0.01 %	0.11 %
1700	9.210E-02	0.15 %	0.07 %	0.01 %	0.17 %	9.231E-02	0.10 %	0.07 %	0.01 %	0.12 %
1800	8.048E-02	0.18 %	0.07 %	0.02 %	0.20 %	8.052E-02	0.12 %	0.07 %	0.02 %	0.14 %
1900	7.030E-02	0.22 %	0.07 %	0.02 %	0.23 %	7.020E-02	0.13 %	0.06 %	0.02 %	0.15 %
2000	6.143E-02	0.25 %	0.07 %	0.05 %	0.26 %	6.118E-02	0.15 %	0.06 %	0.05 %	0.17 %
2100	5.377E-02	0.24 %	0.06 %	0.02 %	0.25 %	5.341E-02	0.14 %	0.06 %	0.02 %	0.16 %
2200	4.722E-02	0.26 %	0.06 %	0.00 %	0.27 %	4.681E-02	0.14 %	0.06 %	0.00 %	0.15 %
2300	4.156E-02	0.30 %	0.06 %	0.01 %	0.30 %	4.126E-02	0.18 %	0.06 %	0.01 %	0.19 %
2400	3.650E-02	0.45 %	0.06 %	0.07 %	0.46 %	3.651E-02	0.24 %	0.05 %	0.07 %	0.26 %
2500	3.206E-02	0.49 %	0.06 %	0.05 %	0.49 %	3.227E-02	0.23 %	0.05 %	0.05 %	0.24 %

11.9 Lamp Behaviour

11.9.1 NIST Lamps

NIST purchased the following four lamps from NPL to use in the comparison.

FEL BN 9101 234 FEL BN 9101 244 FEL BN 9101 251 FEL BN 9101 260

FEL BN 9101 234 remained at NIST serving as a comparison check standard and is therefore not considered part of this comparison.

Measurements were made in the sequence: NIST – NPL – NIST – NPL

There was an initial measurement of the lamps at NPL prior to this sequence, however the decision was made to ignore those results in light of the improvements made subsequently to the facility and hence to the measurement accuracy at NPL.

FEL BN 9101 244 was damaged at NPL during the first main measurement by being operated at reverse polarity. NPL re-aged the lamp with correct polarity and noticed a change of 0.5 % with an 800 nm filter radiometer monitoring the re-ageing, but which stabilised after the first 12 hours of re-ageing. After this the lamp was freshly calibrated and it is this calibration that is considered the first NPL calibration. Because of this change, for this lamp, only the last three measurements: NPL – NIST – NPL can be considered.

NIST measured all intercomparison wavelengths.

11.9.2 Lamp history

Table 11-10 Lamp history for FEL BN 9101 244

Date period	Activity	Burn hours:minutes
August – Sept. 2000	0th round measurements at NPL (not used)	13:55
September 2000	Hand-carried to NIST	
October 2000	1st round measurements at NIST (not useable)	6:16
November 2000	Hand-carried to NPL	
February – April 2002	Correct operation at NPL	3:22
	Operation in reverse polarity at NPL	5:25
	Re-ageing at NPL	27:18
	1st round measurements at NPL	11:07
May 2002	Hand-carried to NIST	
November 2003	2nd round measurements at NIST	5:06
November 2003	Hand-carried to NPL	
November 2003	2nd round measurements at NPL	9:00
March 2004	Hand-carried to NIST	

Table 11-11 Lamp history for FEL BN 9101 251

Date period	Activity	Burn hours:minutes
August – Sept. 2000	0th round measurements at NPL (not used)	10:13
September 2000	Hand-carried to NIST	
October 2000	1st round measurements at NIST	6:58
November 2000	Hand-carried to NPL	
Feb. – April 2002	1st round measurements at NPL	6:27
May 2002	Hand-carried to NIST	
November 2003	2nd round measurements at NIST	4:55
November 2003	Hand-carried to NPL	
November 2003	2nd round measurements at NPL	8:41
March 2004	Hand-carried to NIST	

Table 11-12 Lamp history for FEL BN 9101 260

Date period	Activity	Burn hours:minutes
August – Sept. 2000	0th round measurements at NPL (not used)	7:30
September 2000	Hand-carried to NIST	
October 2000	1st round measurements at NIST	6:40
November 2000	Hand-carried to NPL	
Feb. – April 2002	1st round measurements at NPL	8:04
May 2002	Hand-carried to NIST	
November 2003	2nd round measurements at NIST	5:17
November 2003	Hand-carried to NPL	
November 2003	2nd round measurements at NPL	8:55
March 2004	Hand-carried to NIST	

11.9.3 Lamp electrical stability

The lamp was operated at 8.100 A at both laboratories, the lamp voltage measured was:

Table 11-13 Electrical Potential across lamp as measured by both laboratories

Lamp	Potential first NIST measurement	Potential first NPL measurement	Potential second NIST measurement	Potential second NPL measurement
FEL BN 9101 244	N/A	107.15 V	107.22 V	107.22 V
FEL BN 9101 251	104.96 V	105.05 V	104.99 V	105.03 V
FEL BN 9101 260	106.05 V	106.09 V	105.97 V	106.07 V

11.9.4 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the NIST lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

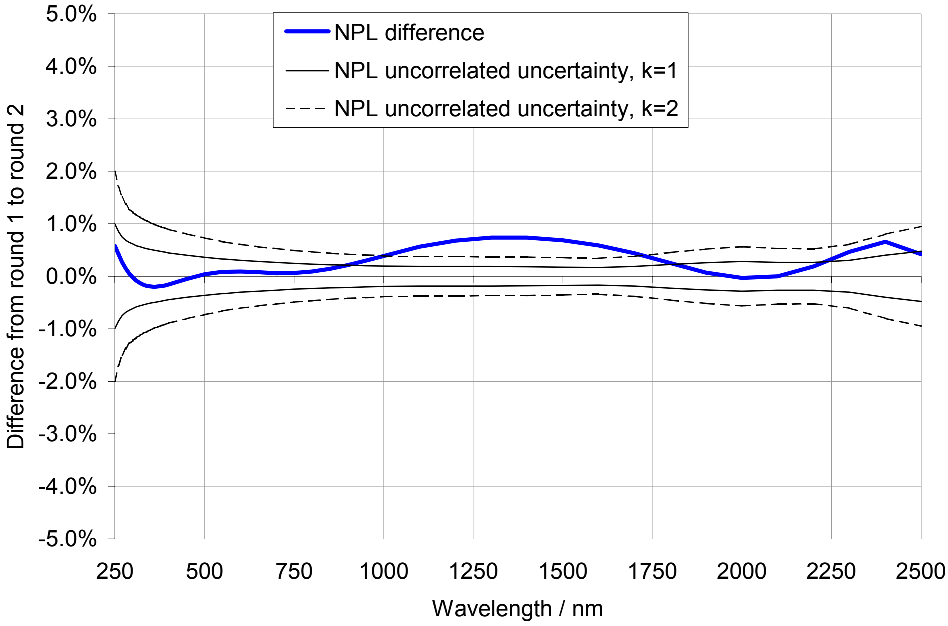

Figure 11-4 Difference between first and second round measurements of FEL BN 9101 244 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

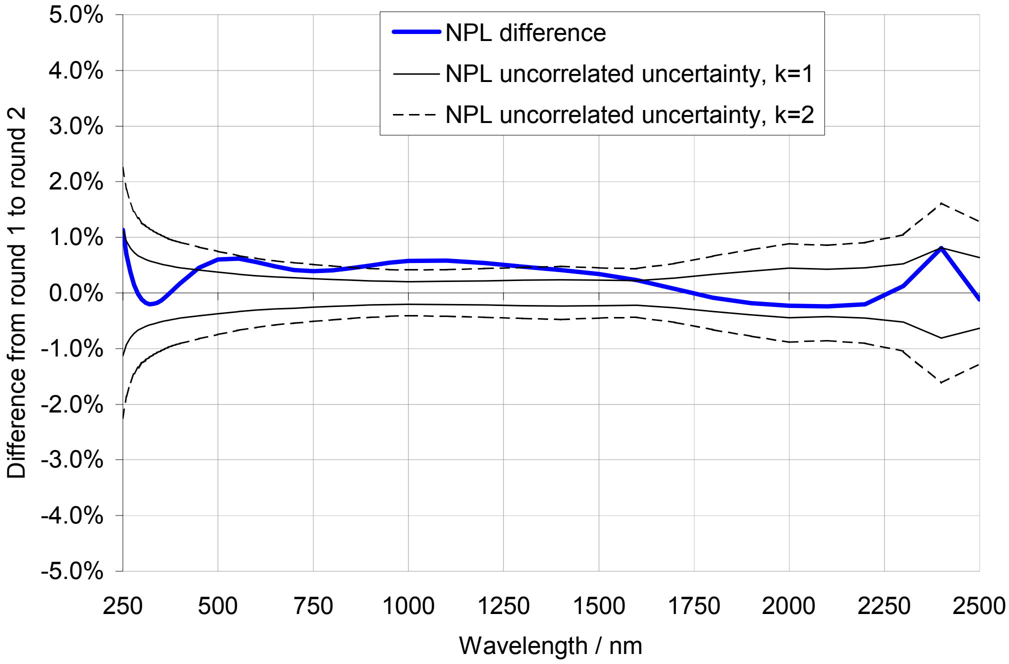

Figure 11-5 Difference between first and second round measurements of FEL BN 9101 251 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

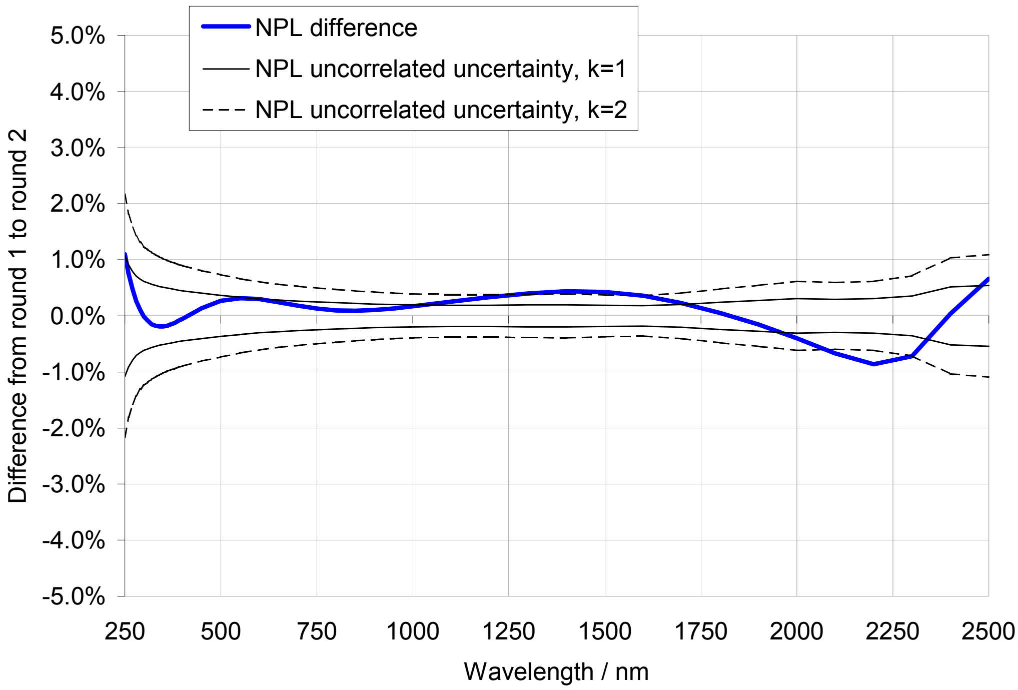

Figure 11-6 Difference between first and second round measurements of FEL BN 9101 260 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

11.9.5 Lamp stability from NIST measurements

As only one measurement of NIST's can be considered for FEL BN 9101 244 because of the damage to the lamp at NPL, there is no graph for this lamp. These graphs show the reproducibility of

NIST's measurements of the remaining lamps. The difference between the first and second NIST measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

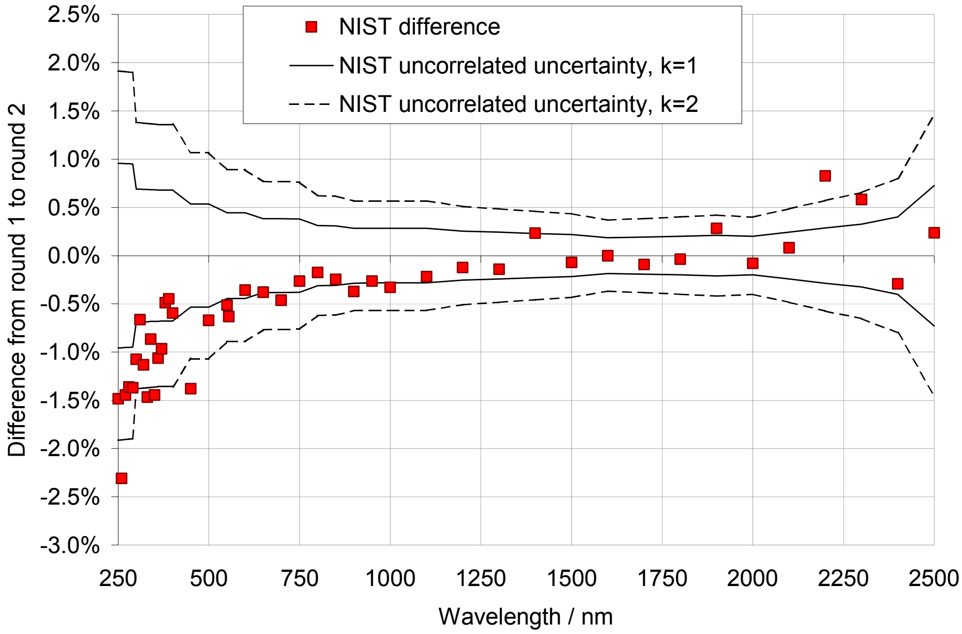

Figure 11-7 Difference between first and second round measurements of FEL BN 9101 251 by NIST. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NIST measurements

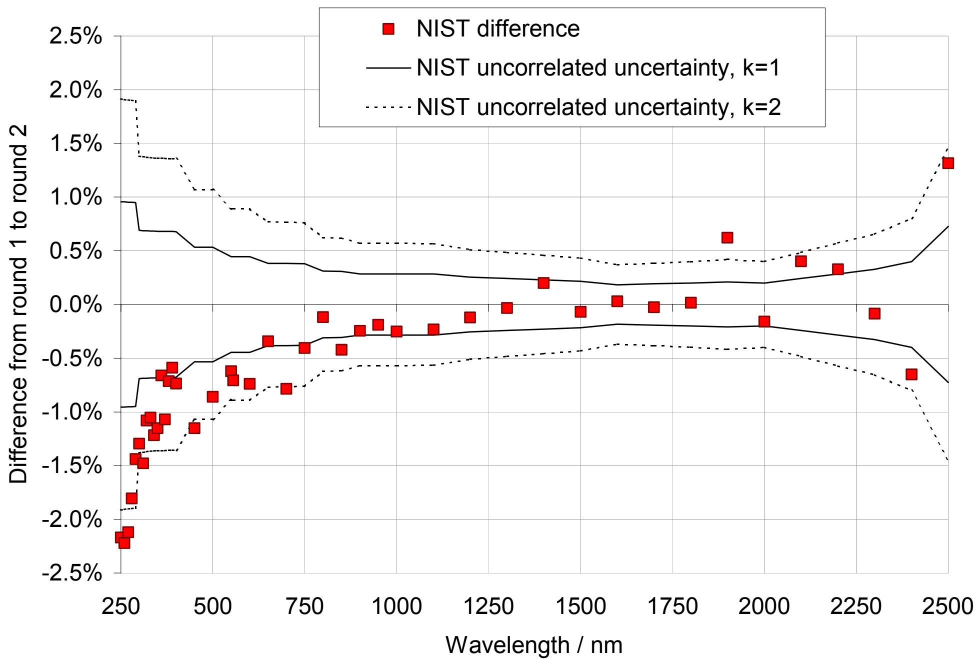

Figure 11-8 Difference between first and second round measurements of FEL BN 9101 260 by NIST. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NIST measurements

11.10 Bilateral comparison between NIST and the comparison scale

This graph shows the difference between the NIST and NPL measurements of the NIST lamps. A version of this graph normalised to show the relative difference between the lamps, but not the absolute difference between the measurements was used to assist in choosing which lamp measurements to use.

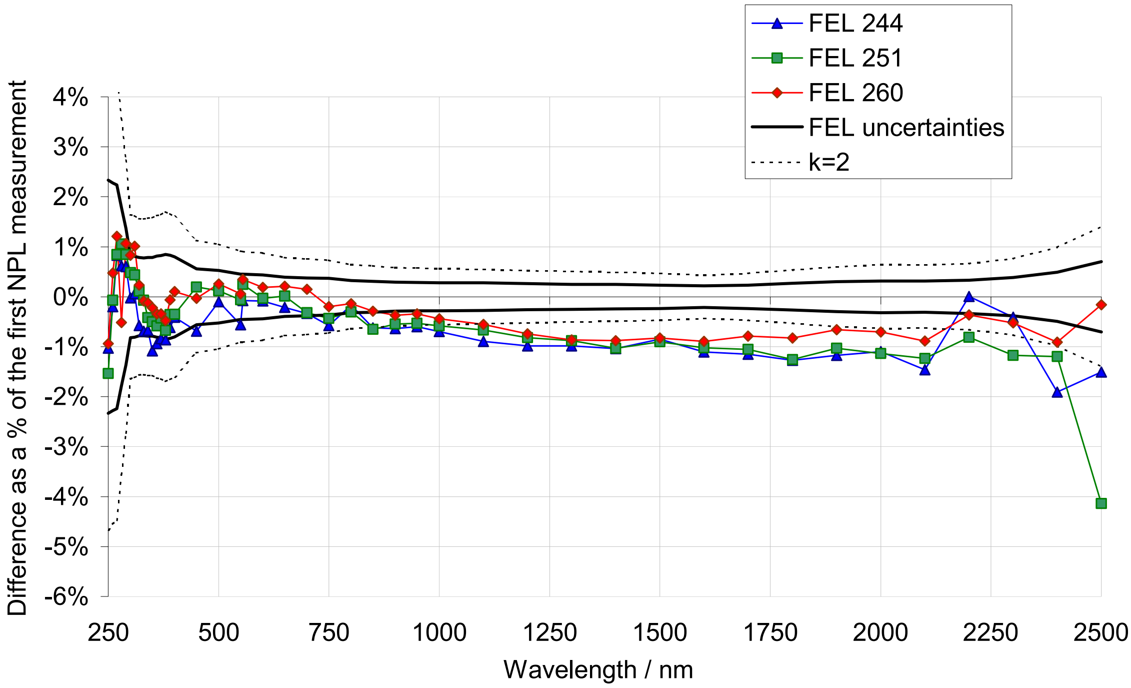

Figure 11-9 Bilateral comparisons of the NIST lamps

11.11 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to NIST the information in the graphs Figure 11-4 to Figure 11-9. It was decided that both participant measurements and both pilot measurements would be used for both FEL BN 9101 251 and for FEL BN 9101 260 and that both pilot measurements and the one participant measurement would be used for FEL BN 9101 244.

11.12 References

1. J. H. Walker, R. D. Saunders, J. K. Jackson, and D. A. McSparron, "Spectral Irradiance Calibrations," NBS Special Publication SP **250-20**, (U. S. Government Printing Office, Washington, D. C., 1987).

2. H. W. Yoon, C. E. Gibson, J. L. Gardner, and P. Y Barnes, "Spectral radiance comparisons of two high-temperature blackbodies with temperatures determined using absolute detectors and ITS-90 techniques," *Temperature: Its Measurement and Control in Science and Industry* **7**, ed. by Dean C. Ripple, (Amer. Inst. Phys. Melville, NY 2003), 601-606.

3. H. W. Yoon, C. E. Gibson, and P. Y. Barnes, "Realization of the National Institute of Standards and Technology detector–based spectral irradiance scale," *Applied Optics* **41** (28), 5879-5890 (2002).

12 Measurements at NMIJ

12.1 Establishment of primary scale

The spectral irradiances of the ETL/NMIJ* standard lamps were determined in 1971 by using three blackbodies (Section 12.1.1 and 12.1.2). The spectral irradiance scale was amended in 1991 using Synchrotron Radiation (Section 12.1.3) and was amended again in 2002 using a new blackbody (Section 12.1.4).

Figure 12-1 is a schematic diagram of the establishment of the primary scale.

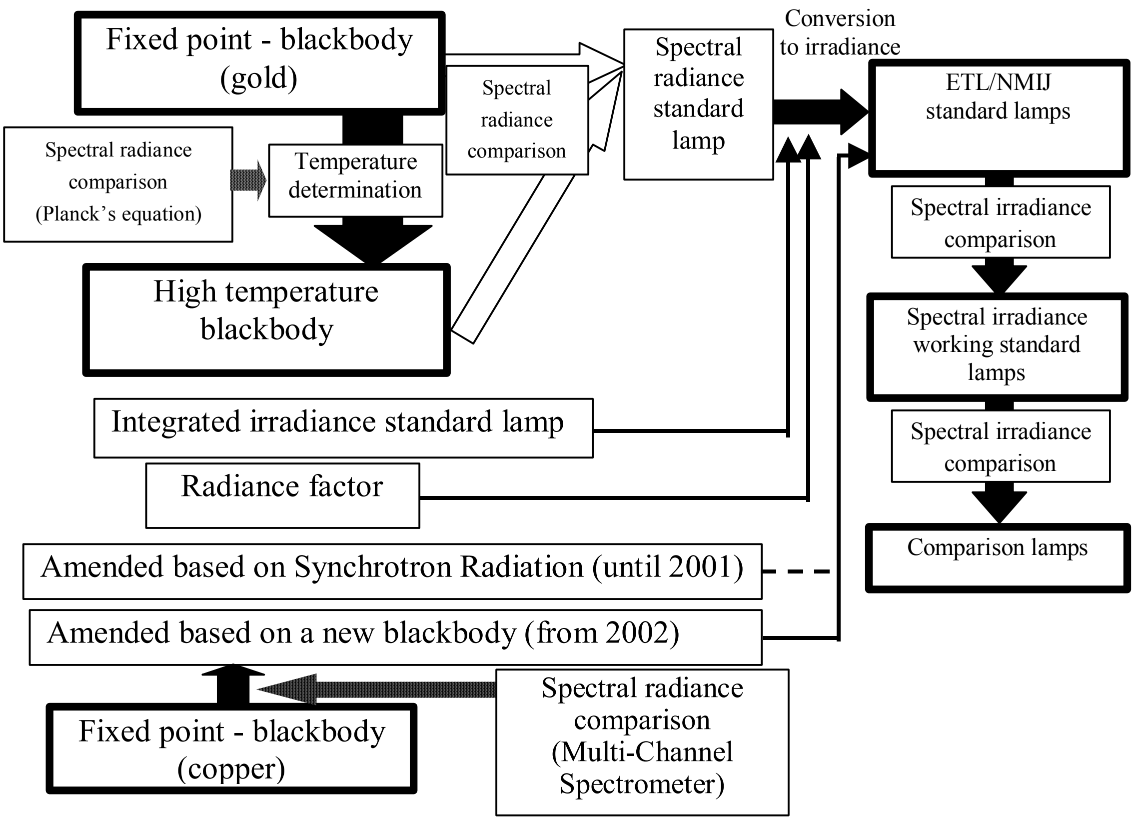

Figure 12-1 Diagram of calibration principle

12.1.1 Spectral radiance scale

The ETL/NMIJ spectral radiance scale was realized in the wavelength range from 250 to 2500 nm based on three blackbodies: a gold-point, a nickel-tube, and a graphite-tube in the following steps:

1.1) The temperature of a graphite-tube blackbody, operated over the range 2200 to 2500 K, was determined from the measured ratio of its spectral radiance to that of the gold-point blackbody at 550, 600 and 650 nm.

* At the start of this comparison the Electrotechnical Laboratory (ETL) was a participant of this comparison. The metrology groups at ETL and NRLM merged in April 2001 to create a new institute: The National Metrology Institute of Japan.

1.2) The temperature of a nickel-tube blackbody, operated over the range 1520 to 1570 K, was determined with an optical pyrometer calibrated against the radiance temperature scale of NRLM (National Research Laboratory of Metrology). The emissivities of the gold-point, the nickel-tube, and the graphite-tube blackbodies were evaluated as above 0.997, 0.996 and 0.998, respectively.

1.3) Six tungsten strip lamps (GE 30A/T24) were compared with the blackbodies described above from 250 to 2500 nm. The spectral radiances of these six tungsten strip lamps were determined by averaging the results of these comparisons. All three blackbodies were used for the wavelengths longer than 1200 nm, whereas wavelengths shorter than 1200 nm were based only on the graphite-tube blackbody.

12.1.2 Spectral irradiance scale 250 – 2500 nm

The ETL/NMIJ spectral irradiance scale was realized in the wavelength range from 250 to 2500 nm based on the above spectral radiance scale and an integrated irradiance standard that was based on an ETL/NMIJ absolute radiometer.

2.1) The spectral distributions of three quartz-bromine lamps (Ushio JPD100V500W) were determined by comparing the spectral radiances of a diffusing surface (coated with $BaSO_4$), which was irradiated alternatively by the tungsten strip lamps, calibrated as described above, and by the quartz-bromine lamps. Condensing optics were used to focus the image of the tungsten strip lamps onto the diffusing surface, whereas the quartz-bromine lamps were set to defocus that image using same optics.

2.2) The spectral radiance factor of a smoked MgO surface was determined from a measurement of reflectance at 580 and 600 nm. The spectral irradiance of each quartz-bromine lamp was determined in this wavelength range by comparing the spectral radiance of the calibrated tungsten strip lamps with the spectral radiances of the MgO surface irradiated by the quartz-bromine lamps. The spectral irradiance at other wavelengths was then determined using the spectral distribution determined in step 2.1 and extrapolation.

2.3) The absolute value of integrated irradiance from each of the quartz-bromine lamps was measured by a radiometer combined with a band-pass (300-2750 nm) filter. The radiometer was calibrated in terms of the ETL/NMIJ absolute radiometric scale. The absolute value of spectral irradiance was calculated from the measured integrated irradiance, the spectral distribution determined in step 2.1 and the spectral transmittance of the filter determined using a monochromator.

2.4) Spectral irradiances of the quartz-bromine lamps were determined by averaging the results of steps 2.2 and 2.3.

12.1.3 Historical amendment below 500 nm

Between 1991 and 2001, the spectral irradiance scale for the wavelengths shorter than 500 nm was amended based on synchrotron radiation. This amendment does not affect the comparison lamps.

3.1) The spectral distributions of each of the quartz-bromine lamps calibrated above was compared with that of synchrotron radiation over the wavelength range of 250 to 500 nm by comparing the spectral radiance of a diffusing surface (coated with $BaSO_4$), which was irradiated alternatively by the quartz-bromine lamps and by synchrotron radiation.

3.2) The spectral irradiance scale determined in step 2.4 was amended so that the spectral distribution would conform to the result of step 3.1 for wavelengths shorter than 500 nm.

12.1.4 Spectral irradiance scale amendment

From 2002, the spectral irradiance scale for the wavelengths shorter than and greater than 500 nm has been amended based on a new graphite-tube blackbody.

4.1) The temperature of the graphite-tube blackbody, whose maximum operating temperature is about 3300 K, was determined by measuring the ratio of its spectral radiance to that of a copper-point blackbody. The ratio was measured every 2 nm from 600 nm to 770 nm

4.2) The spectral distributions of the quartz-bromine lamps, calibrated as described above, were compared with that of the blackbody over the wavelength range 250 to 2500 nm by measuring the spectral radiance of a diffusing surface, which was irradiated alternatively by the quartz-bromine lamps and by the blackbody.

4.3) The spectral irradiance scale determined in step 2.4 was amended to ensure that the spectral distribution would conform to the result of step 4.2 for the wavelengths shorter than and longer than 500 nm.

12.2 Description of the measurement facility

The measurement facility is shown schematically in Figure 12-2.

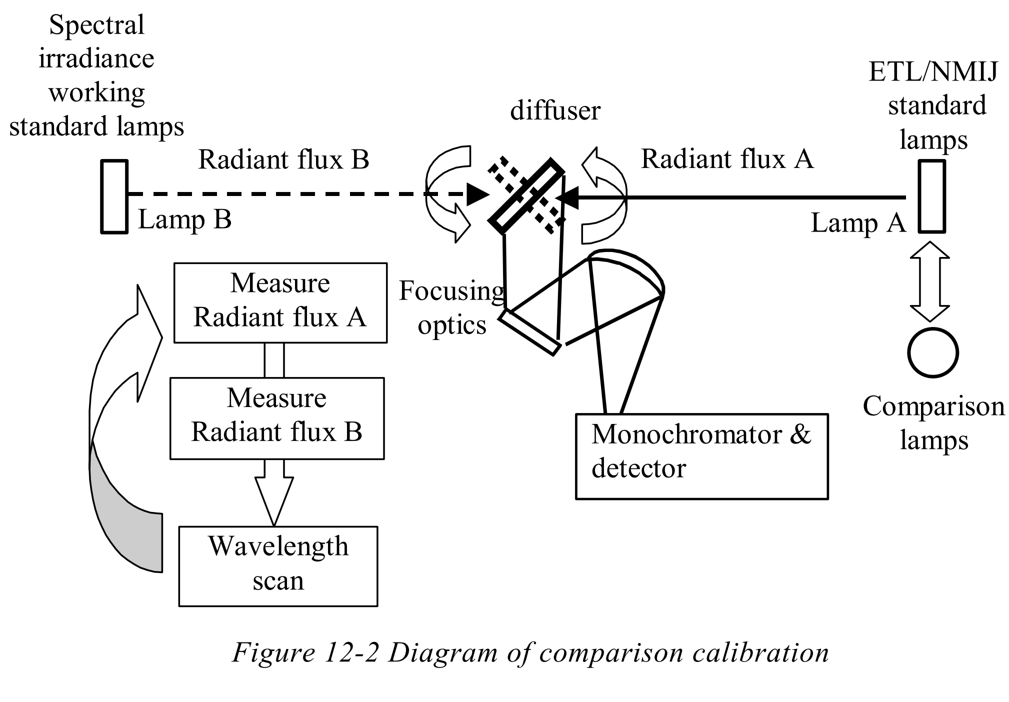

Figure 12-2 Diagram of comparison calibration

12.2.1 Make and type of spectroradiometer

Make: Jasco Bunkoh-Keiki. co. ltd

Type: Czerny-Turner subtractive double-grating monochromator

12.3 Laboratory conditions

Temperature: 23±1ºC, Humidity: 50±10%

All instruments were in a dark room.

12.4 Laboratory transfer standard used

ETL/NMIJ/Ushio quartz bromine lamp (operating voltage: 100 V, power consumption: 500 W)

12.5 Measurement procedure

A spectral irradiance working standard lamp (Lamp B) was calibrated against the ETL/NMIJ standard lamps (Lamp A) and a blackbody. After that, each of the lamps used for international comparison (comparison lamps) were calibrated against the working standard lamp (the schematic is shown in Figure 12-2). The working standard lamp was calibrated twice against the ETL/NMIJ standard lamps and against the blackbody. The comparison lamps were also calibrated twice against the working standard lamp.

The blackbody temperature was determined by comparing the spectral radiance from a blackbody at the freezing temperature of copper.

The blackbody was used to correct the relative spectral irradiance of ETL/NMIJ standard lamps.

12.6 Uncertainty determination

The combined uncertainty in the spectral irradiance calibration of the primary standard lamp is estimated from the following uncertainty factors:

- The spectral radiance uncertainty of the blackbody caused by the temperature uncertainty was estimated from the measurement repeatability of the spectral radiance comparison between the blackbody and the gold-point blackbody, the wavelength uncertainty of the comparison, the size of source effect and the emissivity of the blackbody.
- The graphite-tube blackbody had a silica glass window. The uncertainty in the silica glass window was evaluated from the difference in the window transmittance before and after operation.
- The uncertainty in the spectral radiance comparison between the blackbody and the tungsten strip lamp was dominated by the wavelength uncertainty of the comparator and the repeatability of the comparator signal, when each of the blackbody and the tungsten strip lamps was measured. The combined relative standard uncertainty was calculated from these uncertainties.
- The uncertainty in the radiance-to-irradiance conversion was estimated from the uncertainty induced by repeatability at steps 2.1, 2.2 and 2.3 of the measurements (Section 12.1) and the uncertainty induced by wavelength uncertainty in steps 2.1 and 2.2 of the measurements.
- The uncertainty in the amended spectral irradiance scale based on synchrotron radiation described in steps 3.1 and 3.2 was estimated from the uncertainty of the ratio of synchrotron radiation to the quartz-bromine lamps in step 3.1 and the uncertainty of the calculated radiant flux of the synchrotron radiation. The former uncertainty is dominated by the wavelength setting uncertainty and the measurement repeatability of the quartz-bromine lamps and synchrotron radiation. The latter uncertainty is

mainly caused by the transmittance variation of the window on the synchrotron radiation.

- The uncertainty in the amended spectral irradiance scale based on the new graphite-tube blackbody, as described in steps 4.1 to 4.3, was estimated from the uncertainty of the radiant flux ratio of the new graphite-tube blackbody to the quartz-bromine lamps in step 4.1 and the uncertainty of the calculated radiant flux of the new blackbody. The former uncertainty is dominated by the measurement repeatability of the quartz-bromine lamps and the blackbody. The latter uncertainty is calculated from the spectral radiance uncertainty of the blackbody and the uncertainty in the silica window transmittance.

The combined uncertainty in the comparison of the spectral irradiance working standard lamp with the ETL/NMIJ standard lamp was estimated from the uncertainty of the power applied to lamps, the uncertainty caused by lamp alignment and the uncertainty from the repeatability of the lamps and the comparator used for the calibration.

The combined uncertainty in the comparison of the spectral irradiance working standard lamp with the comparison lamp was estimated from the uncertainty of the power applied to lamps, the uncertainty from the lamp alignment and the uncertainty due to the repeatability of the lamps and the comparator used for the calibration.

Uncertainties in the spectral irradiance calibration are estimated based on *Guide to the Expression of Uncertainty in Measurement* (GUM, 1985). The uncertainty of the primary standard lamp is given in Table 12-1, the uncertainty in the comparison of the spectral irradiance working standard lamp with the ETL/NMIJ standard lamp is given in Table 12-2 and the uncertainty in the comparison of the comparison lamp with the spectral irradiance working standard lamp is given in Table 12-3. The combined uncertainty is given in Table 12-4.

Because the spectral irradiance scale at 500 nm was determined using the blackbodies described in Section 12.1.1, while the spectral irradiance scale for the wavelengths shorter than and greater than 500 nm was amended based on a new graphite-tube blackbody, the uncertainties due to the blackbodies described in Section 12.1.1 are only included at 500 nm.

Table 12-1 Uncertainty budget for the spectral irradiance values of ETL/NMIJ standard lamps. Those uncertainties in brackets are based on the 500 nm uncertainty because the irradiance scale at all other wavelengths was amended using the new graphite-tube blackbody

Uncertainty components		Uncer-tainty type	Relative standard uncertainty (%) (k = 1) 250 – 350 nm	350 – 450 nm	450 – 600 nm	600 – 830 nm	830 – 2300 nm	2300 – 2500 nm
Blackbody temperature determination		B	(1.0)	(1.0)	1.0	(1.0)	(1.0)	(1.0)
Silica glass window transmittance measurements		B	(0.15)	(0.15)	0.15	(0.15)	(0.15)	(0.15)
Spectral radiance comparison	Wavelength accuracy	B	(0.08)	(0.08)	0.08	(0.08)	(0.08)	(0.08)
	Repeatability	A	(0.49)	(0.49)	0.49	(0.49)	(0.49)	(0.49)
Radiance to irradiance conversion	Wavelength accuracy	B	(0.14)	(0.14)	0.14	(0.14)	(0.14)	(0.14)
	Repeatability	A	(0.85)	(0.85)	0.85	(0.85)	(0.85)	(0.85)
Comparison to the new blackbody at wavelengths shorter than and longer than 500 nm	Repeatability of the measurement ratio of lamp and blackbody	A	0.29	0.20	0.15	0.10	0.21	0.54
	Temperature determination	B	< 1.1	< 0.61	< 0.21	< 0.46	< 0.80	< 1.2
	Window transmittance	B	0.10	0.05	0.04	0.04	0.05	0.04
Power uncertainty applied to ETL/NMIJ standard lamps		B	0.02	0.02	0.02	0.02	0.02	0.02
Distance setting uncertainty for ETL/NMIJ standard lamps		B	0.08	0.08	0.08	0.08	0.08	0.08
Combined relative standard uncertainty of spectral irradiance of ETL/NMIJ standard lamps		-	< 1.8	< 1.6	< 1.4	< 1.5	< 1.6	< 1.9

Table 12-2 Uncertainty budget for the comparison in spectral irradiance between ETL/NMIJ standard lamps and the working standard lamps

Uncertainty components	Uncer-tainty type	Relative standard uncertainty (%) (k = 1) 250 – 350 nm	350 – 450 nm	450 – 600 nm	600 – 830 nm	830 – 2300 nm	2300 – 2500 nm
Power applied to ETL/NMIJ standard lamps	B	0.02	0.02	0.02	0.02	0.02	0.02
Power applied to spectral irradiance working standard lamps	B	0.02	0.02	0.02	0.02	0.02	0.02
Distance setting of ETL/NMIJ standard lamps	B	0.08	0.08	0.08	0.08	0.08	0.08
Distance setting of spectral irradiance working standard lamps	B	0.08	0.08	0.08	0.08	0.08	0.08
Wavelength difference in the comparator for spectral irradiance between the measurement for the ETL/NMIJ standard lamps and for spectral irradiance working standard lamps	B	0.15	0.15	0.025	0.0087	0.0028	0.0028
Repeatability	A	0.37	0.13	0.10	0.10	0.36	0.52
Combined relative standard uncertainty of the comparison between ETL/NMIJ standard lamps and the working standard lamps	-	0.42	0.23	0.16	0.15	0.38	0.53

Table 12-3 Uncertainty budget for the comparison in spectral irradiance between the working standard lamps and the comparison lamps

Uncertainty components	Uncertainty type	Relative standard uncertainty (%) (k = 1) 250 – 350 nm	350 – 450 nm	450 – 600 nm	600 – 830 nm	830 – 2300 nm	2300 – 2500 nm
Power applied to spectral irradiance working standard lamps	B	0.02	0.02	0.02	0.02	0.02	0.02
Power applied to comparison lamps	B	0.02	0.02	0.02	0.02	0.02	0.02
Distance setting of spectral irradiance working standard lamps	B	0.08	0.08	0.08	0.08	0.08	0.08
Distance setting of comparison lamps	B	0.08	0.08	0.08	0.08	0.08	0.08
Wavelength difference in the comparator for spectral irradiance between the measurement for the spectral irradiance working standard lamps and comparison lamps	B	0.15	0.15	0.025	0.0087	0.0028	0.0028
Repeatability	A	0.30	0.11	0.11	0.09	0.46	< 2.2
Combined relative standard uncertainty of the comparison between the working standard lamps and comparison lamps	-	0.36	0.22	0.16	0.15	0.47	< 2.2

Table 12-4 Uncertainty budget for the spectral irradiance calibration

Uncertainty components	Relative standard uncertainty (%) (k=1) 250 – 350 nm	350 – 450 nm	450 – 600 nm	600 – 830 nm	830 – 2300 nm	2300 – 2500 nm
Combined relative standard uncertainty of spectral irradiance of ETL/NMIJ standard lamps	< 1.8	< 1.6	< 1.4	< 1.5	< 1.6	< 1.9
Combined relative standard uncertainty of the comparison between ETL/NMIJ standard lamps and the working standard lamps	0.42	0.23	0.16	0.15	0.38	0.53
Combined relative standard uncertainty of the comparison between the working standard lamps and comparison lamps	0.36	0.22	0.16	0.15	0.47	< 2.2
Relative combined standard uncertainty	< 1.9	< 1.6	< 1.4	< 1.5	< 1.7	< 3.0

12.6.1 Correlation

The calibration process of each round was as follows:

1) The ETL/NMIJ working standard lamp was calibrated against ETL/NMIJ standard lamps and ETL/NMIJ blackbody.
2) The comparison lamps were calibrated against the ETL/NMIJ working standard lamp.

The uncertainty of the scale of ETL/NMIJ standard lamps is independent of the calibration round and the same for each international comparison lamp (Entirely correlated). The uncertainty of step (1) depends on the calibration round but is the same for each international comparison lamp (Correlated within a round). The uncertainty of step (2) is different for each comparison lamp and for each calibration round (Entirely uncorrelated).

The uncertainty of step (1) is caused by the uncertainty in calibrating the ETL/NMIJ working standard lamp against the ETL/NMIJ standard lamps (that calibration was carried out twice per round), the uncertainty in comparing the ETL/NMIJ working standard lamp with the new graphite-tube blackbody (that comparison was carried out twice per round) and the uncertainty in the relative spectral irradiance of the new graphite-tube blackbody (the operating conditions of which were different from one round to the next and the relative spectral irradiance of which was determined once a round using a fixed temperature blackbody).

The uncertainty of step (2) is caused by the uncertainty in calibrating the international comparison lamps against the ETL/NMIJ working standard lamp (that calibration was carried out twice per round for each international comparison lamp). It consists of:

A) the repeatability of each international comparison lamp and the ETL/NMIJ calibration system in multiple measurements,

B) the repeatability of the ETL/NMIJ working standard lamp and the ETL/NMIJ calibration system in multiple measurements,

C) the reproducibility of setting the international comparison lamp’s position,

D) the reproducibility of setting the international comparison lamp’s current,

E) the reproducibility of the ETL/NMIJ working standard lamp current and

F) the reproducibility of setting the wavelength of the ETL/NMIJ calibration system.

Note, the international comparison lamp is detached from the calibration system during the comparison of other lamps, but the ETL/NMIJ working standard lamp was set and not detached throughout the calibration process (steps (1) and (2)). Therefore, the reproducibility of setting the ETL/NMIJ working standard lamp position is excluded from this list.

These uncertainties are summarised in Table 12-5 as an example for FEL BN 9101 213. There, “FEL lamp calibration against the working standard lamp [%]” represents uncertainty caused by [A], [B] and [E], “Distance [%]”, “Current [%]” and “Wavelength Uncertainty [%]” represent uncertainty caused by [C], [D] and [F], respectively.

Table 12-5 Full uncertainty budget for the calibration of FEL BN 9101 213 in each round

Wavelength / [nm]	FEL BN 9101 213 Round 1						FEL BN 9101 213 Round 2					
	Scale of ETL/NMIJ standard lamps / [%]	Working standard lamp calibration against ETL/NMIJ blackbody and ETL/NMIJ standard lamps / [%]	Compar-ison lamp calibration against the working standard lamp / [%]	Distance / [%]	Current / [%]	Wavelength Uncertainty / [%]	Scale of ETL/NMIJ standard lamps / [%]	Working standard lamp calibration against ETL/NMIJ blackbody and ETL/NMIJ standard lamps / [%]	Compar-ison lamp calibration against the working standard lamp / [%]	Distance / [%]	Current / [%]	Wavelength Uncertainty / [%]
	Fully correlated	Round correlated	Un-correlated	Un-correlated	Un-correlated	Un-correlated	Fully correlated	Round correlated	Un-correlated	Un-correlated	Un-correlated	Un-correlated
250	1.40	0.87	0.30	0.08	0.02	0.40	1.40	1.10	0.26	0.08	0.02	0.40
260	1.40	0.79	0.15	0.08	0.02	0.30	1.40	1.10	0.10	0.08	0.02	0.30
270	1.40	0.75	0.11	0.08	0.02	0.20	1.40	1.10	0.07	0.08	0.02	0.20
280	1.40	0.76	0.14	0.08	0.02	0.20	1.40	0.99	0.09	0.08	0.02	0.20
290	1.40	0.74	0.09	0.08	0.02	0.20	1.40	0.92	0.07	0.08	0.02	0.20
300	1.40	0.73	0.11	0.08	0.02	0.20	1.40	0.85	0.06	0.08	0.02	0.20
310	1.40	0.69	0.09	0.08	0.02	0.20	1.40	0.79	0.06	0.08	0.02	0.20
320	1.40	0.67	0.09	0.08	0.02	0.20	1.40	0.73	0.05	0.08	0.02	0.20
330	1.40	0.69	0.09	0.08	0.02	0.10	1.40	0.67	0.04	0.08	0.02	0.10
340	1.40	0.66	0.09	0.08	0.02	0.10	1.40	0.62	0.04	0.08	0.02	0.10
350	1.40	0.67	0.09	0.08	0.02	0.10	1.40	0.58	0.05	0.08	0.02	0.10
360	1.40	0.66	0.09	0.08	0.02	0.10	1.40	0.54	0.06	0.08	0.02	0.10
370	1.40	0.67	0.10	0.08	0.02	0.10	1.40	0.51	0.05	0.08	0.02	0.10
380	1.40	0.66	0.08	0.08	0.02	0.10	1.40	0.49	0.05	0.08	0.02	0.10
390	1.40	0.68	0.10	0.08	0.02	0.09	1.40	0.46	0.06	0.08	0.02	0.09

400	1.40	0.66	0.08	0.08	0.02	0.09	1.40	0.44	0.06	0.08	0.02	0.09
450	1.40	0.65	0.09	0.08	0.02	0.06	1.40	0.36	0.05	0.08	0.02	0.06
500	1.40	0.23	0.07	0.08	0.02	0.04	1.40	0.10	0.05	0.08	0.02	0.04
550	1.40	0.27	0.08	0.08	0.02	0.03	1.40	0.14	0.04	0.08	0.02	0.03
600	1.40	0.26	0.06	0.08	0.02	0.02	1.40	0.23	0.05	0.08	0.02	0.02
650	1.40	0.36	0.07	0.08	0.02	0.02	1.40	0.29	0.05	0.08	0.02	0.02
700	1.40	0.43	0.07	0.08	0.02	0.01	1.40	0.39	0.06	0.08	0.02	0.01
750	1.40	0.45	0.06	0.08	0.02	0.01	1.40	0.41	0.05	0.08	0.02	0.01
800	1.40	0.47	0.07	0.08	0.02	0.01	1.40	0.47	0.06	0.08	0.02	0.01
850	1.40	0.56	0.07	0.08	0.02	0.00	1.40	0.51	0.06	0.08	0.02	0.00
900	1.40	0.55	0.07	0.08	0.02	0.00	1.40	0.55	0.06	0.08	0.02	0.00
950	1.40	0.55	0.06	0.08	0.02	0.00	1.40	0.59	0.06	0.08	0.02	0.00
1000	1.40	0.55	0.05	0.08	0.02	0.00	1.40	0.62	0.06	0.08	0.02	0.00
1100	1.40	0.55	0.06	0.08	0.02	0.00	1.40	0.67	0.05	0.08	0.02	0.00
1200	1.40	0.56	0.06	0.08	0.02	0.01	1.40	0.72	0.05	0.08	0.02	0.01
1300	1.40	0.56	0.07	0.08	0.02	0.01	1.40	0.76	0.05	0.08	0.02	0.01
1400	1.40	0.55	0.06	0.08	0.02	0.01	1.40	0.79	0.04	0.08	0.02	0.01
1500	1.40	0.55	0.06	0.08	0.02	0.01	1.40	0.81	0.07	0.08	0.02	0.01
1600	1.40	0.56	0.05	0.08	0.02	0.01	1.40	0.83	0.07	0.08	0.02	0.01
1700	1.40	0.55	0.06	0.08	0.02	0.01	1.40	0.75	0.06	0.08	0.02	0.01
1800	1.40	0.55	0.06	0.08	0.02	0.01	1.40	0.79	0.07	0.08	0.02	0.01
1900	1.40	0.55	0.08	0.08	0.02	0.01	1.40	0.83	0.23	0.08	0.02	0.01
2000	1.40	0.57	0.19	0.08	0.02	0.01	1.40	0.83	0.45	0.08	0.02	0.01
2100	1.40	0.83	0.22	0.08	0.02	0.01	1.40	0.81	0.40	0.08	0.02	0.01
2200	1.40	0.57	0.15	0.08	0.02	0.01	1.40	0.83	0.33	0.08	0.02	0.01
2300	1.40	0.62	0.33	0.08	0.02	0.01	1.40	0.76	0.46	0.08	0.02	0.01
2400	1.40	0.95	0.74	0.08	0.02	0.01	1.40	1.00	0.92	0.08	0.02	0.01
2500	1.40	1.30	2.20	0.08	0.02	0.00	1.40	1.30	2.20	0.08	0.02	0.00

12.7 NMIJ Results

NMIJ measured three lamps. The results for FEL BN 9101 213 are given in Table 12-6 and the results for FEL BN 9101 220 are given in Table 12-7 and the results for FEL BN 9101 252 are given in Table 12-8.

Table 12-6 NMIJ Results for FEL BN 9101 213. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 213	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.344E-04	0.51 %	0.87 %	1.40 %	1.72 %	1.349E-04	0.48 %	1.10 %	1.40 %	1.85 %
260	2.348E-04	0.17 %	0.79 %	1.40 %	1.62 %	2.357E-04	0.13 %	1.10 %	1.40 %	1.79 %
270	3.912E-04	0.14 %	0.75 %	1.40 %	1.59 %	3.927E-04	0.11 %	1.10 %	1.40 %	1.78 %
280	6.209E-04	0.16 %	0.76 %	1.40 %	1.60 %	6.230E-04	0.12 %	0.99 %	1.40 %	1.72 %
290	9.436E-04	0.12 %	0.74 %	1.40 %	1.59 %	9.472E-04	0.11 %	0.92 %	1.40 %	1.68 %
300	1.383E-03	0.14 %	0.73 %	1.40 %	1.58 %	1.386E-03	0.10 %	0.85 %	1.40 %	1.64 %
310	1.964E-03	0.12 %	0.69 %	1.40 %	1.57 %	1.968E-03	0.10 %	0.79 %	1.40 %	1.61 %
320	2.709E-03	0.12 %	0.67 %	1.40 %	1.56 %	2.715E-03	0.10 %	0.73 %	1.40 %	1.58 %
330	3.649E-03	0.12 %	0.69 %	1.40 %	1.57 %	3.660E-03	0.09 %	0.67 %	1.40 %	1.55 %
340	4.800E-03	0.12 %	0.66 %	1.40 %	1.55 %	4.812E-03	0.09 %	0.62 %	1.40 %	1.53 %
350	6.195E-03	0.12 %	0.67 %	1.40 %	1.56 %	6.208E-03	0.09 %	0.58 %	1.40 %	1.52 %
360	7.848E-03	0.12 %	0.66 %	1.40 %	1.55 %	7.867E-03	0.10 %	0.54 %	1.40 %	1.50 %
370	9.772E-03	0.13 %	0.67 %	1.40 %	1.56 %	9.790E-03	0.09 %	0.51 %	1.40 %	1.49 %
380	1.199E-02	0.11 %	0.66 %	1.40 %	1.55 %	1.202E-02	0.10 %	0.49 %	1.40 %	1.49 %
390	1.456E-02	0.13 %	0.68 %	1.40 %	1.56 %	1.459E-02	0.10 %	0.46 %	1.40 %	1.48 %
400	1.726E-02	0.11 %	0.66 %	1.40 %	1.55 %	1.730E-02	0.10 %	0.44 %	1.40 %	1.47 %
450	3.541E-02	0.12 %	0.65 %	1.40 %	1.55 %	3.548E-02	0.10 %	0.36 %	1.40 %	1.45 %
500	5.945E-02	0.11 %	0.23 %	1.40 %	1.42 %	5.956E-02	0.10 %	0.10 %	1.40 %	1.41 %
550	8.664E-02	0.12 %	0.27 %	1.40 %	1.43 %	8.683E-02	0.09 %	0.14 %	1.40 %	1.41 %
555										
600	1.141E-01	0.10 %	0.26 %	1.40 %	1.43 %	1.142E-01	0.09 %	0.23 %	1.40 %	1.42 %
650	1.390E-01	0.11 %	0.36 %	1.40 %	1.45 %	1.394E-01	0.10 %	0.29 %	1.40 %	1.43 %
700	1.592E-01	0.11 %	0.43 %	1.40 %	1.47 %	1.596E-01	0.10 %	0.39 %	1.40 %	1.46 %
750	1.759E-01	0.10 %	0.45 %	1.40 %	1.47 %	1.762E-01	0.10 %	0.41 %	1.40 %	1.46 %
800	1.876E-01	0.11 %	0.47 %	1.40 %	1.48 %	1.879E-01	0.10 %	0.47 %	1.40 %	1.48 %
850	1.948E-01	0.11 %	0.56 %	1.40 %	1.51 %	1.952E-01	0.10 %	0.51 %	1.40 %	1.49 %
900	1.981E-01	0.11 %	0.55 %	1.40 %	1.51 %	1.985E-01	0.10 %	0.55 %	1.40 %	1.51 %
950	1.979E-01	0.10 %	0.55 %	1.40 %	1.51 %	1.983E-01	0.10 %	0.59 %	1.40 %	1.52 %
1000	1.946E-01	0.10 %	0.55 %	1.40 %	1.51 %	1.950E-01	0.10 %	0.62 %	1.40 %	1.53 %
1100	1.829E-01	0.10 %	0.55 %	1.40 %	1.51 %	1.833E-01	0.09 %	0.67 %	1.40 %	1.55 %
1200	1.664E-01	0.10 %	0.56 %	1.40 %	1.51 %	1.668E-01	0.10 %	0.72 %	1.40 %	1.58 %
1300	1.495E-01	0.11 %	0.56 %	1.40 %	1.51 %	1.496E-01	0.10 %	0.76 %	1.40 %	1.60 %
1400	1.344E-01	0.10 %	0.55 %	1.40 %	1.51 %	1.347E-01	0.09 %	0.79 %	1.40 %	1.61 %
1500	1.163E-01	0.10 %	0.55 %	1.40 %	1.51 %	1.165E-01	0.11 %	0.81 %	1.40 %	1.62 %
1600	1.020E-01	0.09 %	0.56 %	1.40 %	1.51 %	1.022E-01	0.11 %	0.83 %	1.40 %	1.63 %
1700	8.926E-02	0.10 %	0.55 %	1.40 %	1.51 %	8.930E-02	0.10 %	0.75 %	1.40 %	1.59 %
1800	7.817E-02	0.10 %	0.55 %	1.40 %	1.51 %	7.831E-02	0.11 %	0.79 %	1.40 %	1.61 %
1900	6.959E-02	0.12 %	0.55 %	1.40 %	1.51 %	6.977E-02	0.24 %	0.83 %	1.40 %	1.65 %
2000	6.048E-02	0.21 %	0.57 %	1.40 %	1.53 %	6.049E-02	0.46 %	0.83 %	1.40 %	1.69 %
2100	5.258E-02	0.23 %	0.83 %	1.40 %	1.64 %	5.266E-02	0.41 %	0.81 %	1.40 %	1.67 %
2200	4.602E-02	0.17 %	0.57 %	1.40 %	1.52 %	4.562E-02	0.34 %	0.83 %	1.40 %	1.66 %
2300	4.071E-02	0.34 %	0.62 %	1.40 %	1.57 %	4.090E-02	0.47 %	0.76 %	1.40 %	1.66 %

2400	3.608E-02	0.74 %	0.95 %	1.40 %	1.85 %	3.628E-02	0.92 %	1.00 %	1.40 %	1.95 %
2500	3.374E-02	2.20 %	1.30 %	1.40 %	2.91 %	3.456E-02	2.20 %	1.30 %	1.40 %	2.91 %

Table 12-7 NMIJ Results for FEL BN 9101 220. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 220	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.374E-04	0.48 %	0.87 %	1.40 %	1.72 %	1.385E-04	0.51 %	1.10 %	1.40 %	1.85 %
260	2.404E-04	0.13 %	0.79 %	1.40 %	1.61 %	2.424E-04	0.15 %	1.10 %	1.40 %	1.79 %
270	4.002E-04	0.11 %	0.75 %	1.40 %	1.59 %	4.037E-04	0.11 %	1.10 %	1.40 %	1.78 %
280	6.337E-04	0.13 %	0.76 %	1.40 %	1.60 %	6.393E-04	0.14 %	0.99 %	1.40 %	1.72 %
290	9.686E-04	0.11 %	0.74 %	1.40 %	1.59 %	9.749E-04	0.12 %	0.92 %	1.40 %	1.68 %
300	1.419E-03	0.11 %	0.73 %	1.40 %	1.58 %	1.429E-03	0.11 %	0.85 %	1.40 %	1.64 %
310	2.021E-03	0.10 %	0.69 %	1.40 %	1.56 %	2.034E-03	0.11 %	0.79 %	1.40 %	1.61 %
320	2.786E-03	0.10 %	0.67 %	1.40 %	1.55 %	2.804E-03	0.10 %	0.73 %	1.40 %	1.58 %
330	3.755E-03	0.10 %	0.69 %	1.40 %	1.56 %	3.778E-03	0.10 %	0.67 %	1.40 %	1.56 %
340	4.942E-03	0.09 %	0.66 %	1.40 %	1.55 %	4.974E-03	0.10 %	0.62 %	1.40 %	1.53 %
350	6.382E-03	0.10 %	0.67 %	1.40 %	1.55 %	6.421E-03	0.10 %	0.58 %	1.40 %	1.52 %
360	8.090E-03	0.10 %	0.66 %	1.40 %	1.55 %	8.135E-03	0.09 %	0.54 %	1.40 %	1.50 %
370	1.008E-02	0.09 %	0.67 %	1.40 %	1.55 %	1.013E-02	0.10 %	0.51 %	1.40 %	1.49 %
380	1.238E-02	0.09 %	0.66 %	1.40 %	1.55 %	1.244E-02	0.11 %	0.49 %	1.40 %	1.49 %
390	1.503E-02	0.09 %	0.68 %	1.40 %	1.56 %	1.511E-02	0.10 %	0.46 %	1.40 %	1.48 %
400	1.783E-02	0.09 %	0.66 %	1.40 %	1.55 %	1.792E-02	0.09 %	0.44 %	1.40 %	1.47 %
450	3.658E-02	0.09 %	0.65 %	1.40 %	1.55 %	3.673E-02	0.09 %	0.36 %	1.40 %	1.45 %
500	6.137E-02	0.09 %	0.23 %	1.40 %	1.42 %	6.164E-02	0.09 %	0.10 %	1.40 %	1.41 %
550	8.940E-02	0.09 %	0.27 %	1.40 %	1.43 %	8.977E-02	0.09 %	0.14 %	1.40 %	1.41 %
555										
600	1.176E-01	0.09 %	0.26 %	1.40 %	1.43 %	1.180E-01	0.09 %	0.23 %	1.40 %	1.42 %
650	1.434E-01	0.09 %	0.36 %	1.40 %	1.45 %	1.439E-01	0.09 %	0.29 %	1.40 %	1.43 %
700	1.640E-01	0.09 %	0.43 %	1.40 %	1.47 %	1.647E-01	0.08 %	0.39 %	1.40 %	1.46 %
750	1.812E-01	0.08 %	0.45 %	1.40 %	1.47 %	1.818E-01	0.08 %	0.41 %	1.40 %	1.46 %
800	1.931E-01	0.08 %	0.47 %	1.40 %	1.48 %	1.938E-01	0.09 %	0.47 %	1.40 %	1.48 %
850	2.005E-01	0.09 %	0.56 %	1.40 %	1.51 %	2.013E-01	0.08 %	0.51 %	1.40 %	1.49 %
900	2.039E-01	0.08 %	0.55 %	1.40 %	1.51 %	2.046E-01	0.08 %	0.55 %	1.40 %	1.51 %
950	2.036E-01	0.08 %	0.55 %	1.40 %	1.51 %	2.044E-01	0.08 %	0.59 %	1.40 %	1.52 %
1000	2.003E-01	0.08 %	0.55 %	1.40 %	1.51 %	2.009E-01	0.08 %	0.62 %	1.40 %	1.53 %
1100	1.880E-01	0.09 %	0.55 %	1.40 %	1.51 %	1.887E-01	0.09 %	0.67 %	1.40 %	1.55 %
1200	1.709E-01	0.08 %	0.56 %	1.40 %	1.51 %	1.715E-01	0.08 %	0.72 %	1.40 %	1.58 %
1300	1.535E-01	0.08 %	0.56 %	1.40 %	1.51 %	1.539E-01	0.09 %	0.76 %	1.40 %	1.60 %
1400	1.381E-01	0.08 %	0.55 %	1.40 %	1.51 %	1.386E-01	0.08 %	0.79 %	1.40 %	1.61 %
1500	1.194E-01	0.08 %	0.55 %	1.40 %	1.51 %	1.198E-01	0.08 %	0.81 %	1.40 %	1.62 %
1600	1.047E-01	0.09 %	0.56 %	1.40 %	1.51 %	1.050E-01	0.08 %	0.83 %	1.40 %	1.63 %
1700	9.160E-02	0.09 %	0.55 %	1.40 %	1.51 %	9.184E-02	0.08 %	0.75 %	1.40 %	1.59 %
1800	8.019E-02	0.09 %	0.55 %	1.40 %	1.51 %	8.050E-02	0.08 %	0.79 %	1.40 %	1.61 %
1900	7.145E-02	0.09 %	0.55 %	1.40 %	1.51 %	7.175E-02	0.27 %	0.83 %	1.40 %	1.65 %
2000	6.195E-02	0.17 %	0.57 %	1.40 %	1.52 %	6.218E-02	0.28 %	0.83 %	1.40 %	1.65 %
2100	5.396E-02	0.23 %	0.83 %	1.40 %	1.64 %	5.418E-02	0.33 %	0.81 %	1.40 %	1.65 %
2200	4.674E-02	0.23 %	0.57 %	1.40 %	1.53 %	4.694E-02	0.27 %	0.83 %	1.40 %	1.65 %
2300	4.174E-02	0.43 %	0.62 %	1.40 %	1.59 %	4.179E-02	0.44 %	0.76 %	1.40 %	1.65 %
2400	3.691E-02	0.74 %	0.95 %	1.40 %	1.85 %	3.663E-02	0.34 %	1.00 %	1.40 %	1.75 %
2500	3.505E-02	2.20 %	1.30 %	1.40 %	2.91 %	3.352E-02	1.60 %	1.30 %	1.40 %	2.49 %

Table 12-8 NMIJ Results for FEL BN 9101 252. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 252	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.274E-04	0.46 %	0.87 %	1.40 %	1.71 %	1.277E-04	0.51 %	1.10 %	1.40 %	1.85 %
260	2.229E-04	0.17 %	0.79 %	1.40 %	1.62 %	2.236E-04	0.14 %	1.10 %	1.40 %	1.79 %
270	3.720E-04	0.16 %	0.75 %	1.40 %	1.60 %	3.735E-04	0.10 %	1.10 %	1.40 %	1.78 %
280	5.909E-04	0.18 %	0.76 %	1.40 %	1.60 %	5.925E-04	0.13 %	0.99 %	1.40 %	1.72 %
290	9.015E-04	0.13 %	0.74 %	1.40 %	1.59 %	9.026E-04	0.11 %	0.92 %	1.40 %	1.68 %
300	1.324E-03	0.13 %	0.73 %	1.40 %	1.58 %	1.325E-03	0.10 %	0.85 %	1.40 %	1.64 %
310	1.886E-03	0.15 %	0.69 %	1.40 %	1.57 %	1.887E-03	0.09 %	0.79 %	1.40 %	1.61 %
320	2.602E-03	0.14 %	0.67 %	1.40 %	1.56 %	2.605E-03	0.09 %	0.73 %	1.40 %	1.58 %
330	3.511E-03	0.13 %	0.69 %	1.40 %	1.57 %	3.514E-03	0.09 %	0.67 %	1.40 %	1.55 %
340	4.626E-03	0.13 %	0.66 %	1.40 %	1.55 %	4.629E-03	0.09 %	0.62 %	1.40 %	1.53 %
350	5.979E-03	0.13 %	0.67 %	1.40 %	1.56 %	5.980E-03	0.09 %	0.58 %	1.40 %	1.52 %
360	7.584E-03	0.13 %	0.66 %	1.40 %	1.55 %	7.586E-03	0.09 %	0.54 %	1.40 %	1.50 %
370	9.451E-03	0.13 %	0.67 %	1.40 %	1.56 %	9.456E-03	0.09 %	0.51 %	1.40 %	1.49 %
380	1.161E-02	0.14 %	0.66 %	1.40 %	1.55 %	1.161E-02	0.09 %	0.49 %	1.40 %	1.49 %
390	1.412E-02	0.13 %	0.68 %	1.40 %	1.56 %	1.411E-02	0.09 %	0.46 %	1.40 %	1.48 %
400	1.676E-02	0.14 %	0.66 %	1.40 %	1.55 %	1.676E-02	0.09 %	0.44 %	1.40 %	1.47 %
450	3.445E-02	0.13 %	0.65 %	1.40 %	1.55 %	3.443E-02	0.09 %	0.36 %	1.40 %	1.45 %
500	5.796E-02	0.13 %	0.23 %	1.40 %	1.42 %	5.794E-02	0.09 %	0.10 %	1.40 %	1.41 %
550	8.460E-02	0.13 %	0.27 %	1.40 %	1.43 %	8.457E-02	0.09 %	0.14 %	1.40 %	1.41 %
555										
600	1.114E-01	0.14 %	0.26 %	1.40 %	1.43 %	1.114E-01	0.09 %	0.23 %	1.40 %	1.42 %
650	1.360E-01	0.12 %	0.36 %	1.40 %	1.45 %	1.359E-01	0.09 %	0.29 %	1.40 %	1.43 %
700	1.557E-01	0.12 %	0.43 %	1.40 %	1.47 %	1.557E-01	0.08 %	0.39 %	1.40 %	1.46 %
750	1.721E-01	0.12 %	0.45 %	1.40 %	1.48 %	1.720E-01	0.09 %	0.41 %	1.40 %	1.46 %
800	1.836E-01	0.12 %	0.47 %	1.40 %	1.48 %	1.834E-01	0.09 %	0.47 %	1.40 %	1.48 %
850	1.906E-01	0.12 %	0.56 %	1.40 %	1.51 %	1.905E-01	0.09 %	0.51 %	1.40 %	1.49 %
900	1.939E-01	0.11 %	0.55 %	1.40 %	1.51 %	1.937E-01	0.08 %	0.55 %	1.40 %	1.51 %
950	1.937E-01	0.11 %	0.55 %	1.40 %	1.51 %	1.936E-01	0.09 %	0.59 %	1.40 %	1.52 %
1000	1.904E-01	0.12 %	0.55 %	1.40 %	1.51 %	1.903E-01	0.08 %	0.62 %	1.40 %	1.53 %
1100	1.789E-01	0.11 %	0.55 %	1.40 %	1.51 %	1.787E-01	0.09 %	0.67 %	1.40 %	1.55 %
1200	1.626E-01	0.11 %	0.56 %	1.40 %	1.51 %	1.625E-01	0.09 %	0.72 %	1.40 %	1.58 %
1300	1.460E-01	0.11 %	0.56 %	1.40 %	1.51 %	1.459E-01	0.09 %	0.76 %	1.40 %	1.60 %
1400	1.313E-01	0.12 %	0.55 %	1.40 %	1.51 %	1.313E-01	0.08 %	0.79 %	1.40 %	1.61 %
1500	1.136E-01	0.11 %	0.55 %	1.40 %	1.51 %	1.135E-01	0.09 %	0.81 %	1.40 %	1.62 %
1600	9.952E-02	0.10 %	0.56 %	1.40 %	1.51 %	9.947E-02	0.09 %	0.83 %	1.40 %	1.63 %
1700	8.707E-02	0.10 %	0.55 %	1.40 %	1.51 %	8.699E-02	0.09 %	0.75 %	1.40 %	1.59 %
1800	7.628E-02	0.12 %	0.55 %	1.40 %	1.51 %	7.626E-02	0.09 %	0.79 %	1.40 %	1.61 %
1900	6.781E-02	0.11 %	0.55 %	1.40 %	1.51 %	6.788E-02	0.27 %	0.83 %	1.40 %	1.65 %
2000	5.886E-02	0.17 %	0.57 %	1.40 %	1.52 %	5.888E-02	0.29 %	0.83 %	1.40 %	1.65 %
2100	5.132E-02	0.33 %	0.83 %	1.40 %	1.66 %	5.126E-02	0.33 %	0.81 %	1.40 %	1.65 %
2200	4.492E-02	0.16 %	0.57 %	1.40 %	1.52 %	4.466E-02	0.27 %	0.83 %	1.40 %	1.65 %
2300	3.954E-02	0.30 %	0.62 %	1.40 %	1.56 %	3.949E-02	0.44 %	0.76 %	1.40 %	1.65 %
2400	3.488E-02	0.75 %	0.95 %	1.40 %	1.85 %	3.451E-02	0.22 %	1.00 %	1.40 %	1.73 %
2500	3.236E-02	2.20 %	1.30 %	1.40 %	2.91 %	3.128E-02	2.00 %	1.30 %	1.40 %	2.77 %

12.8 Pilot Results

NPL's results for FEL BN 9101 213 are given in Table 12-9 and the results for FEL BN 9101 220 are given in Table 12-10 and the results for FEL BN 9101 252 are given in Table 12-11.

Table 12-9 NPL Results for FEL BN 9101 213. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 213	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.270E-04	1.17 %	0.48 %	2.00 %	2.37 %	1.334E-04	0.38 %	0.45 %	2.00 %	2.08 %
260	2.231E-04	0.87 %	0.46 %	2.00 %	2.23 %	2.332E-04	0.29 %	0.43 %	2.00 %	2.07 %
270	3.718E-04	0.65 %	0.44 %	2.00 %	2.15 %	3.869E-04	0.24 %	0.41 %	2.00 %	2.06 %
280	5.916E-04	0.50 %	0.43 %	1.50 %	1.64 %	6.135E-04	0.21 %	0.40 %	1.50 %	1.57 %
290	9.039E-04	0.40 %	0.41 %	1.00 %	1.15 %	9.342E-04	0.19 %	0.38 %	1.00 %	1.09 %
300	1.332E-03	0.33 %	0.40 %	0.25 %	0.57 %	1.373E-03	0.18 %	0.37 %	0.25 %	0.48 %
310	1.900E-03	0.28 %	0.39 %	0.28 %	0.56 %	1.953E-03	0.17 %	0.36 %	0.28 %	0.49 %
320	2.634E-03	0.25 %	0.37 %	0.25 %	0.52 %	2.702E-03	0.16 %	0.35 %	0.25 %	0.46 %
330	3.559E-03	0.23 %	0.36 %	0.28 %	0.51 %	3.642E-03	0.16 %	0.34 %	0.28 %	0.47 %
340	4.696E-03	0.21 %	0.35 %	0.33 %	0.53 %	4.798E-03	0.15 %	0.33 %	0.33 %	0.49 %
350	6.069E-03	0.20 %	0.34 %	0.36 %	0.54 %	6.190E-03	0.15 %	0.32 %	0.36 %	0.50 %
360	7.694E-03	0.19 %	0.33 %	0.43 %	0.58 %	7.837E-03	0.14 %	0.31 %	0.43 %	0.55 %
370	9.588E-03	0.18 %	0.32 %	0.46 %	0.59 %	9.754E-03	0.14 %	0.30 %	0.46 %	0.57 %
380	1.176E-02	0.18 %	0.31 %	0.52 %	0.63 %	1.195E-02	0.13 %	0.29 %	0.52 %	0.61 %
390	1.422E-02	0.17 %	0.31 %	0.50 %	0.61 %	1.444E-02	0.13 %	0.29 %	0.50 %	0.59 %
400	1.697E-02	0.17 %	0.30 %	0.46 %	0.58 %	1.721E-02	0.13 %	0.28 %	0.46 %	0.55 %
450	3.493E-02	0.18 %	0.27 %	0.10 %	0.33 %	3.532E-02	0.12 %	0.25 %	0.10 %	0.29 %
500	5.868E-02	0.16 %	0.24 %	0.01 %	0.29 %	5.922E-02	0.11 %	0.22 %	0.01 %	0.25 %
550	8.565E-02	0.14 %	0.22 %	0.00 %	0.26 %	8.634E-02	0.10 %	0.20 %	0.00 %	0.22 %
555	8.841E-02	0.14 %	0.22 %	0.00 %	0.25 %	8.912E-02	0.10 %	0.20 %	0.00 %	0.22 %
600	1.129E-01	0.13 %	0.20 %	0.00 %	0.24 %	1.138E-01	0.09 %	0.19 %	0.00 %	0.21 %
650	1.381E-01	0.12 %	0.18 %	0.00 %	0.22 %	1.391E-01	0.09 %	0.17 %	0.00 %	0.19 %
700	1.595E-01	0.12 %	0.17 %	0.00 %	0.21 %	1.606E-01	0.08 %	0.16 %	0.00 %	0.18 %
750	1.762E-01	0.11 %	0.16 %	0.01 %	0.20 %	1.774E-01	0.08 %	0.15 %	0.01 %	0.17 %
800	1.880E-01	0.11 %	0.15 %	0.00 %	0.18 %	1.893E-01	0.08 %	0.14 %	0.00 %	0.16 %
850	1.952E-01	0.10 %	0.14 %	0.00 %	0.17 %	1.965E-01	0.08 %	0.13 %	0.00 %	0.15 %
900	1.984E-01	0.10 %	0.13 %	0.00 %	0.17 %	1.997E-01	0.07 %	0.12 %	0.00 %	0.14 %
950	1.983E-01	0.10 %	0.13 %	0.01 %	0.16 %	1.995E-01	0.07 %	0.12 %	0.01 %	0.14 %
1000	1.956E-01	0.10 %	0.12 %	0.01 %	0.16 %	1.966E-01	0.07 %	0.11 %	0.01 %	0.13 %
1100	1.846E-01	0.13 %	0.11 %	0.01 %	0.17 %	1.853E-01	0.08 %	0.10 %	0.01 %	0.13 %
1200	1.692E-01	0.18 %	0.10 %	0.02 %	0.20 %	1.698E-01	0.09 %	0.09 %	0.02 %	0.13 %
1300	1.521E-01	0.22 %	0.09 %	0.00 %	0.24 %	1.526E-01	0.09 %	0.09 %	0.00 %	0.12 %
1400	1.350E-01	0.25 %	0.09 %	0.01 %	0.27 %	1.354E-01	0.08 %	0.08 %	0.01 %	0.12 %
1500	1.188E-01	0.24 %	0.08 %	0.01 %	0.26 %	1.192E-01	0.08 %	0.08 %	0.01 %	0.11 %
1600	1.042E-01	0.24 %	0.08 %	0.01 %	0.25 %	1.045E-01	0.07 %	0.07 %	0.01 %	0.10 %
1700	9.123E-02	0.31 %	0.07 %	0.01 %	0.32 %	9.149E-02	0.08 %	0.07 %	0.01 %	0.11 %
1800	7.979E-02	0.41 %	0.07 %	0.02 %	0.41 %	8.002E-02	0.09 %	0.07 %	0.02 %	0.12 %
1900	6.968E-02	0.50 %	0.07 %	0.02 %	0.50 %	6.992E-02	0.10 %	0.06 %	0.02 %	0.12 %
2000	6.082E-02	0.56 %	0.07 %	0.05 %	0.57 %	6.105E-02	0.11 %	0.06 %	0.05 %	0.13 %
2100	5.321E-02	0.54 %	0.06 %	0.02 %	0.54 %	5.335E-02	0.10 %	0.06 %	0.02 %	0.12 %
2200	4.680E-02	0.56 %	0.06 %	0.00 %	0.57 %	4.677E-02	0.10 %	0.06 %	0.00 %	0.11 %
2300	4.128E-02	0.63 %	0.06 %	0.01 %	0.64 %	4.115E-02	0.12 %	0.06 %	0.01 %	0.14 %
2400	3.625E-02	1.03 %	0.06 %	0.07 %	1.04 %	3.627E-02	0.13 %	0.05 %	0.07 %	0.16 %
2500	3.210E-02	0.80 %	0.06 %	0.05 %	0.80 %	3.224E-02	0.11 %	0.05 %	0.05 %	0.13 %

Table 12-10 NPL Results for FEL BN 9101 220. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 220	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.327E-04	0.87 %	0.48 %	2.00 %	2.23 %	1.338E-04	0.46 %	0.45 %	2.00 %	2.10 %
260	2.327E-04	0.65 %	0.46 %	2.00 %	2.15 %	2.347E-04	0.35 %	0.43 %	2.00 %	2.08 %
270	3.874E-04	0.49 %	0.44 %	2.00 %	2.11 %	3.905E-04	0.28 %	0.41 %	2.00 %	2.06 %
280	6.158E-04	0.38 %	0.43 %	1.50 %	1.61 %	6.205E-04	0.24 %	0.40 %	1.50 %	1.57 %
290	9.401E-04	0.30 %	0.41 %	1.00 %	1.12 %	9.467E-04	0.21 %	0.38 %	1.00 %	1.09 %
300	1.384E-03	0.26 %	0.40 %	0.25 %	0.54 %	1.393E-03	0.19 %	0.37 %	0.25 %	0.49 %
310	1.974E-03	0.22 %	0.39 %	0.28 %	0.53 %	1.985E-03	0.18 %	0.36 %	0.28 %	0.49 %
320	2.736E-03	0.20 %	0.37 %	0.25 %	0.49 %	2.749E-03	0.17 %	0.35 %	0.25 %	0.46 %
330	3.694E-03	0.19 %	0.36 %	0.28 %	0.49 %	3.709E-03	0.16 %	0.34 %	0.28 %	0.47 %
340	4.874E-03	0.18 %	0.35 %	0.33 %	0.51 %	4.890E-03	0.15 %	0.33 %	0.33 %	0.49 %
350	6.296E-03	0.17 %	0.34 %	0.36 %	0.52 %	6.314E-03	0.15 %	0.32 %	0.36 %	0.50 %
360	7.981E-03	0.16 %	0.33 %	0.43 %	0.57 %	7.999E-03	0.14 %	0.31 %	0.43 %	0.55 %
370	9.943E-03	0.15 %	0.32 %	0.46 %	0.58 %	9.960E-03	0.14 %	0.30 %	0.46 %	0.57 %
380	1.219E-02	0.15 %	0.31 %	0.52 %	0.63 %	1.221E-02	0.13 %	0.29 %	0.52 %	0.61 %
390	1.474E-02	0.15 %	0.31 %	0.50 %	0.60 %	1.475E-02	0.13 %	0.29 %	0.50 %	0.59 %
400	1.759E-02	0.14 %	0.30 %	0.46 %	0.57 %	1.760E-02	0.13 %	0.28 %	0.46 %	0.55 %
450	3.616E-02	0.14 %	0.27 %	0.10 %	0.32 %	3.614E-02	0.13 %	0.25 %	0.10 %	0.29 %
500	6.068E-02	0.13 %	0.24 %	0.01 %	0.27 %	6.062E-02	0.11 %	0.22 %	0.01 %	0.25 %
550	8.845E-02	0.11 %	0.22 %	0.00 %	0.24 %	8.834E-02	0.10 %	0.20 %	0.00 %	0.23 %
555	9.129E-02	0.11 %	0.22 %	0.00 %	0.24 %	9.118E-02	0.10 %	0.20 %	0.00 %	0.22 %
600	1.165E-01	0.10 %	0.20 %	0.00 %	0.22 %	1.164E-01	0.09 %	0.19 %	0.00 %	0.21 %
650	1.423E-01	0.10 %	0.18 %	0.00 %	0.21 %	1.422E-01	0.09 %	0.17 %	0.00 %	0.19 %
700	1.642E-01	0.10 %	0.17 %	0.00 %	0.20 %	1.640E-01	0.09 %	0.16 %	0.00 %	0.18 %
750	1.812E-01	0.09 %	0.16 %	0.01 %	0.18 %	1.811E-01	0.09 %	0.15 %	0.01 %	0.17 %
800	1.932E-01	0.09 %	0.15 %	0.00 %	0.17 %	1.931E-01	0.08 %	0.14 %	0.00 %	0.16 %
850	2.005E-01	0.08 %	0.14 %	0.00 %	0.16 %	2.004E-01	0.08 %	0.13 %	0.00 %	0.15 %
900	2.037E-01	0.08 %	0.13 %	0.00 %	0.16 %	2.037E-01	0.08 %	0.12 %	0.00 %	0.15 %
950	2.034E-01	0.08 %	0.13 %	0.01 %	0.15 %	2.035E-01	0.08 %	0.12 %	0.01 %	0.14 %
1000	2.004E-01	0.08 %	0.12 %	0.01 %	0.15 %	2.005E-01	0.08 %	0.11 %	0.01 %	0.14 %
1100	1.889E-01	0.10 %	0.11 %	0.01 %	0.15 %	1.890E-01	0.08 %	0.10 %	0.01 %	0.13 %
1200	1.731E-01	0.13 %	0.10 %	0.02 %	0.16 %	1.732E-01	0.09 %	0.09 %	0.02 %	0.13 %
1300	1.556E-01	0.15 %	0.09 %	0.00 %	0.18 %	1.556E-01	0.09 %	0.09 %	0.00 %	0.13 %
1400	1.381E-01	0.17 %	0.09 %	0.01 %	0.19 %	1.381E-01	0.09 %	0.08 %	0.01 %	0.12 %
1500	1.217E-01	0.17 %	0.08 %	0.01 %	0.19 %	1.216E-01	0.08 %	0.08 %	0.01 %	0.11 %
1600	1.067E-01	0.15 %	0.08 %	0.01 %	0.17 %	1.066E-01	0.08 %	0.07 %	0.01 %	0.11 %
1700	9.339E-02	0.18 %	0.07 %	0.01 %	0.20 %	9.335E-02	0.09 %	0.07 %	0.01 %	0.11 %
1800	8.164E-02	0.23 %	0.07 %	0.02 %	0.24 %	8.157E-02	0.11 %	0.07 %	0.02 %	0.13 %
1900	7.129E-02	0.26 %	0.07 %	0.02 %	0.27 %	7.118E-02	0.12 %	0.06 %	0.02 %	0.14 %
2000	6.223E-02	0.30 %	0.07 %	0.05 %	0.31 %	6.210E-02	0.13 %	0.06 %	0.05 %	0.16 %
2100	5.443E-02	0.30 %	0.06 %	0.02 %	0.30 %	5.432E-02	0.13 %	0.06 %	0.02 %	0.14 %
2200	4.784E-02	0.30 %	0.06 %	0.00 %	0.31 %	4.773E-02	0.12 %	0.06 %	0.00 %	0.13 %
2300	4.225E-02	0.35 %	0.06 %	0.01 %	0.35 %	4.203E-02	0.16 %	0.06 %	0.01 %	0.17 %
2400	3.728E-02	0.62 %	0.06 %	0.07 %	0.63 %	3.685E-02	0.20 %	0.05 %	0.07 %	0.21 %
2500	3.280E-02	0.43 %	0.06 %	0.05 %	0.44 %	3.265E-02	0.11 %	0.05 %	0.05 %	0.13 %

Table 12-11 NPL Results for FEL BN 9101 252. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 252	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.243E-04	1.12 %	0.48 %	2.00 %	2.34 %	1.266E-04	1.25 %	0.45 %	2.00 %	2.40 %
260	2.181E-04	0.83 %	0.46 %	2.00 %	2.21 %	2.213E-04	0.93 %	0.43 %	2.00 %	2.25 %
270	3.633E-04	0.62 %	0.44 %	2.00 %	2.14 %	3.672E-04	0.71 %	0.41 %	2.00 %	2.16 %
280	5.779E-04	0.47 %	0.43 %	1.50 %	1.63 %	5.823E-04	0.56 %	0.40 %	1.50 %	1.65 %
290	8.827E-04	0.36 %	0.41 %	1.00 %	1.14 %	8.870E-04	0.46 %	0.38 %	1.00 %	1.17 %
300	1.301E-03	0.29 %	0.40 %	0.25 %	0.55 %	1.304E-03	0.40 %	0.37 %	0.25 %	0.60 %
310	1.856E-03	0.25 %	0.39 %	0.28 %	0.54 %	1.857E-03	0.36 %	0.36 %	0.28 %	0.58 %
320	2.573E-03	0.22 %	0.37 %	0.25 %	0.50 %	2.570E-03	0.32 %	0.35 %	0.25 %	0.54 %
330	3.476E-03	0.20 %	0.36 %	0.28 %	0.50 %	3.467E-03	0.30 %	0.34 %	0.28 %	0.53 %
340	4.588E-03	0.19 %	0.35 %	0.33 %	0.52 %	4.570E-03	0.28 %	0.33 %	0.33 %	0.54 %
350	5.930E-03	0.18 %	0.34 %	0.36 %	0.53 %	5.902E-03	0.26 %	0.32 %	0.36 %	0.55 %
360	7.521E-03	0.17 %	0.33 %	0.43 %	0.57 %	7.478E-03	0.25 %	0.31 %	0.43 %	0.58 %
370	9.374E-03	0.16 %	0.32 %	0.46 %	0.59 %	9.315E-03	0.23 %	0.30 %	0.46 %	0.60 %
380	1.150E-02	0.16 %	0.31 %	0.52 %	0.63 %	1.142E-02	0.22 %	0.29 %	0.52 %	0.64 %
390	1.391E-02	0.16 %	0.31 %	0.50 %	0.61 %	1.381E-02	0.22 %	0.29 %	0.50 %	0.62 %
400	1.661E-02	0.15 %	0.30 %	0.46 %	0.57 %	1.648E-02	0.21 %	0.28 %	0.46 %	0.58 %
450	3.422E-02	0.15 %	0.27 %	0.10 %	0.32 %	3.396E-02	0.21 %	0.25 %	0.10 %	0.34 %
500	5.754E-02	0.14 %	0.24 %	0.01 %	0.27 %	5.714E-02	0.19 %	0.22 %	0.01 %	0.29 %
550	8.403E-02	0.12 %	0.22 %	0.00 %	0.25 %	8.352E-02	0.16 %	0.20 %	0.00 %	0.26 %
555	8.674E-02	0.12 %	0.22 %	0.00 %	0.24 %	8.623E-02	0.15 %	0.20 %	0.00 %	0.25 %
600	1.108E-01	0.11 %	0.20 %	0.00 %	0.23 %	1.103E-01	0.14 %	0.19 %	0.00 %	0.23 %
650	1.356E-01	0.10 %	0.18 %	0.00 %	0.21 %	1.350E-01	0.14 %	0.17 %	0.00 %	0.22 %
700	1.565E-01	0.10 %	0.17 %	0.00 %	0.20 %	1.560E-01	0.13 %	0.16 %	0.00 %	0.21 %
750	1.729E-01	0.10 %	0.16 %	0.01 %	0.19 %	1.723E-01	0.13 %	0.15 %	0.01 %	0.20 %
800	1.844E-01	0.09 %	0.15 %	0.00 %	0.18 %	1.839E-01	0.12 %	0.14 %	0.00 %	0.19 %
850	1.913E-01	0.09 %	0.14 %	0.00 %	0.17 %	1.909E-01	0.12 %	0.13 %	0.00 %	0.18 %
900	1.943E-01	0.09 %	0.13 %	0.00 %	0.16 %	1.940E-01	0.12 %	0.12 %	0.00 %	0.17 %
950	1.941E-01	0.09 %	0.13 %	0.01 %	0.15 %	1.938E-01	0.13 %	0.12 %	0.01 %	0.17 %
1000	1.912E-01	0.09 %	0.12 %	0.01 %	0.15 %	1.909E-01	0.13 %	0.11 %	0.01 %	0.17 %
1100	1.802E-01	0.12 %	0.11 %	0.01 %	0.16 %	1.799E-01	0.16 %	0.10 %	0.01 %	0.19 %
1200	1.652E-01	0.16 %	0.10 %	0.02 %	0.19 %	1.648E-01	0.18 %	0.09 %	0.02 %	0.20 %
1300	1.485E-01	0.20 %	0.09 %	0.00 %	0.22 %	1.482E-01	0.18 %	0.09 %	0.00 %	0.20 %
1400	1.317E-01	0.23 %	0.09 %	0.01 %	0.24 %	1.315E-01	0.18 %	0.08 %	0.01 %	0.20 %
1500	1.159E-01	0.22 %	0.08 %	0.01 %	0.24 %	1.158E-01	0.17 %	0.08 %	0.01 %	0.19 %
1600	1.016E-01	0.20 %	0.08 %	0.01 %	0.22 %	1.014E-01	0.16 %	0.07 %	0.01 %	0.17 %
1700	8.887E-02	0.24 %	0.07 %	0.01 %	0.25 %	8.866E-02	0.19 %	0.07 %	0.01 %	0.20 %
1800	7.775E-02	0.29 %	0.07 %	0.02 %	0.30 %	7.740E-02	0.23 %	0.07 %	0.02 %	0.24 %
1900	6.798E-02	0.34 %	0.07 %	0.02 %	0.35 %	6.755E-02	0.27 %	0.06 %	0.02 %	0.27 %
2000	5.940E-02	0.39 %	0.07 %	0.05 %	0.40 %	5.902E-02	0.31 %	0.06 %	0.05 %	0.32 %
2100	5.195E-02	0.38 %	0.06 %	0.02 %	0.39 %	5.173E-02	0.29 %	0.06 %	0.02 %	0.30 %
2200	4.558E-02	0.40 %	0.06 %	0.00 %	0.41 %	4.554E-02	0.28 %	0.06 %	0.00 %	0.29 %
2300	4.018E-02	0.46 %	0.06 %	0.01 %	0.46 %	4.017E-02	0.38 %	0.06 %	0.01 %	0.38 %
2400	3.546E-02	0.69 %	0.06 %	0.07 %	0.69 %	3.528E-02	0.39 %	0.05 %	0.07 %	0.40 %
2500	3.121E-02	0.61 %	0.06 %	0.05 %	0.61 %	3.112E-02	0.24 %	0.05 %	0.05 %	0.26 %

12.9 Lamp Behaviour

12.9.1 NMIJ Lamps

The following lamps were supplied to NMIJ by NPL:

FEL BN 9101 213 FEL BN 9101 220 FEL BN 9101 252

Measurements were made in the sequence: NPL – NMIJ – NPL – NMIJ

There was an initial measurement of the lamps at NPL prior to this sequence, followed by a measurement at NMIJ. However, this first NMIJ measurement was made at the wrong current because they did not receive the second protocol. Therefore, these first measurements by NPL and NMIJ have been ignored for the comparison.

NMIJ measured all intercomparison wavelengths except 555 nm.

12.9.2 Lamp history

Table 12-12 Lamp history for FEL BN 9101 213

Date period	Activity	Burn hours:minutes
March – April 2001	0th round measurements at NPL (ignored)	6:50
April 2001	Hand-carried to NMIJ	
January 2002	0th round measurements at NMIJ @ 8.3 A	3:44
February 2002	Hand-carried to NPL	
July – September 2002	1st round measurements at NPL	12:19
September 2002	Hand-carried to NMIJ	
December 2002	1st round measurements at NMIJ	3:44
February 2003	Hand-carried to NPL	
June – August 2003	2nd round measurements at NPL	12:25
October 2003	Hand-carried to NMIJ	
December 2003	2nd round measurements at NMIJ	3:47

Table 12-13 Lamp history for FEL BN 9101 220

Date period	Activity	Burn hours:minutes
March – April 2001	0th round measurements at NPL (ignored)	9:34
April 2001	Hand-carried to NMIJ	
January 2002	0th round measurements at NMIJ @ 8.3 A	3:44
February 2002	Hand-carried to NPL	
July – September 2002	1st round measurements at NPL	11:15
September 2002	Hand-carried to NMIJ	
December 2002	1st round measurements at NMIJ	3:44
February 2003	Hand-carried to NPL	
June – August 2003	2nd round measurements at NPL	12:21
October 2003	Hand-carried to NMIJ	
December 2003	2nd round measurements at NMIJ	3:47

Table 12-14 Lamp history for FEL BN 9101 252

Date period	Activity	Burn hours:minutes
March – April 2001	0th round measurements at NPL (ignored)	6:50
April 2001	Hand-carried to NMIJ	
January 2002	0th round measurements at NMIJ @ 8.3 A	3:44
February 2002	Hand-carried to NPL	
July – September 2002	1st round measurements at NPL	12:19
September 2002	Hand-carried to NMIJ	
December 2002	1st round measurements at NMIJ	3:44
February 2003	Hand-carried to NPL	
June – August 2003	2nd round measurements at NPL	12:25
October 2003	Hand-carried to NMIJ	
December 2003	2nd round measurements at NMIJ	3:47

12.9.3 Lamp electrical stability

The lamp was operated at 8.100 A at both laboratories, the lamp voltage measured was:

Table 12-15 Electrical Potential across lamp as measured by both laboratories

Lamp	Potential first NPL measurement	Potential first NMIJ measurement	Potential second NPL measurement	Potential second NMIJ measurement
FEL BN 9101 213	103.1 V	103.1 V	103.1 V	103.1 V
FEL BN 9101 220	107.4 V	107.4 V	107.3 V	107.4 V
FEL BN 9101 252	104.0 V	104.1 V	104.2 V	104.1 V

12.9.4 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the NMIJ lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

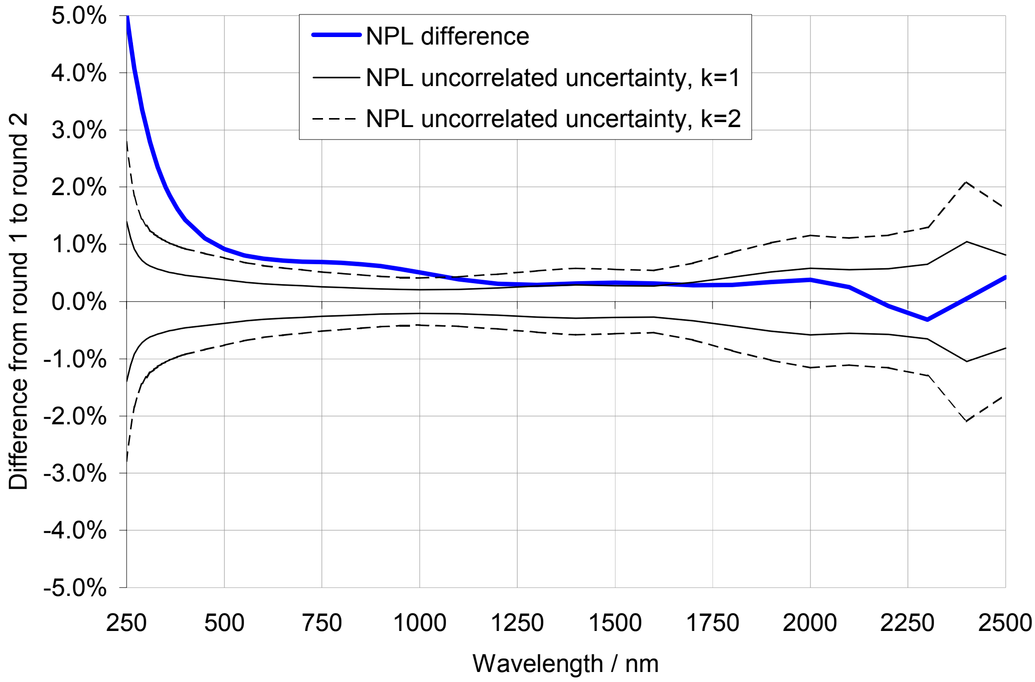

Figure 12-3 Difference between first and second round measurements of FEL BN 9101 213 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

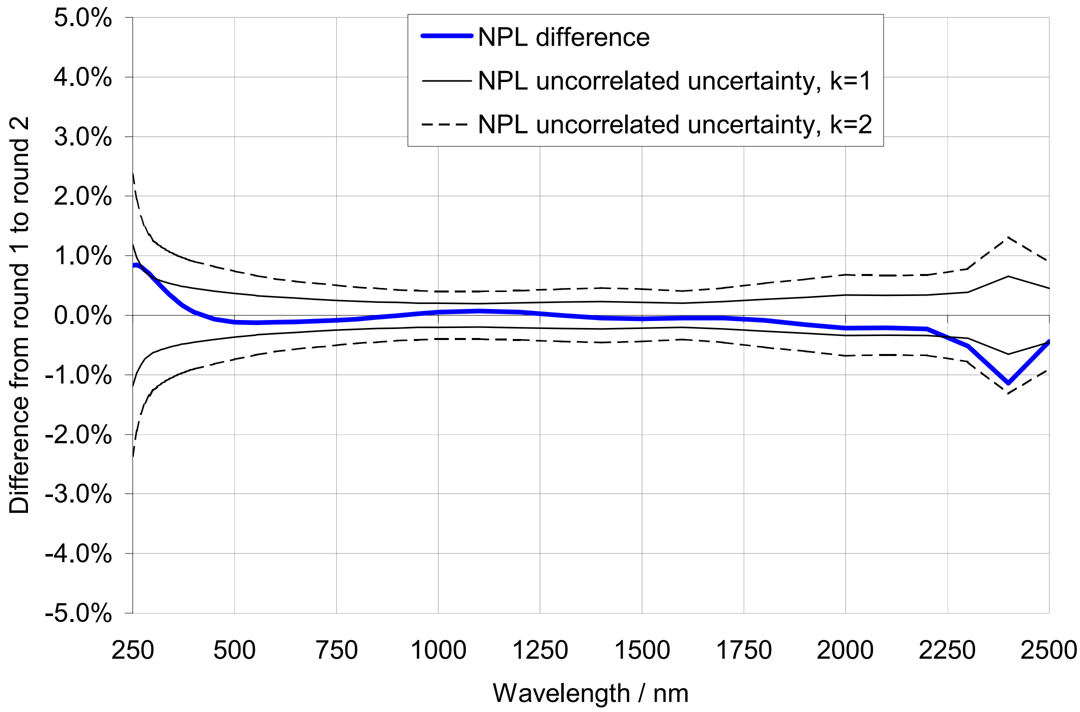

Figure 12-4 Difference between first and second round measurements of FEL BN 9101 220 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

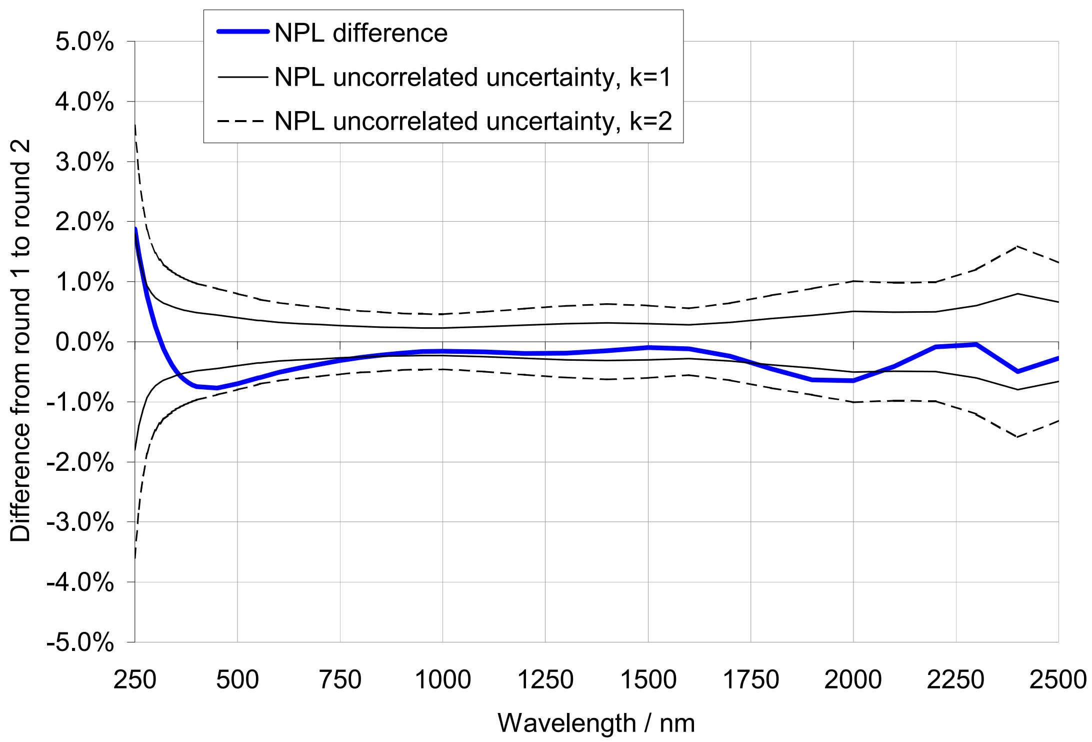

Figure 12-5 Difference between first and second round measurements of FEL BN 9101 252 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

12.9.5 Lamp stability from NMIJ measurements

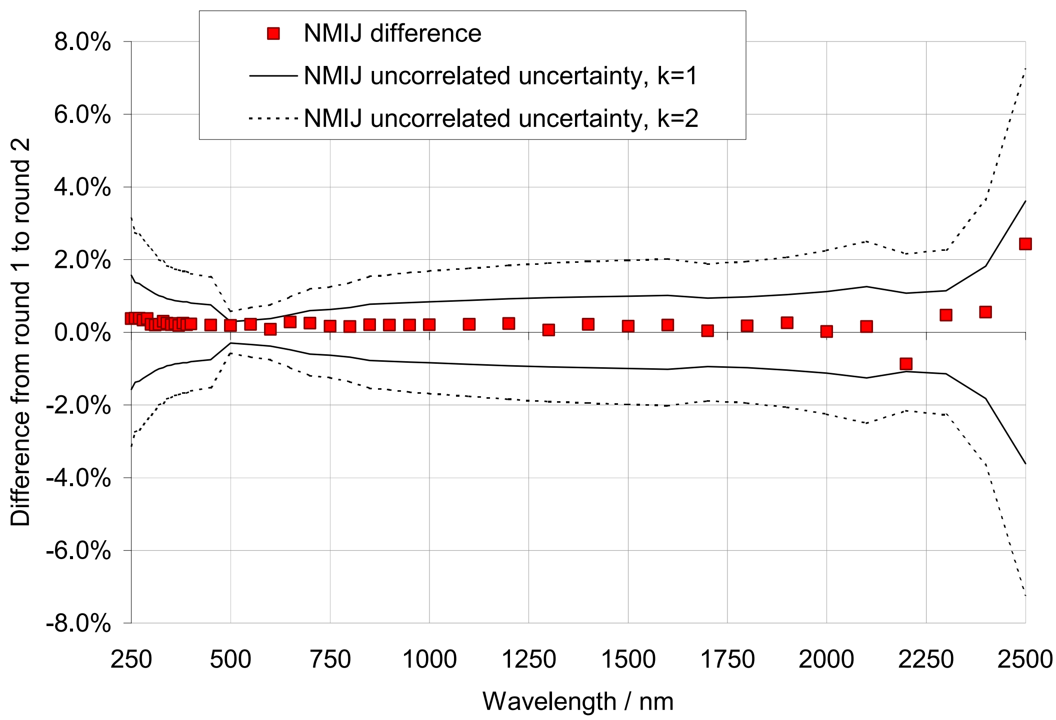

Figure 12-6 Difference between first and second round measurements of FEL BN 9101 213 by NMIJ. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NMIJ measurements

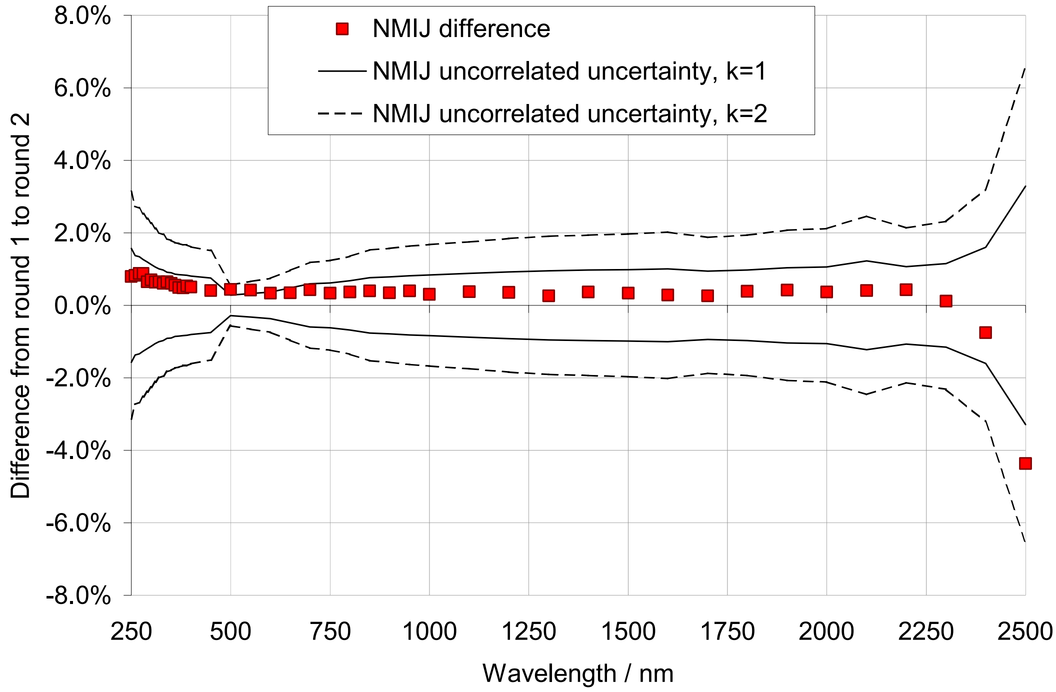

Figure 12-7 Difference between first and second round measurements of FEL BN 9101 220 by NMIJ. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NMIJ measurements

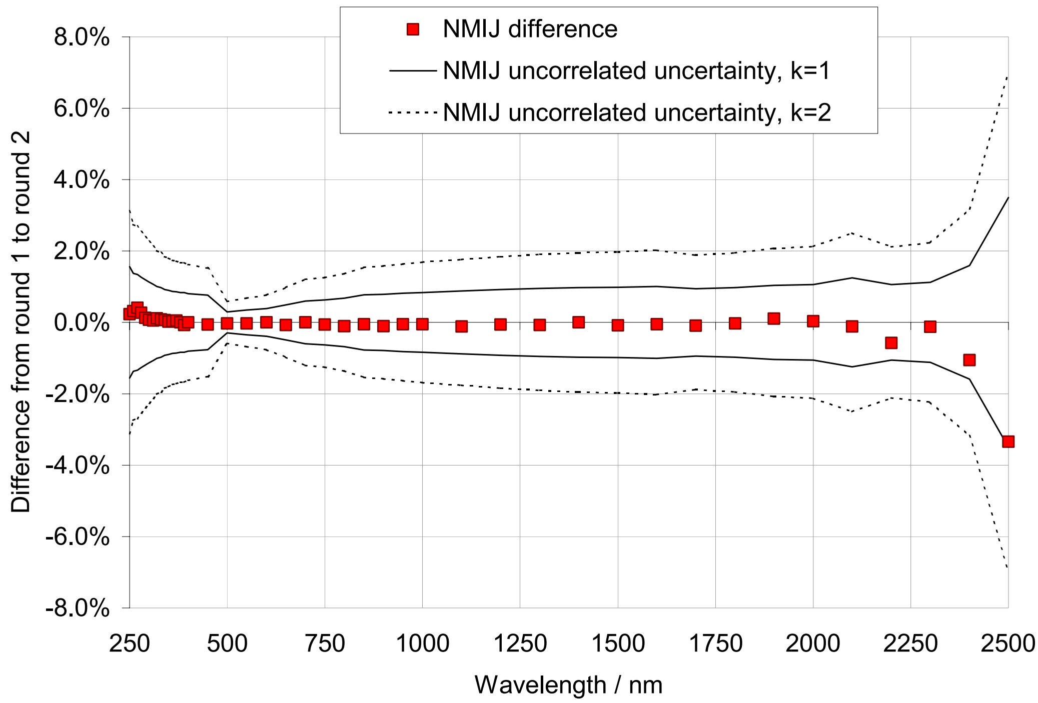

Figure 12-8 Difference between first and second round measurements of FEL BN 9101 252 by NMIJ. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NMIJ measurements

12.10 Bilateral comparison between NMIJ and the comparison scale

This graph shows the difference between the NMIJ and NPL measurements of the NMIJ lamps. A version of this graph normalised to show the relative difference between the lamps, but not the absolute difference between the measurements was used to assist in choosing which lamp measurements to use.

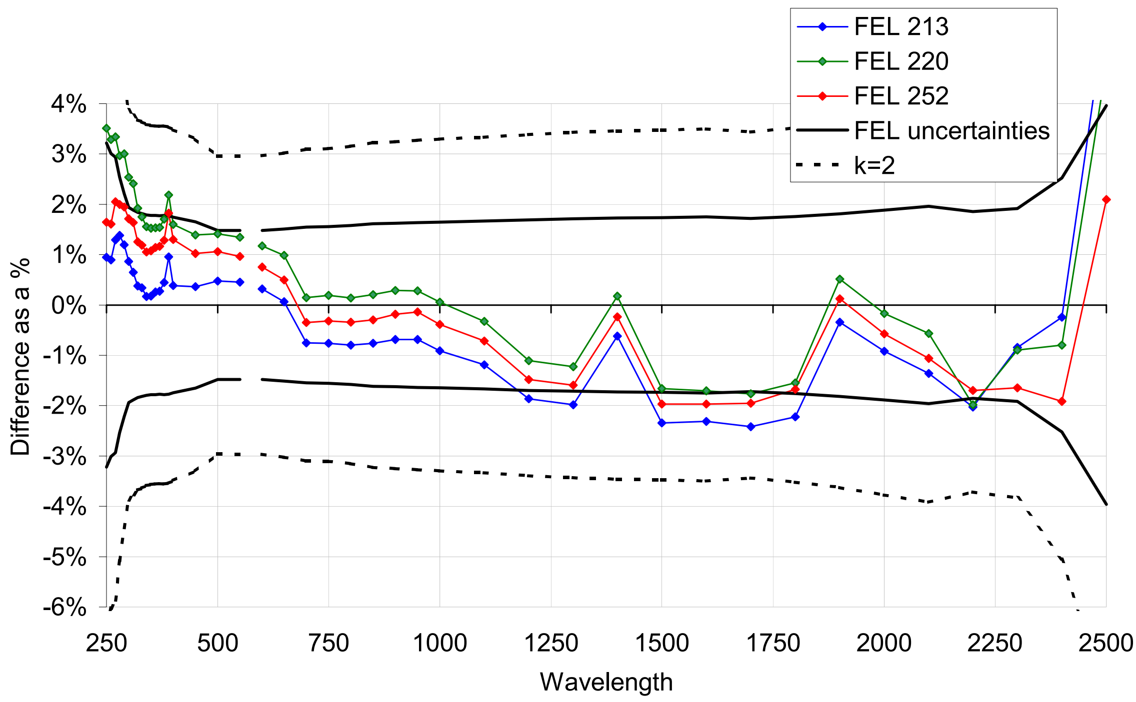

Figure 12-9 Bilateral comparisons of the NMIJ lamps to the comparison reference scale

12.11 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to NMIJ the information in the graphs Figure 12-3 to Figure 12-9. It was decided that both participant measurements and both pilot measurements would be used for both FEL BN 9101 220 and for FEL BN 9101 252, but that only the second NPL measurement would be used for FEL BN 9101 213. This lamp shows a difference between the rounds that is larger than NPL's uncertainties. Therefore, it is assumed that the lamp changed on the first journey from NPL to NMIJ.

13 Measurements at NPL

It should be noted that although much of the following facility description and technique is common to that used for establishing the key comparison reference scale (used to allow intercomparison between participants in key comparison K1-a) it differs in detail. The purpose of this reference was only to ensure long-term stability and maintain low uncertainty due to the comparison process, but whilst also seeking to minimise effort of the pilot. The differences between the NPL primary scale and the comparison scale are discussed in Chapter 3.

13.1 Primary scale realisation

The NPL spectral irradiance scale was formerly integrated into our measurement services and consequently became our disseminated scale in May 2003, as reported at the last CCPR meeting. The scale is based on the use of the absolute spectral radiance emitted from a high temperature blackbody through Planck's law. The critical input variable being thermodynamic temperature, which is determined by a filter radiometer whose spectral response has been calibrated against the NPL primary standard cryogenic radiometer. This traceability chain is shown schematically in Figure 13-1.

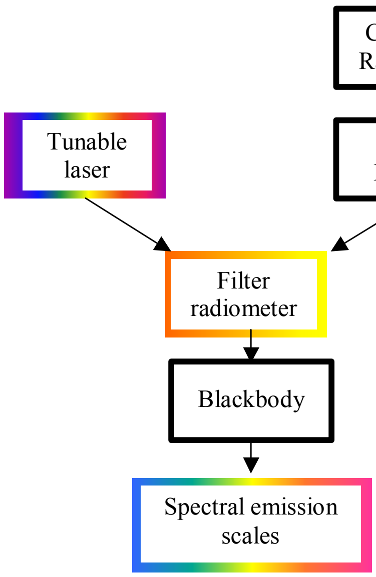

Figure 13-1 Traceability chain for the primary spectral irradiance scale at NPL

The traceability to SI comes from the determination of the blackbody temperature through filter radiometry.

Filter radiometers were calibrated by comparison with two trap detectors against a tuneable laser-illuminated integrating sphere source. Measurements were made in approximately 0.1 nm intervals across the full transmittance range of the filter radiometer. The trap detectors, in turn, were calibrated against the cryogenic radiometer. This was done with a direct laser beam as a source. The calibrated aperture on the trap detector was used to convert spectral responsivity to spectral irradiance responsivity. A more detailed description of this process can be found in the literature [1].

13.2 Description of the calibration facility

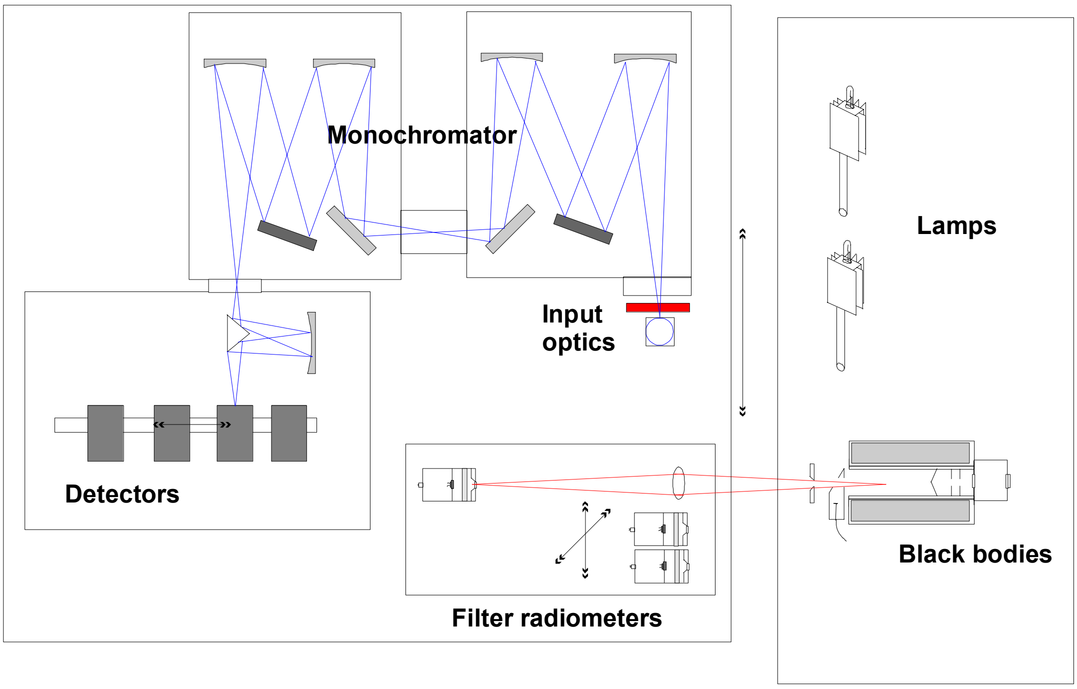

Figure 13-2 SRIPS Facility diagram

The Spectral Radiance and Irradiance Primary Scales (SRIPS) facility, shown schematically above in Figure 13-2, was used not only for establishing the NPL spectral irradiance scale, but also for all NPL's measurements of lamps, as pilot, for this Key Comparison. The primary source was a BB3500 blackbody source purchased from VNIIOFI, typically operated at temperatures around 3050 K. The thermodynamic temperature of the blackbody was determined absolutely using a group of filter radiometers built at NPL and calibrated traceably to the primary cryogenic radiometer at NPL.

A McPherson 207 double grating monochromator was used to select the wavelengths and measurements were made with a range of photodetectors. The monochromator and detectors were mounted on a large translation stage that could be moved in front of each source in turn. The entire facility was computer controlled.

13.2.1 The Blackbody Source

The primary source was a BB3500 blackbody supplied to NPL by VNIIOFI in early 1999. This source is similar in design to the BB3200pg used at a number of other laboratories, which has been extensively investigated [2]. It consists of a cavity made from pyrolytic graphite rings that are directly heated by an electrical current of around 650 A. Measurements at NPL [3] showed the uniformity of the cavity to be < ± 0.05 % and, under active optical stabilisation from the front, a long-term average stability of < ± 0.005 % and short term stability of ± 0.2 % (in radiance) at 800 nm were achieved.

Investigations have shown [4] that this blackbody suffers from the same ultraviolet absorption around 380 nm as has been observed with the BB3200pg [5]. For this reason, the blackbody temperature was kept relatively low, around 3050 K.

The radiance of the blackbody was determined from Planck's law, based on a measure of its thermodynamic temperature via filter radiometers, and the geometry defined by a water-cooled, brass, diamond-turned, aperture in front of the blackbody and the aperture on the integrating sphere at the front of the monochromator.

13.2.2 The Monochromator

The monochromator used was a McPherson 207 monochromator, arranged in an additive-mode double Czerny-Turner configuration. The monochromator was used with four grating pairs. These are listed in Table 13-1.

Table 13-1 SRIPS monochromator gratings

Grating "name"	Lines per mm	Blaze wavelength	Wavelength range	Measurement Bandwidth
UV	1200	250 nm	300 – 400 nm	2.5 nm
Visible	1200	500 nm	350 – 1000 nm	2.5 nm
IR	600	1.2 µm	900 – 1700 nm	5 nm
IR2	300	2.5 µm	1600 – 3000 nm	5 nm

Light entered the monochromator through a 50 mm diameter spectralon integrating sphere, with a 16 mm diameter precision aperture, at the entrance port of the monochromator. Order sorting filters were placed between this sphere and the monochromator.

The order sorting filter blocking, monochromator wavelength accuracy and stray light have all been thoroughly investigated [6] and an assessment of their uncertainty contribution is presented in this section.

Unfortunately the monochromator could not be used below 300 nm because it suffered from a re-entrant spectrum, where the zeroth order light reflected off the first mirror and back onto the grating. Whilst under normal circumstances a replacement monochromator would have been sought, due to perceived time constraints at the start of the project associated with a planned move of the facility and the need to complete the comparison before such a move, this was not carried out. A compromise solution was therefore devised for this region of the spectrum.

For wavelengths below 300 nm, narrow band interference filters were used for wavelength selection and to establish a relative scale. Additional filters at wavelengths between 300 and 350 nm were used to ensure a significant overlap with the monochromator measurements and thus allow absolute values to be determined. The filters were housed in a filter wheel in front of a GaAsP detector. A UG5 filter was also used to reduce longer wavelength stray light. This is described in more detail below.

13.2.3 Detectors

On the SRIPS facility a range of photodiodes, optimised for each spectral region, were used. A GaAsP photodiode was used for wavelengths below 300 nm with the interference filters. A Si photodiode was used from 300 nm to 1100 nm; and from 1000 nm to 1600 nm, an InGaAs detector. For wavelengths from 1600 nm to 2500 nm an InSb photoconductor with an integral cold filter, to minimise sensitivity to longer wavelengths, was used in a phase sensitive detection mode.

All the detectors were temperature stabilised to minimise drifts. The InSb detector was cooled by a liquid nitrogen filled housing. The other detectors were temperature-controlled through water-cooled housings.

The signal from these detectors was amplified using transimpedance current to voltage converters manufactured by Vinculum Ltd. The amplifiers were housed in the same cooled housing as the detectors. The InSb detector was further amplified with the voltage amplifier of the phase sensitive detection system following rectification through the phase locked to the frequency of an optical chopper placed in front of the integrating sphere.

13.2.4 Filter Radiometers

The blackbody temperature was measured with an 800 nm filter radiometer used in conjunction with a geometric system to allow it to measure spectral radiance, in a similar manner to that described previously [1].

The filter radiometer comprised a diamond-turned brass aperture, a wedged 10 nm bandwidth interference filter and a silicon photodiode and was housed in a water-cooled jacket. A Vinculum transimpedance amplifier was connected to the silicon photodiode and held in the same water jacket.

A 300 mm focal length lens was used at a distance of 600 mm to image light from the blackbody aperture so as to overfill the filter radiometer aperture. This aperture, and a thin-film aperture on the lens defined the geometry of the measurement. The filter radiometer was used in the same *f*/55 geometry in which it had been calibrated. The lens transmittance was calculated using the Fresnel equations, which had previously [7] been shown to agree within 0.05 % of the measured value at this wavelength. A correction was also applied for differences in "size-of-source" based on measurements using similar techniques to those described previously [1].

Additional filter radiometers operating in "irradiance mode" (without a lens) were used to monitor any drift in the primary filter radiometer.

13.3 Laboratory Conditions

Measurements were made in a laboratory maintained at 20 ± 3 ºC. The humidity of the laboratory was not controlled.

13.4 Laboratory transfer standards

All measurements were made directly against the primary ultra-high temperature blackbody and no intermediate transfer standards were used. In addition to the lamps for this comparison, NPL reference lamps were calibrated throughout the comparison and in early 2003 FEL-type lamps were calibrated to hold the primary spectral irradiance scale for NPL. These lamps are used to disseminate that scale to the customers.

13.5 Measurement Procedure

The full tungsten spectral range (250 to 2500 nm) was split into five regions, corresponding to wavelengths measurable on each of the four gratings in Table 13-1 and the UV filter wheel. Each wavelength region overlapped with the longer wavelength region by at least two wavelengths. Each measurement region corresponded to a separate lamp switch on and warm up. The IR region was subdivided for two detectors, but the lamp was not switched off between those measurements.

Table 13-2 Wavelengths measured at NPL for the CCPR K1-a comparison

Name	Detector	Grating	Start wavelength	Stop wavelength	Step size and extra wavelengths
UVFW	GaAsP	filter wheel	250	350	(250-310 in 10 nm + 330, 350 nm)
UV	Si	UV	300	400	10 nm
Vis	Si	Visible	350	1000	50 nm + 555 nm
IR Si	Si	IR	800	1150	50 nm
IR InGaAs	InGaAs	IR	1100	1700	50 nm
IR2	InSb	IR2	1600	2500	100 nm

All lamps were measured in all spectral regions on at least two occasions. The lamps were realigned between these measurements in a new position on the SRIPS facility, which also used a different resistor for determining the lamp current.

For the UVFW, UV grating, Visible grating and IR grating regions, measurements were made in the following sequence:

1) Measurement of the temperature of the blackbody with a filter radiometer
2) Measurement of the blackbody with the SRIPS monochromator over a particular wavelength range, e.g. 350 (50) 1000 nm.
3) Measurement of the temperature of the blackbody with the filter radiometer. If it had changed too much, steps 1-3 were repeated and the previous results discarded.
4) Measurement of the lamps with the SRIPS monochromator over the same wavelength range, sequentially with each lamp being turned on after the previous was turned off
5) Measurement of the temperature of the blackbody with a filter radiometer
6) Measurement of the blackbody with the SRIPS monochromator over the same wavelength range
7) Measurement of the temperature of the blackbody with the filter radiometer.

In the IR2 region, the blackbody was less sensitive to any temperature variation, but the monochromator system was less stable. Therefore, the measurement sequence was altered:

1) Measurement of the temperature of the blackbody with a filter radiometer
2) Measurement of the blackbody with the SRIPS monochromator at one wavelength
3) Measurement of the lamp with the SRIPS monochromator at that wavelength
4) Measurement of the blackbody with the SRIPS monochromator at that wavelength
5) Repetition of steps 2 to 4 for all the other relevant wavelengths
6) Measurement of the temperature of the blackbody with the filter radiometer.

13.6 Analysis of Measurement Results

13.6.1 Measurement Equation — Monochromator

At any wavelength, the SRIPS facility measures both the blackbody and the lamp. The signal when measuring the blackbody is:

$$V^{\mathrm{BB}}(\lambda) = \pi\, g \cdot \int R^{\mathrm{SRIPS,BB}}(l) \cdot L^{BB}(T,l) \cdot S(l,\lambda) \cdot dl + \text{stray light} + \text{electronic noise} \quad (13\text{-}1)$$

Here, g is the geometric factor, which is described below. V^{BB} is the signal measured by the SRIPS detector, $R^{\mathrm{SRIPS,BB}}$ is the responsivity of the SRIPS facility during the blackbody measurements, L^{BB} is the radiance of the blackbody as given by Planck's law.

S is the slit function of the monochromator, normalised to have a unit area and l is an integration constant, equivalent to wavelength, but only over the slit width. The integral is over the extent of the slit function, usually 5–10 nm. Over this wavelength range there will be a small change in the blackbody radiance and also a (usually small) change in the SRIPS responsivity, therefore these functions lie inside the integral. Stray light and electrical noise were determined using a shutter.

The actual signal SRIPS measures when calibrating the lamp is given by a similar equation (*A* is the area of the integrating sphere aperture):

$$V^{\text{lamp}}(\lambda) = A \cdot \int R^{\text{SRIPS,lamp}}(l) \cdot E^{\text{lamp}}(\lambda) \cdot S(l,\lambda) \cdot dl + \text{stray light} + \text{electronic noise} \quad (13\text{-}2)$$

And when the second blackbody scan is made, the signal is given by Equation (13-1) again, although the stray-light and electrical noise may be different and the responsivity of SRIPS may have drifted a small amount.

If the sources can be considered to be varying only slowly with wavelength over the slit function, then the integrals can be removed. This approximation is reasonable when the two sources are spectrally similar, as for a blackbody and lamp, as is discussed below.

Taking this approximation, the two equations can be combined to give:

$$E^{\text{lamp}}(\lambda) = K\kappa(\lambda)\frac{\pi g}{A} L^{\text{BB}}(\lambda;T)\frac{V^{\text{lamp}}(\lambda)}{V^{\text{BB}}(\lambda)}\frac{R^{\text{SRIPS,BB}}(\lambda)}{R^{\text{SRIPS,lamp}}(\lambda)} \quad (13\text{-}3)$$

Where E^{lamp} is the desired lamp irradiance. The final term should be unity, if the SRIPS facility has not drifted. It is left in at this stage for the purposes of uncertainty calculations. Here *K* is an additional constant introduced to account for any difference between the measured lamp geometry (alignment distance, tilt etc) and the defined lamp geometry at which the lamp should be measured. *K* is unity, but has an associated uncertainty. Similarly $\kappa(\lambda)$ is a term introduced to account for any difference between the measured lamp current and the defined lamp current at which the lamp should be measured. $\kappa(\lambda)$ has a value of nominally unity, but has a small, wavelength dependent uncertainty.

In practice two measurements of the blackbody have been made at potentially different temperatures. The average of the two ratios: $L^{\text{BB}}/V^{\text{BB}}$ is used, where L^{BB} is calculated for the average of the blackbody temperature measured before and after the relevant monochromator scan.

The geometric factor comes from the form factor for radiative transfer between two coaxial circular discs, but is multiplied by the area of the emitting aperture in order to make a version that is symmetrical from one disc to the other:

$$g = \frac{2\pi r_1^2 r_2^2}{(r_1^2 + r_2^2 + d^2) + \sqrt{(r_1^2 + r_2^2 + d^2)^2 - 4r_1^2 r_2^2}} \quad (13\text{-}4)$$

Here r_1 and r_2 are the radii of the two discs and d is the distance between them. For SRIPS measurements these are the radii of the blackbody and the integrating sphere aperture making the entrance aperture to the monochromator system.

The radiance of a blackbody in air is given by Planck's law using air wavelengths and the refractive index of air, n.

$$L_{BB} = \frac{2h(c/n)^2}{\lambda^5(\exp[hc/n\lambda kT] - 1)} \quad (13\text{-}5)$$

13.6.2 Measurement Equation/Technique - UV filters

In order to measure the shortest wavelengths without using the monochromator, a series of interference filters were used. Nominally these had 10 nm bandwidths and central wavelengths of 250, 260, 270, 280, 290, 300, 310, 330 and 350 nm. The measured transmittance is shown in Figure 13-3. They were used in combination with a UG5 filter and a GaAsP photodiode.

The secondary peaks seen in many of these filters, and the fact that their profiles overlap so significantly, mean that the measurements from these filters cannot be considered in isolation. It was therefore necessary to model the irradiance of the lamp mathematically.

The signal actually measured when the blackbody is in front of a given filter is:

$$V(T) = G\pi g \int L(\lambda,T)\,\tau_i(\lambda)\,d\lambda \qquad (13\text{-}6)$$

Where G is the amplifier gain, g is the geometric factor for the blackbody and UVFW detector apertures, L is the blackbody radiance, τ_i is the transmittance of the ith filter, and r is the spectral responsivity of the detector.

The signal when measuring the blackbody is given in (13-6), the signal when measuring the lamp is similar:

$$V^{\text{lamp}}(T) = G\,A \int E^{\text{lamp}}(\lambda)\,\tau_i(\lambda)\,d\lambda \qquad (13\text{-}7)$$

Where E^{lamp} is the lamp spectral irradiance, and A is the area of the detector aperture. These two equations can be combined to give:

$$\int E^{\text{lamp}}(\lambda)\,\tau_i(\lambda)\,d\lambda = \frac{V_i^{\text{lamp}}}{V_i^{\text{BB}}}\frac{\pi g}{A}\int L(\lambda,T)\,\tau_i(\lambda)\,d\lambda \qquad (13\text{-}8)$$

The right hand side of this equation can be calculated. However the equation cannot be solved for E^{lamp} at a particular wavelength.

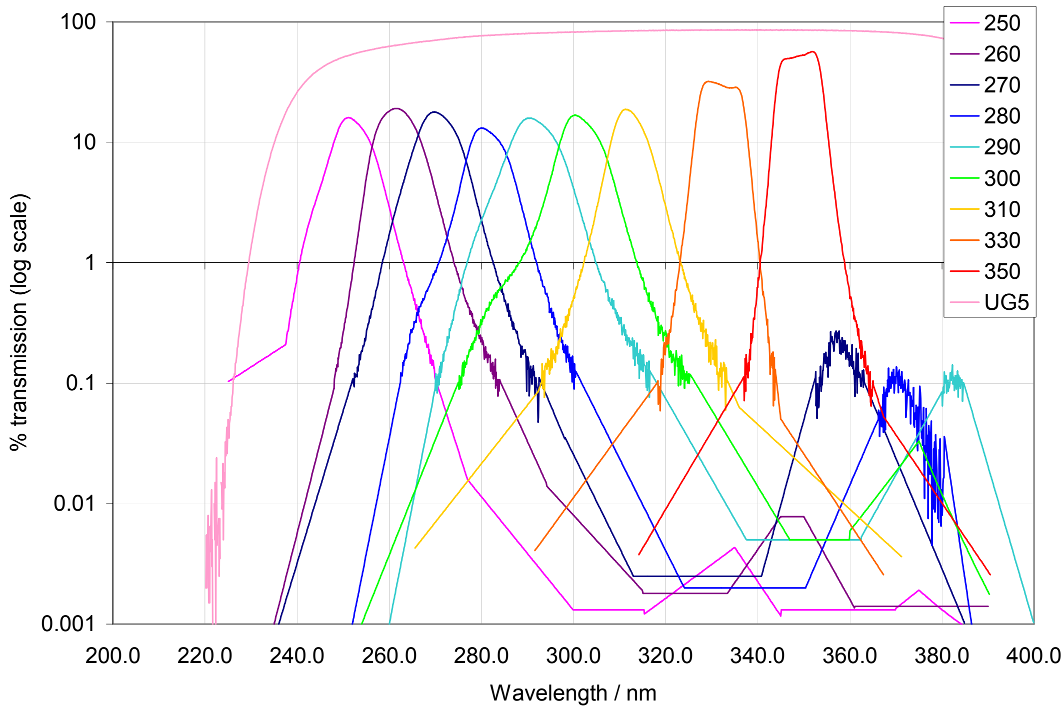

Figure 13-3 Transmittance of the filters used in the UV filter wheel. The measurements were made with both a 0.15 nm bandwidth and a 5 nm bandwidth. The narrow band measurements were used to get the shape of the main peaks, and the broadband measurements to determine the shape of the wings and small secondary peaks, which were subsequently modelled. The quality of this model was verified by calibrating the blackbody against itself at 2900 and 3100 K.

The solution starts with the assumption that in the UV region, from 250 to 350 nm, the lamp can be modelled by a Planck equation multiplied by a polynomial of up to order 8.

Given this, Equation (13-8) can be rewritten as:

$$\int E^{\text{lamp}}(\lambda, T, \mathbf{a}) \cdot \tau_i(\lambda) \cdot r(\lambda)\, d\lambda = C_i \qquad (13\text{-}9)$$

Where C_i is the right-hand side of Equation (13-8) for the *i*th filter (integral performed over entire spectral transmittance of filter) and $E^{\text{lamp}}(\lambda, T, \mathbf{a})$ is the lamp irradiance modelled as a Planck-polynomial.

There are nine of these equations, one for each filter, and these must be solved simultaneously. This is done by modelling the lamp irradiance as a Planck equation at temperature T multiplied by a polynomial. The coefficients of all polynomials of order 1 to 8 were determined through a least squares fit weighted by the Type A component of the calibration. As the order number increased the weighted residual decreased and then reached a plateau, which was statistically equal to one. The lowest polynomial that was on the plateau was used to determine the lamp irradiance, typically this was a 4th or 5th order polynomial.

The results from this model were considered relative because the geometry of the filter wheel measurements was not independent of the source. For this reason the results were normalised to those made using the grating spectroradiometer.

13.6.3 Disseminated NPL_{2003} Spectral irradiance scale

In addition to using a Planck-polynomial model to determine the spectral irradiance at the wavelengths of the UV filter wheel, another Planck-polynomial model was used to combine all spectral irradiance measurements for a lamp. This enabled the knowledge of the physical nature of the lamp to be used to reduce the uncorrelated Type A uncertainties of the original measurements. This mathematical “smoothing” can be considered a form of averaging. Each reference lamp had been calibrated on at least two independent occasions at all wavelengths. All measurement data were used simultaneously to determine the final lamp model.

The model is based on a Planck curve, representing the blackbody part of the lamp’s irradiance, multiplied by an empirically determined polynomial, representing the (assumed smoothly varying) emissivity. It is applied in the following steps:

1. A Planck equation is fitted to the original data points. The temperature, T above, is adjusted using a weighted least-squares fit. The weights come from the Type A measurement standard uncertainties of the original data points.
2. Using the temperature determined in the first part, now considered a constant, a series of polynomials G_n, (n = 1 … 40) is fitted by adjusting **a** according to a weighted least-squares fit.
3. The root-mean-square weighted residual for each Planck-polynomial model is listed, and the most appropriate polynomial order is then chosen by the user.
4. The Planck-polynomial model is evaluated at the wavelengths of interest. The associated standard uncertainties are also calculated.

The root-mean-square weighted residual is calculated from the difference between each original measurement point and the fit at that value. The weighting comes from the measurement standard uncertainties at each point. If the model is consistent with the data and the associated uncertainties, the root-mean-square weighted residual will be statistically equal to one. A significantly larger value will imply either that the uncertainties are under-estimated, or that the model is unsuitable for the measured results. A significantly smaller value will imply either that the uncertainties are over-estimated, or that the model was following the noise of the data and was thus not behaving smoothly. If the Planck-polynomial model is appropriate, then as the order of the polynomial is increased, it is expected that the root-mean-square weighted residual will decrease, possibly erratically, before settling to an essentially constant value close to one. At high orders, there will be a further decrease as the noise is fitted. The polynomial order chosen is usually the first value on the plateau with a value less than 1, although some element of subjective judgement is occasionally required.

Figure 13-4 shows the root-mean-square residual for different polynomial orders applied to real lamp data. For different lamps, different polynomial orders are required, but, consistently with the measurement standard uncertainties, almost all FEL lamps could be fitted with a polynomial of order between 8 and 15. This shows that the model is suitable for lamp interpolation. It also adds confidence to the suitability of the uncorrelated components of the uncertainty budget described below.

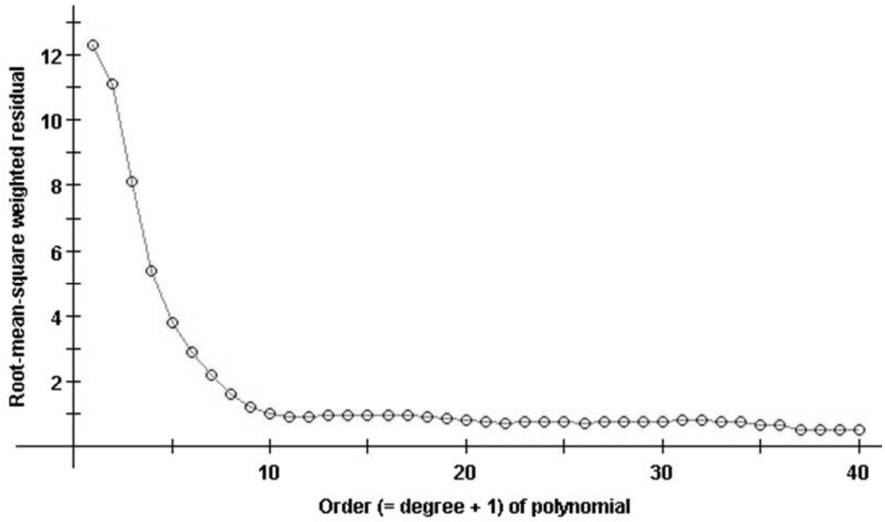

Figure 13-4 Root-mean-square weighted residual for different polynomial orders for the Planck-polynomial model. Real lamp data.

13.7 Uncertainty Analysis

13.7.1 Uncertainty in Constants

This section discusses the uncertainty in the constants in equation (13-3) in section 13.6.1, K, $\kappa(\lambda)$, g and A.

K is a measure of the quality of the alignment of the lamp on the day of measurement. It is wavelength independent and has a value that is nominally taken as unity. Although an estimate of its value can be reduced somewhat by averaging measurements over different days, it is predominantly a systematic effect. K has a value of 1 ± 0.0006.

$\kappa(\lambda)$ is a measure of the quality of the lamp's current control. The lamp's current controls the power supplied to the lamp and therefore the power output of the lamp. The uncertainty in the lamp's current is 0.0015 A in 8.100 A (mostly this is from drift in the resistor following calibration, for a freshly calibrated resistor, the uncertainty is about a factor of ten lower). To convert this to an uncertainty in lamp irradiance at a given wavelength we need to consider that the lamp approximates to a blackbody at 3100 K and therefore the spectral effect of this current uncertainty will be given by the Planck equation due to a change in temperature caused by the change in current. From the Stefan-Boltzmann law, the power output of the lamp is proportional to T^4 and from basic electrical laws the input power is proportional to I^2.

Therefore, the temperature is proportional to $I^{½}$. The sensitivity coefficient can be calculated from:

$$\frac{\partial E}{\partial I}=\frac{\partial E}{\partial T}\frac{\partial T}{\partial I}$$
$$\frac{\partial E}{\partial T}=E\cdot\frac{hc}{nk\lambda T^2}\cdot\frac{1}{1-\exp[-hc/nk\lambda T]} \quad (13\text{-}10)$$
$$\frac{\partial E}{\partial I}=\frac{T}{2I}$$

These equations seem to over-estimate the uncertainty when compared to an experimental verification made by operating the lamp at 8.100 A, 8.105 A and 8.110 A and comparing the differences. Note that a smaller uncertainty, of around 0.0005 A, is the stability of the lamp current during lamp calibration and most of this uncertainty is due to the calibration of the resistor. This corresponds to an uncertainty of 0.08% at 250 nm and 0.02% at 1000 nm.

The uncertainty associated with an estimate of the value $\pi g / A$ is due to geometry. It is a constant at all wavelengths and for all separate lamp measurements made within a few months of each other. The effect is taken as a Type B uncertainty of 0.08%. The relevant apertures are r_1=4 mm ± 0.1 μm, r_2=8 mm ± 0.1 μm and the distance between them is 500 ± 0.2 mm. The sensitivity coefficients can be written:

$$\frac{\partial \,{}^{\pi g}\!/_{A}}{\partial r_1}=4\pi r_1\left[\frac{1}{F+\sqrt{G}}-\frac{r_1^2\left(1+\left[F-2r_2^2\right]/\sqrt{G}\right)}{\left(F+\sqrt{G}\right)^2}\right] \quad (13\text{-}11)$$

$$\frac{\partial \,{}^{\pi g}\!/_{A}}{\partial r_2}=\frac{-4\pi r_1^2 r_2}{\left(F+\sqrt{G}\right)^2}\cdot\left[1+\frac{F-2r_1^2}{\sqrt{G}}\right] \quad (13\text{-}12)$$

$$\frac{\partial \,{}^{\pi g}\!/_{A}}{\partial d}=\frac{-2\pi r_1^2}{\left(F+\sqrt{G}\right)^2}\cdot 2d\cdot\left(1+\frac{F}{\sqrt{G}}\right) \quad (13\text{-}13)$$

where:

$$F=(r_1^2+r_2^2+d^2)$$
$$G=F^2-4r_1^2r_2^2 \quad (13\text{-}14)$$
$$A=\pi r_2^2$$

13.7.2 Uncertainty in Blackbody Radiance

The blackbody temperature is given by the Planck equation.

$$L^{BB}(\lambda;T)=\alpha(\lambda)\varepsilon\frac{2h(c/n)^2}{\lambda^5(\exp[hc/n\lambda kT]-1)} \quad (13\text{-}15)$$

Here h is the Planck constant, 6.626 0693(11) × 10^{-34} J s, c is the speed of light, 299 792 458 m s^{-1} (exact), k is the Boltzmann constant, 1.380 6505(24) × 10-23 J K^{-1}, n is the air refractive index, 1.00029 ± 0.00005 and ε is the emissivity of the blackbody, which is 0.99988 ± 0.00010.

α is from the absorption of the blackbody. For a small region around 380 nm the carbon gas emitted by the blackbody absorbs the radiation and the blackbody does not obey the Planck equation. At this stage it is difficult to make a correction for this, therefore there is an additional wavelength dependent uncertainty in this narrow spectral region to account for the absorption.

13.7.3 Uncertainty in blackbody temperature

The dominant uncertainty source up to 1000 nm is the uncertainty in the temperature of the blackbody. The temperature of the blackbody is measured using a filter radiometer whose spectral responsivity, $R(\lambda)$, has been calibrated. The filter radiometer is placed in front of the blackbody and light is focussed onto it using a lens. Four measurements are taken: a light reading, V^{light}, a dark reading, V^{dark}, an out-of-band reading V^{OOB} (with a long-pass filter in front of the filter radiometer — this accounts for any filter radiometer responsivity at wavelengths longer than the longest calibration wavelength) and a dark out-of-band reading $V^{\text{OOB, Dark}}$, with the long pass filter and the shutter.

The signal, V, can be compared with the expected signal in the following equation:

$$\begin{aligned} V &= V^{\text{light}} - V^{\text{dark}} - V^{\text{OOB}} + V^{\text{OOB,Dark}} \\ &= sGUS \cdot g\pi R \cdot \int_{\lambda_0}^{\lambda_1} r(\lambda)\,\tau(\lambda)\,L(\lambda;T)\,d\lambda \end{aligned} \qquad (13\text{-}16)$$

Here L is the radiance of the blackbody given by Equation (13-15), τ is the, wavelength-dependent lens transmittance, g is the geometric factor, given by (13-4), but this time with the lens and filter radiometer apertures, G is the electronic gain of the amplifier and s is the size-of-source effect, a measure of the amount of light scattered by imperfections in the lens. U is the uniformity of the blackbody—the difference between the signal measured and the signal that would be measured if a larger area of the blackbody were observed (because the spectral irradiance calibration facility sees a larger area of blackbody. S is a measure of the blackbody stability between the time when the temperature is measured and the time when the spectral irradiance is measured. S has a value of unity, but an associated uncertainty.

The responsivity of the filter radiometer has been split into two components. The absolute responsivity, R, (in A W^{-1}) has been separated from the relative spectral responsivity to simplify the error analysis (R is the component correlated at all wavelengths, r is entirely uncorrelated from one wavelength to the next).

The filter radiometer responsivity has been calibrated at discrete wavelengths; therefore, Equation (13-16) is replaced by a discrete version, using the trapezium rule:

$$V(T) = C\sum_{j=1}^{N} r_j L(\lambda_j, T)\cdot\delta\lambda_j \qquad (13\text{-}17)$$

Here C combines all the uncertainties on the outside of the integral in Equation (13-16). $\delta\lambda_j$ is $\left(\lambda_{j+1} - \lambda_{j-1}\right)/2$ for all but the first $\left(\left(\lambda_2 - \lambda_1\right)/2\right)$ and last $\left(\left(\lambda_N - \lambda_{N-1}\right)/2\right)$ values.

The Newton-Raphson technique is used to determine the temperature of the blackbody given the signal. This is robust for this calculation because only one value of temperature can be associated with each signal.

According to normal uncertainty analysis, as described in the Guide to the Uncertainty of Measurement (GUM) [8], given a function $f(x_1,x_2,x_3...)$, the uncertainty associated with the function, u_f should be derived from the uncertainties calculated from the individual parts. However, here the temperature cannot be described as a function of the other variables. Instead we must use the techniques for a "multivariate, implicit, real valued model" as described in section 6.3.4 of the 6th best practice guide from the Software Support for Metrology programme at NPL [9]. This requires Equation (13-17) to be written in the form $h(Y,X)=0$:

$$h(T,C,V,r_1...r_N,\tau_1...\tau_N) = \left[C\sum_{j=1}^{N} r_j L(\lambda_j,T)\cdot\delta\lambda_j\right] - V = 0 \qquad (13\text{-}18)$$

The best practice guide supplies methods for determining the uncertainty in T due to the uncertainties in all the other components. The following equations are therefore needed to determine the uncertainty in temperature due to uncertainties in each of the components:

$$\left(\frac{\partial h}{\partial T}\right)^2 u^2(T) = u^2(V)\left(\frac{\partial h}{\partial V}\right)^2 + u^2(C)\left(\frac{\partial h}{\partial C}\right)^2 + \sum_{i=1}^{N} u^2(r_i)\left(\frac{\partial h}{\partial r_i}\right)^2 \qquad (13\text{-}19)$$

$$\left(\frac{\partial h}{\partial T}\right)^2 = \left[C\sum_{j=1}^{N}\left(r_j\,\tau_j\,\delta\lambda_j\,\frac{\partial L(\lambda_j;T)}{\partial T}\right)\right]^2 \qquad (13\text{-}20)$$

$$\left(\frac{\partial h}{\partial V}\right)^2 = 1 \qquad (13\text{-}21)$$

$$\left(\frac{\partial h}{\partial C}\right)^2 = \left(\frac{V}{C}\right)^2 \qquad (13\text{-}22)$$

$$\sum_{j=1}^{N}\left(\frac{\partial h}{\partial r_j}\right)^2 u^2(r_j) = \sum_{j=1}^{N}\left[C\,\tau_j\,L(\lambda_j;T)\delta\lambda_j\right]^2 u^2(r_j) \qquad (13\text{-}23)$$

$$\frac{\partial L(\lambda_j;T)}{\partial T} = \frac{2h^2c^3\exp[hc/n\lambda kT]}{n^3\lambda^6 kT^2\left(\exp[hc/n\lambda kT]-1\right)^2} \qquad (13\text{-}24)$$

These equations assume no correlation and there are no correlations between V and C (although there may be some correlations within C), nor between either of these and the r_j s.

13.7.3.1 Uncertainty in signal levels

The signal level used in Equation (13-17) is the light signal level minus the dark signal and minus the out-of-band. This is treated as a Type B uncertainty and comes dominantly from the uncertainty in the calibration of the voltmeter and the electrical noise in the dark reading. The uncertainty in the out-of-band comes from the quality of the filter used for the out-of-band measurements along with any differences between the temperature of the blackbody during out-of-band measurements and during blackbody temperature measurements.

The uncertainty in the measured signal is:

$$u_V^2 = u_{V\text{light}}^2 + u_{V\text{dark}}^2 + u_{V\text{OOB}}^2 + u_{V\text{OOB, dark}}^2 + \left(\frac{V}{K}\right)^2 u_K^2 \qquad (13\text{-}25)$$

The final term represents the calibration uncertainty of the voltmeter. It assumes that it is the same for all four measurements and that they should all be multiplied by a, nominally unity, correction factor K. Therefore voltmeter non-linearities are assumed to be negligible. K is 1 with an uncertainty of 0.005%.

Typically, V is 1.8 V and u_V is 0.76 mV. From Equations (13-21) and (13-19), this corresponds to a temperature uncertainty of 0.08 K.

13.7.3.2 Size-of-source

The size-of-source effect is 0.22 ± 0.02 %. From Equations (13-22) and (13-19), this corresponds to a temperature uncertainty of 0.10 K.

13.7.3.3 Amplifier gain

The amplifier was calibrated at an accredited laboratory. The quoted uncertainty on the amplifier measurements is 0.01 % at 95 % confidence, or a standard uncertainty of 0.005 %. From Equations (13-22) and (13-19), this corresponds to a temperature uncertainty of 0.03 K.

13.7.3.4 Lens transmittance

The lens transmittance was calculated using the Fresnel equations, which had previously [9] been shown to agree within 0.05 % of the measured value at this wavelength. This is considered the uncertainty in the lens transmittance, with a rectangular distribution function. From Equations (13-22) and (13-19), this corresponds to a temperature uncertainty of 0.15 K.

Although the lens transmittance is a wavelength dependent quantity and therefore inside the integral, the values are entirely correlated and therefore the uncertainty is considered in C.

13.7.3.5 Geometric factor

The geometric factor is derived from the size of the apertures on the filter radiometer and lens and the distance between them. However, the full expression for g is not required to work out the effect of these uncertainties. This is because the area of the filter radiometer aperture is used in calculating the spectral responsivity during its calibration, and this area is calculated from the same aperture calibration. This calculation is therefore exactly the same as that for the geometric factor in the spectral irradiance measurement, and so uses Equations (13-11) to (13-14). For a 0.1 μm uncertainty in the filter radiometer and lens aperture diameters and a 0.2 mm uncertainty in the distance, and for the normal setup, g/A has a standard uncertainty of 0.07 %, which corresponds to a temperature uncertainty of 0.34 K.

13.7.3.6 FR absolute responsivity

The absolute responsivity of the filter radiometer after a fresh calibration has a standard uncertainty of 0.02 %. There is also an uncertainty due to any difference between the calibration set up of the filter radiometer and its use. The most significant problem with that is the size-of-source effect, which is large enough to be considered elsewhere, but the temperature of the filter radiometer and the f-number of the optical setup are also important. Care is taken to make sure these conditions are matched as closely as possible. Therefore there is only a small additional uncertainty, of 0.01 % from this.

The overall uncertainty is 0.022 %, corresponding to a temperature uncertainty of 0.12 K.

13.7.3.7 Blackbody stability

When the blackbody is used as a reference source on the SRIPS facility, its temperature is measured twice before the monochromator scan and twice afterwards. If the difference between the maximum and minimum filter radiometer readings with an 800 nm filter radiometer is greater than 0.2 %, then the results are ignored and the scan repeated. The uncertainty in the averaged temperature is typically 0.0 5%, corresponding to a temperature uncertainty of 0.26 K.

13.7.3.8 Blackbody uniformity

The uniformity of the blackbody is measured by scanning a filter radiometer with a 5 mm aperture in front of the blackbody at the distance of the integrating sphere. The central reading is similar to the temperature measurement and the overall scan is similar to the area of the integrating sphere aperture. The average of all the measurements is compared with the central reading. Of course a uniformity scan takes time and therefore the stability of the blackbody will also affect the measurement. However the stability is noisy at the 0.1-0.2 % level on a very short timescale. This means that there is no steady drift across the uniformity scan; instead, each individual point will have its own stability component completely uncorrelated with the points either side of it. This means that the averaging technique will also remove some of the stability uncertainty.

The uncertainty in the uniformity correction is 0.06 %, with a rectangular distribution, corresponding to a temperature uncertainty of 0.18 K.

13.7.3.9 Emissivity

In addition to its effect in calculating the irradiance of the blackbody, the emissivity will also play a part in calculating its temperature. At the filter radiometer wavelength the uncertainty in blackbody emissivity is 0.02 %, with a rectangular distribution, corresponding to a temperature uncertainty of 0.06 K. This does give a mathematical correlation between the blackbody irradiance calculation and temperature measurement but it is far too small to be significant.

13.7.3.10 Filter radiometer relative responsivity

The calibration of the filter radiometer has three distinct regions. In the wings, where the responsivity of the filter radiometer is low, the predominant uncertainty is signal to noise at around 0.5 % of the signal. On the steep slopes of the profile, the predominant uncertainty is due to wavelength fluctuations, this is expressed as a responsivity uncertainty of around 0.14 %. In the central, flatter region the signal to noise is good and any wavelength fluctuations are less significant. Here the uncertainty drops to 0.02 %. These uncertainties are entirely random and therefore the integration will “average out” their effect. The overall effect on temperature is 0.005 K.

13.7.3.11 Uncertainty in trapezium rule

The numerical integration is carried out using the trapezium rule, because the filter radiometers have been calibrated at discrete wavelengths. An estimate of the uncertainty introduced by this can be obtained by calculating the temperature using all the points and then by using only half the points. The difference gives an uncertainty of 0.004 K at this temperature. Because of the large number of points (1150), this difference is small enough that more involved methods for determining the integral, and its uncertainty, are not required.

13.7.3.12 Overall uncertainty in temperature

Table 13-3 Uncertainty components and overall uncertainty in the blackbody temperature measurement (Standard uncertainties at the 66% confidence level)

Uncertainty component	Uncertainty as a percentage of value, where appropriate	Temperature uncertainty / K
Geometric factor	0.067%	0.344
Stability of blackbody	0.050%	0.258
Uniformity of blackbody	0.035%	0.179
Lens transmittance	0.029%	0.149
FR absolute responsivity	0.022%	0.115
Size of source effect	0.020%	0.103
Voltage measurement and out of band		0.077
Emissivity	0.012%	0.060
Amplifier gain	0.005%	0.026
FR relative responsivity		0.005
Mathematical approximations		0.004
Overall Temperature uncertainty		0.523

Combining these equations and these uncertainty sources for a blackbody at 3050 K measured with filter radiometer 800W50S1337A, the overall standard (66 % confidence) uncertainty in temperature is 0.52 K. This value should be combined with the uncertainties of all the other components in

Equation (13-15) to give the overall uncertainty in blackbody radiance. The effect of the temperature uncertainty on wavelength can be seen from that equation.

13.7.3.13 Overall Uncertainty in blackbody radiance

The blackbody radiance is calculated from Equation (13-15). The uncertainty components to consider come from the temperature, as described in the previous section, the absorption due to carbon at wavelengths around 380 nm and, to a much smaller degree, to the uncertainty in the emissivity correction. The overall standard uncertainty due to these factors is shown in Figure 13-5.

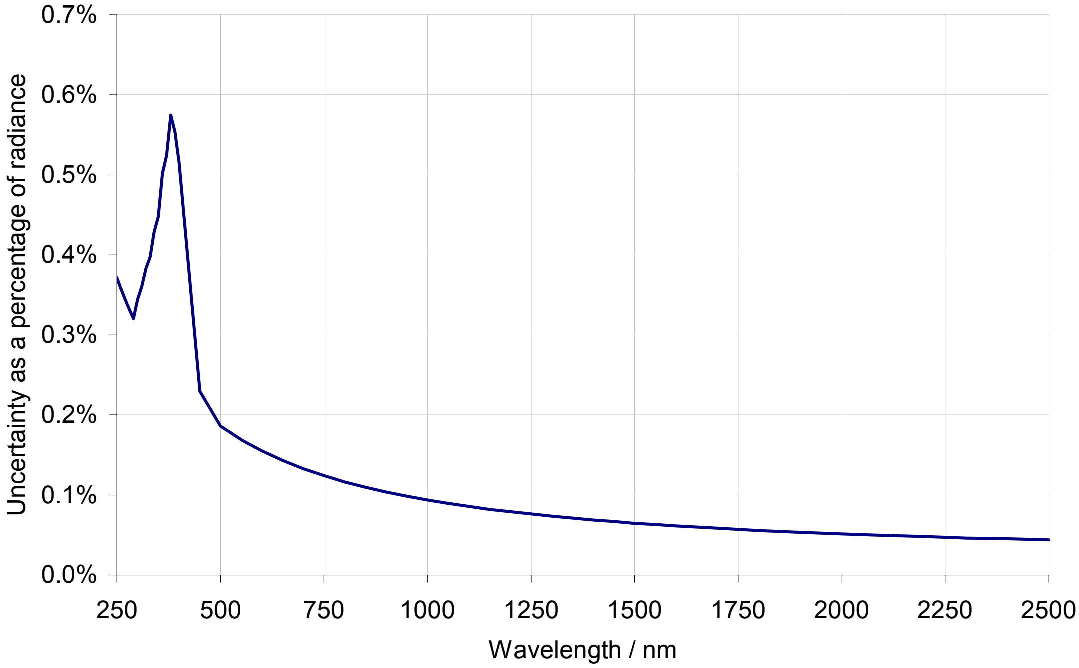

Figure 13-5 Standard uncertainty in blackbody radiance and a percentage of spectral radiance and as a function of wavelength

13.7.4 Uncertainty in Lamp-Blackbody Signal Ratios

The final uncertainty that needs to be considered is the uncertainty in the final two terms of Equation (13-3). That is the uncertainty in:

$$\frac{V^{\text{lamp}}(\lambda)}{V^{\text{BB}}(\lambda)}\frac{R^{\text{SRIPS,BB}}(\lambda)}{R^{\text{SRIPS,lamp}}(\lambda)} \qquad (13\text{-}26)$$

The uncertainty in the ratios comes from any non-linearity in the response of the system or the measurement of the signals and in any drift in the facility between the measurement of the blackbody and the measurement of the lamp, along with the noise on the signals. However there is an additional uncertainty due to whether this ratio is really the desired ratio, this uncertainty comes from the wavelength accuracy and the effect of the monochromator bandwidth.

13.7.4.1 Linearity

The uncertainty in V_{lamp}/V_{BB} is the uncertainty in the linearity and repeatability of the voltage measurements with the voltmeter. Because of the ratio, the absolute calibration of the voltmeter is irrelevant. The linearity and noise level are better than 0.001 %.

13.7.4.2 Noise

The predominant uncertainty in many spectral regions is the uncertainty in the ratio $R^{BB}_{SRIPS} / R^{lamp}_{SRIPS}$.

In the normal procedure, the blackbody scan is taken before and after the lamp scan. The difference between these two measurements (when any change in temperature is accounted for) is due to the stability of the source and the stability of SRIPS. The source stability is insignificant because the source is highly stable, as measured by the filter radiometer; its insignificance is confirmed by the fact that the blackbody differences show no spectral component. Therefore it can be assumed that these differences give the repeatability of SRIPS. There is typically no drift from the first to the second blackbody scan. This means that the repeatability calculated between blackbody measurements is equivalent to the SRIPS repeatability between the blackbody and lamp measurements.

The differences have been measured on many occasions and variations from day to day are or statistical rather than of experimental significance. This uncertainty has been determined from a standard deviation of the differences between the blackbody measurements on ten randomly chosen days. The results are shown in Figure 13-6.

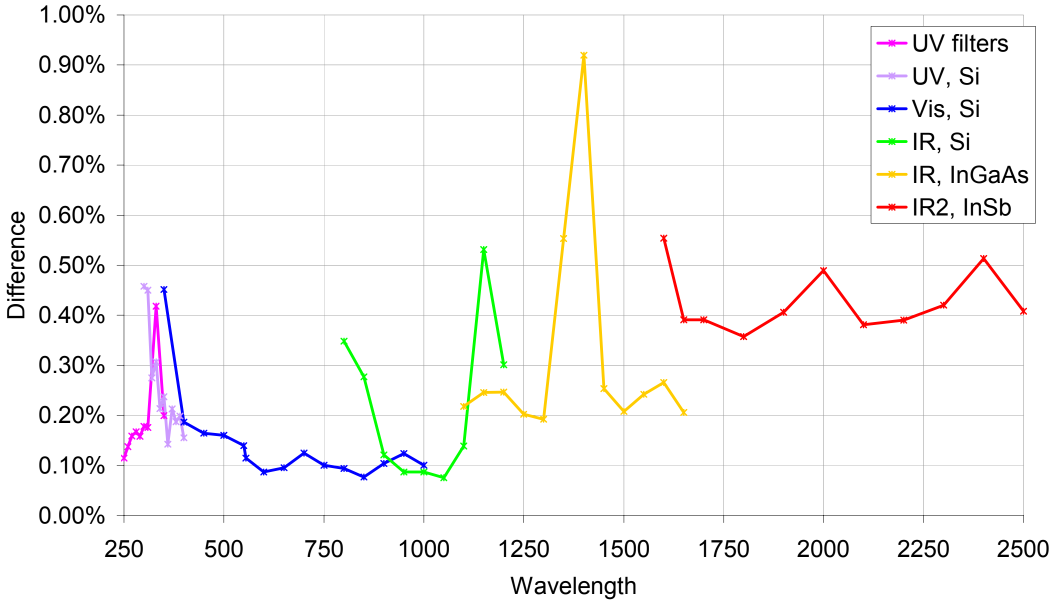

Figure 13-6 Repeatability of SRIPS as determined by the standard deviation of the difference between the two blackbody scans taken on ten different occasions.

The increases at the end of different spectral regions are due to the decrease in detector responsivity or grating throughput and therefore a lower signal and higher signal to noise. Around the water absorption lines (the peak at 1350-1400 nm) the repeatability worsens and the uncertainty must be higher, however not as high as this repeatability implies. In general, the standard deviation of the two blackbody measurements can be considered as the uncertainty in the stability of the SRIPS facility since the repeatability is random, rather than being a drift. However, at water vapour lines the difference comes from a change in room humidity. This is a drift, so averaging the blackbody measurements either side of the lamp measurement is an extremely good approximation to what the conditions were like during the lamp scan. For this reason the effect of humidity changes are smaller than expected and the uncertainty budget in this region has been reduced by dividing the repeatability by $\sqrt{2}$.

13.7.5 Wavelength accuracy

The ratios were carried out at the measured wavelengths, which may be slightly different to the calculated wavelengths because of uncertainty in the monochromator's wavelength accuracy. Strictly this should be treated as a wavelength uncertainty, however it can more easily be considered as an uncertainty in irradiance levels by looking at the effect of the wavelength error.

There is an uncertainty in the wavelength of around 0.05 nm. The effect of this depends on how smoothly varying both sources are, as well as how smoothly the responsivity SRIPS. If the ratio of the signals of the two sources varies strongly with wavelength, the wavelength uncertainty will become more important. For two similar sources smoothly varying, with wavelength measured at wavelengths where there are no spectral features on the grating or in the spectral responsivity of the detector, then the wavelength uncertainty is unimportant. For the gratings chosen, the effect is tiny. The effect would be larger if the sources were different—especially if one were a line source. The Taylor expansion of V_{lamp}/V_{BB} is:

$$\tilde{V}(\lambda+\delta\lambda)=\frac{V^{\mathrm{lamp}}(\lambda+\delta\lambda)}{V^{\mathrm{BB}}(\lambda+\delta\lambda)}\approx\tilde{V}(\lambda)+\delta\lambda\cdot\frac{d\tilde{V}}{d\lambda} \qquad (13\text{-}27)$$

Therefore the uncertainties are calculated from the ratio of the second to the first term in Equation (13-27).

13.7.6 Monochromator bandwidth

Equation (13-3) makes the assumption that when Equation (13-2) is divided by (13-1) after the dark signal is removed, the responsivity of SRIPS cancels out. This would only be true if the slit function were infinitely narrow.

The question is how similar the measured ratio $V_{\mathrm{Lamp}}(\lambda)/V_{\mathrm{BB}}(\lambda)$ is to the assumed ratio $\tilde{V}_{Lamp}/\tilde{V}_{BB}=\frac{R(\lambda)\cdot E_{lamp}(\lambda)\cdot A}{R(\lambda)\cdot L_{BB}(\lambda)\cdot g\pi}$. The full integral equation is generally unsolvable. However, under certain specific conditions a solution can be found.

This problem has been looked at as part of a project [10] on lamp spectral modelling, and for a triangular slit function an approximation can be made. For a triangular slit function, of full width $2\Delta\lambda$ and a unit area, the following equation holds:

$$V(\lambda)=\tilde{V}(\lambda)-\tfrac{1}{12}(\Delta\lambda)^2\tilde{V}''(\lambda)+\tfrac{1}{240}(\Delta\lambda)^4\tilde{V}^{iv}(\lambda)+\ldots \qquad (13\text{-}28)$$

Equation (13-28) can be applied to each source and then the ratio taken. If the two sources are very similar (as is the case for an FEL calibrated against a blackbody), the correction to the ratio is tiny, even if the correction to each individual source is significant. This means that Equation (13-3) can be used without correction.

This equation has been applied to the blackbody and FEL measurements on the SRIPS facility and the ratio taken. The monochromator bandwidth in each appropriate spectral region is considered. Figure 13-7 shows the difference between the ratio as measured and the ratio assumed.

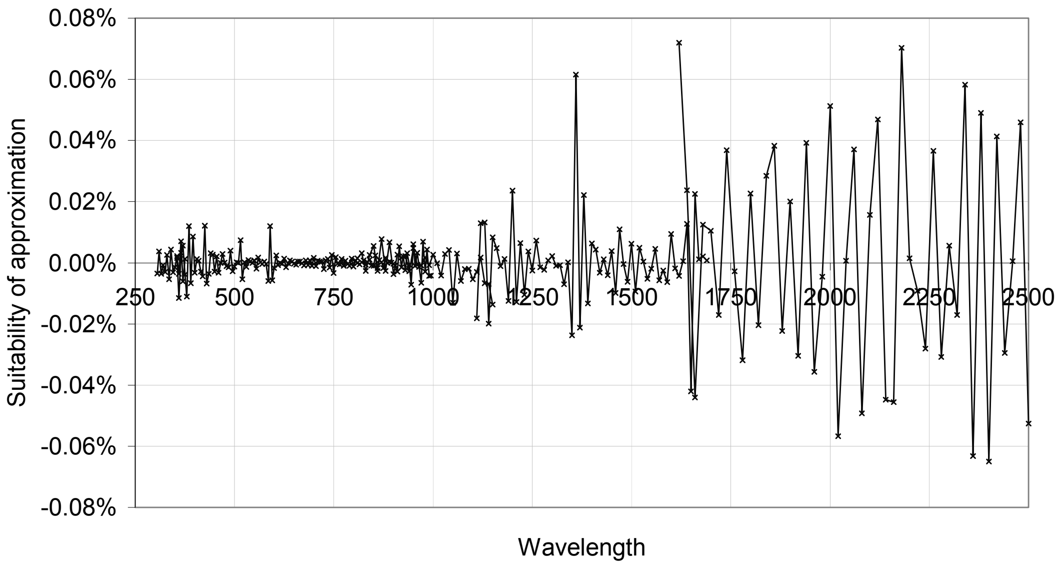

Figure 13-7 Suitability of normal approximation under normal conditions when calibrating an FEL against the blackbody.

13.7.7 UV filter wheel uncertainties

In the region covered by the UV filter wheel the dominant sources of uncertainty are the repeatability of the measurements, the temperature of the blackbody, the knowledge of the filter transmittances and detector responsivity and the accuracy of the UV grating measurements at the overlap wavelengths. In addition there is an uncertainty from the ability of a Planck-polynomial model to describe the spectral irradiance of the lamp in this region.

The first two of these can be determined as described in sections 13.7.4 and 13.7.2 respectively. The uncertainty in the overlap comes from the absolute level accuracy of the UV grating measurements.

The effect of the uncertainty in the knowledge of the filter transmittance can be estimated from the residual difference between calculated and measured ratios of the blackbody radiance combined with each filter for a blackbody at 2900 K and a blackbody at 3100 K.

The weighted least squares residual of the fit of the modelled data to the lamp irradiance has been found to be statistically equal to one for an average of many lamp calibrations. This means that the model is consistent with the data, including the random component of the uncertainties.

However, because of the unusual nature of this analysis, the Type B uncertainties have been estimated pessimistically.

13.8 Overall Uncertainty in Lamp Irradiance

13.8.1 Single lamp calibration

The standard uncertainty (66% confidence) for a single calibration of a lamp can be obtained by combining in quadrature the uncertainties discussed in Section 13.7. This is shown in Figure 13-8. This figure includes lines for each grating and detector, as listed in Table 13-2.

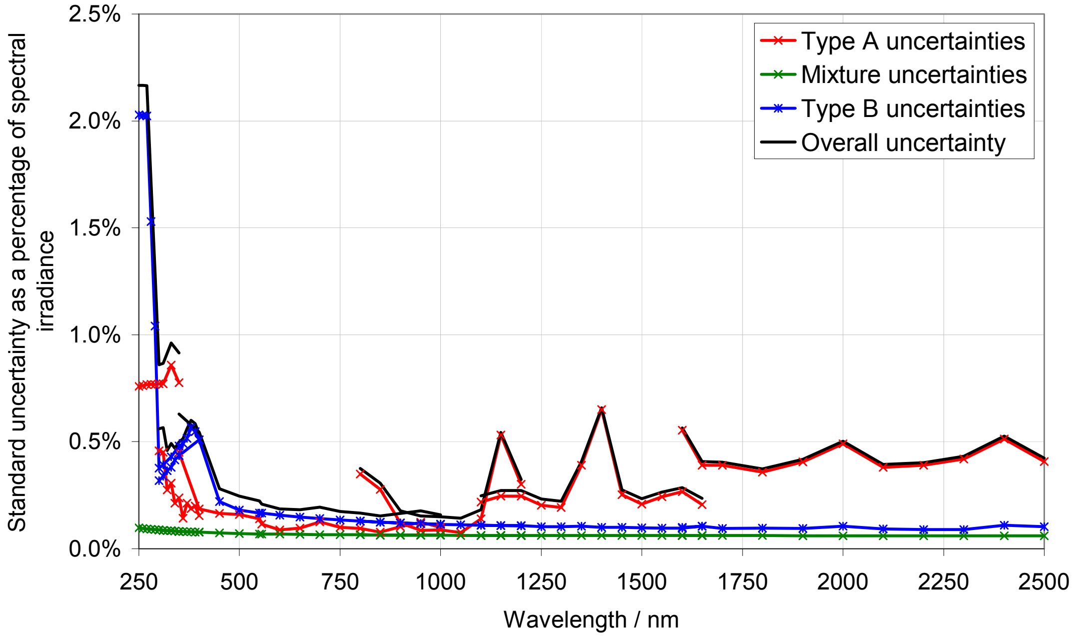

Figure 13-8 Uncertainty in a single calibration of a lamp as a function of wavelength and grating. Where a wavelength has two uncertainties shown, this is because two gratings and/or detectors are used at this wavelength.

Figure 13-8 shows curves for three types of uncertainty. The results are tabulated in Table 13-5. Here, Type A uncertainties can be treated entirely statistically. There is no correlation from one lamp calibration to the next, nor from one wavelength to the next. Type B uncertainties are uncertainties that are correlated between wavelengths, at least within a spectral region, and between one lamp calibration and the next. "Mixture" uncertainties are correlated between wavelengths for one calibration, but are uncorrelated from one lamp alignment to the next.

The Planck-polynomial model's smoothing properties will reduce the Type A uncertainties and multiple lamp calibrations will reduce the "mixture" uncertainties. The components of uncertainty that were considered as belonging to each type are listed in Table 13-4.

Table 13-4 Sources of uncertainty organised by type

Type B	Type A	Mixture
Blackbody-integrating sphere geometry	Noise	Lamp alignment
Blackbody temperature		Lamp current
Other components of blackbody radiance		
Wavelength accuracy		
Monochromator bandwidth		
System linearity		

Table 13-5 Uncertainties before modelling for a single measurement of a lamp. All uncertainties are standard uncertainties (k=1)

Grating, Detector	Wavelength	Type A uncertainties	Mixture uncertainties	Type B uncertainties	Overall uncertainty
UVFW	250	0.76 %	0.10 %	2.03 %	2.17 %
UVFW	260	0.76 %	0.10 %	2.03 %	2.17 %
UVFW	270	0.77 %	0.09 %	2.02 %	2.17 %
UVFW	280	0.77 %	0.09 %	1.53 %	1.71 %
UVFW	290	0.77 %	0.09 %	1.04 %	1.29 %
UVFW	300	0.77 %	0.09 %	0.38 %	0.86 %
UVFW	310	0.77 %	0.09 %	0.39 %	0.87 %
UVFW	330	0.86 %	0.08 %	0.43 %	0.96 %
UVFW	350	0.78 %	0.08 %	0.48 %	0.91 %
UV, Si	300	0.46 %	0.09 %	0.32 %	0.56 %
UV, Si	310	0.45 %	0.09 %	0.34 %	0.57 %
UV, Si	320	0.27 %	0.08 %	0.36 %	0.46 %
UV, Si	330	0.31 %	0.08 %	0.38 %	0.49 %
UV, Si	340	0.21 %	0.08 %	0.41 %	0.47 %
UV, Si	350	0.24 %	0.08 %	0.44 %	0.50 %
UV, Si	360	0.14 %	0.08 %	0.49 %	0.52 %
UV, Si	370	0.21 %	0.08 %	0.52 %	0.56 %
UV, Si	380	0.19 %	0.08 %	0.57 %	0.60 %
UV, Si	390	0.20 %	0.08 %	0.55 %	0.58 %
UV, Si	400	0.16 %	0.08 %	0.51 %	0.54 %
Vis, Si	350	0.45 %	0.08 %	0.44 %	0.63 %
Vis, Si	400	0.19 %	0.08 %	0.51 %	0.54 %
Vis, Si	450	0.16 %	0.07 %	0.22 %	0.28 %
Vis, Si	500	0.16 %	0.07 %	0.18 %	0.25 %
Vis, Si	550	0.14 %	0.07 %	0.17 %	0.22 %
Vis, Si	555	0.11 %	0.07 %	0.17 %	0.21 %
Vis, Si	600	0.09 %	0.07 %	0.16 %	0.19 %
Vis, Si	650	0.10 %	0.07 %	0.15 %	0.18 %
Vis, Si	700	0.12 %	0.07 %	0.14 %	0.19 %
Vis, Si	750	0.10 %	0.07 %	0.13 %	0.17 %
Vis, Si	800	0.09 %	0.06 %	0.13 %	0.17 %
Vis, Si	850	0.08 %	0.06 %	0.12 %	0.15 %
Vis, Si	900	0.10 %	0.06 %	0.12 %	0.17 %
Vis, Si	950	0.12 %	0.06 %	0.12 %	0.18 %
Vis, Si	1000	0.10 %	0.06 %	0.11 %	0.16 %
IR, Si	800	0.35 %	0.06 %	0.13 %	0.37 %
IR, Si	850	0.28 %	0.06 %	0.12 %	0.31 %
IR, Si	900	0.12 %	0.06 %	0.12 %	0.18 %
IR, Si	950	0.09 %	0.06 %	0.12 %	0.15 %
IR, Si	1000	0.09 %	0.06 %	0.11 %	0.15 %
IR, Si	1050	0.08 %	0.06 %	0.11 %	0.14 %
IR, Si	1100	0.14 %	0.06 %	0.11 %	0.18 %
IR, Si	1150	0.53 %	0.06 %	0.11 %	0.54 %
IR, InGaAs	1100	0.22 %	0.06 %	0.11 %	0.25 %
IR, InGaAs	1150	0.25 %	0.06 %	0.11 %	0.27 %
IR, InGaAs	1200	0.25 %	0.06 %	0.11 %	0.27 %
IR, InGaAs	1250	0.20 %	0.06 %	0.10 %	0.23 %
IR, InGaAs	1300	0.19 %	0.06 %	0.10 %	0.22 %
IR, InGaAs	1350	0.39 %	0.06 %	0.10 %	0.41 %

IR, InGaAs	1400	0.65 %	0.06 %	0.10 %	0.66 %
IR, InGaAs	1450	0.25 %	0.06 %	0.10 %	0.28 %
IR, InGaAs	1500	0.21 %	0.06 %	0.10 %	0.23 %
IR, InGaAs	1550	0.24 %	0.06 %	0.10 %	0.26 %
IR, InGaAs	1600	0.27 %	0.06 %	0.10 %	0.29 %
IR, InGaAs	1650	0.21 %	0.06 %	0.10 %	0.24 %
IR2, InSb	1600	0.55 %	0.06 %	0.10 %	0.56 %
IR2, InSb	1650	0.39 %	0.06 %	0.11 %	0.41 %
IR2, InSb	1700	0.39 %	0.06 %	0.10 %	0.40 %
IR2, InSb	1800	0.36 %	0.06 %	0.10 %	0.37 %
IR2, InSb	1900	0.41 %	0.06 %	0.09 %	0.42 %
IR2, InSb	2000	0.49 %	0.06 %	0.11 %	0.50 %
IR2, InSb	2100	0.38 %	0.06 %	0.09 %	0.39 %
IR2, InSb	2200	0.39 %	0.06 %	0.09 %	0.40 %
IR2, InSb	2300	0.42 %	0.06 %	0.09 %	0.43 %
IR2, InSb	2400	0.51 %	0.06 %	0.11 %	0.53 %
IR2, InSb	2500	0.41 %	0.06 %	0.10 %	0.42 %

To determine the overall lamp irradiance and its uncertainty, all calibration measurements of a lamp were supplied to the Planck-polynomial model along with the Type A uncertainties for each calibration. The Planck-polynomial model supplied the best values for the lamp spectral irradiance at each wavelength, along with new, reduced, Type A uncertainties. These were then combined in quadrature with the Type B uncertainties and the Mixture uncertainties, after the latter were reduced by the square root of the number of independent lamp alignments.

The overall uncertainty for each lamp has been calculated separately, however, Figure 13-9 shows the uncertainties calculated for a typical lamp.

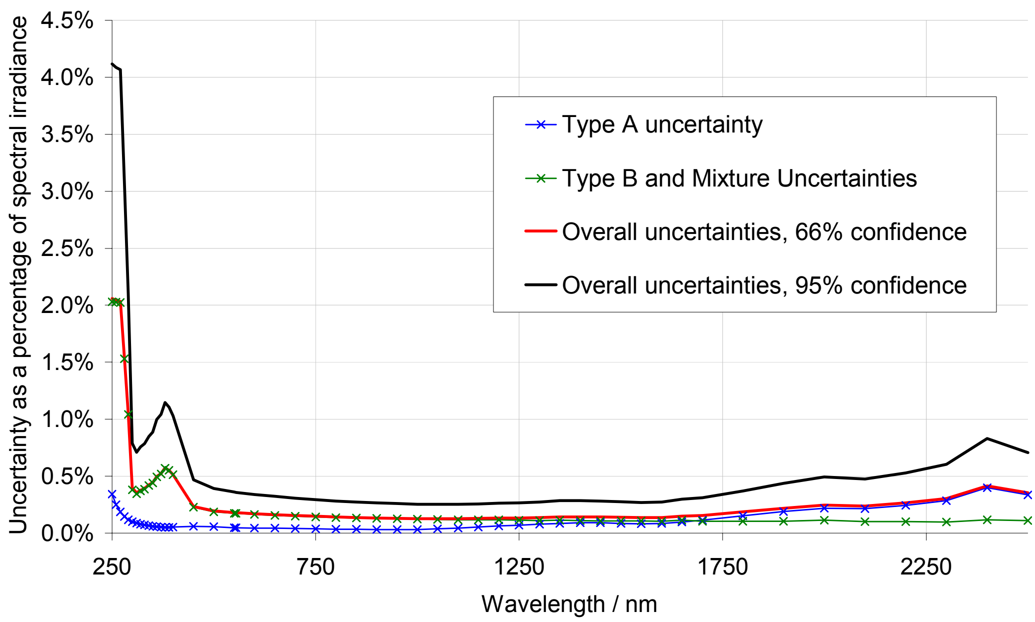

Figure 13-9 Overall uncertainties after modelling for one NPL reference lamp

13.8.2 Uncertainty correlations

The correlations described above are those that are correlated from one wavelength to the next and from one individual measurement to the next. These correlations must be understood in order to model the lamp irradiance data using the Planck-polynomial model described in Section 13.6.3. These are different from the correlations required for the comparison analysis. The uncertainties required for the comparison are described in Chapter 3.

13.9 References

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14 Measurements at NRC

14.1 Primary scale realization

The spectral irradiance scale for NRC is a composite of three sources, each of which is used in a different wavelength region:

1) CIE World Mean of 1975: This Mean is a result of the CIE international comparison of spectral irradiance scales which was reported in Reference [1]. The NRC scale for the wavelength (λ) region (300 nm ≤ λ < 700 nm) is based on a set of ten 500 watt quartz halogen lamps which were calibrated from the NRC lamps used in this intercomparison. The calibration values used were the values of the World Mean of this CIE comparison. The calibration values for the lamps GS-143, GS-262, and F-176 in the wavelength range (300 nm ≤ λ < 700 nm) used for this report is based on the values of spectral irradiance from these ten lamps. The transfer of the calibration to these three lamps was performed in 1990 at the same time as our participation in the last CCPR comparison reported in Reference [2].

2) NRC Primary Realization: The NRC scale for the wavelength region (700 nm ≤ λ ≤ 1600 nm) is based on the realization of a spectral irradiance scale at NRC using interference filters in conjunction with absolute radiometers. This work is described in References [3] and [4]. The three lamps (GS-143, GS-262, F-176) were calibrated in 1990 at the same time as the last CCPR comparison [2].

3) NBS Calibration: The scale used by NRC for the wavelength regions (250 nm ≤ λ < 300 nm) and (1600 nm < λ ≤ 2500 nm) is derived from two calibrated lamps purchased from NBS (now NIST). Lamp F-176 has an NBS calibration [5] for the wavelength region (250 nm ≤ λ ≤ 1600 nm) and lamp F-201 has an NBS calibration [6] for the wavelength region (250 nm ≤ λ ≤ 2400 nm). The spectral irradiance for the wavelength of 2500 nm is extrapolated from the NBS calibration of lamp F-201. Note that although these NBS lamps have a calibration in the wavelength region (300 nm ≤ λ ≤ 1600 nm), the NBS values were not used for the results given in this report for the wavelength region (300 nm ≤ λ ≤ 1600 nm).

The lamps used and the origin of the primary scale for the spectral irradiance used in this report are summarized in Table 14-1.

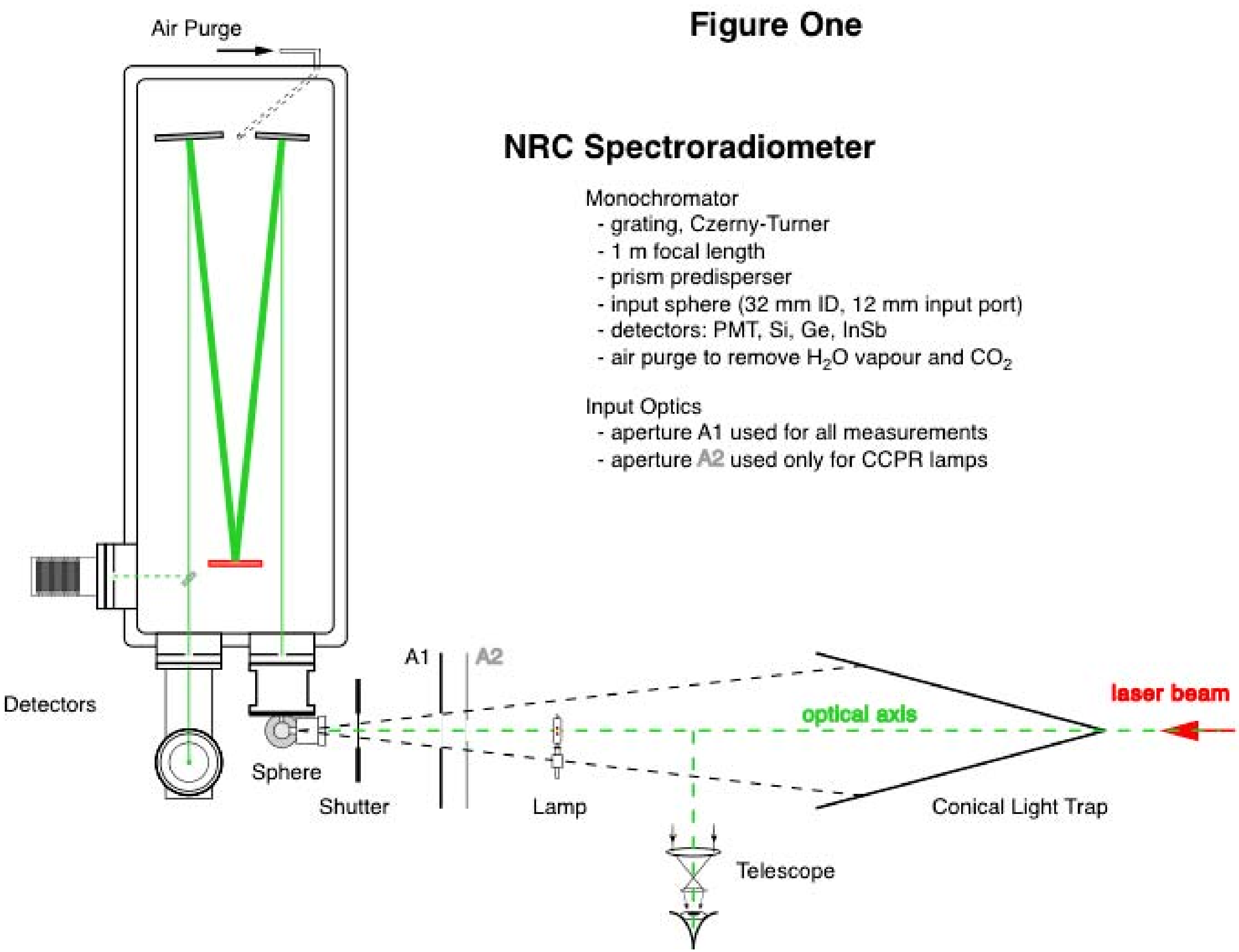
Table 14-1 Primary Scale and Standard Lamps Used for NRC Spectral Irradiance Scale

Wavelength range	Origin of primary scale	Standard lamps used
250 nm ≤ λ < 300 nm	NBS	F-176, F-201
300 nm ≤ λ < 700 nm	World Mean 1975	GS-143, GS-262, F-176
700 nm ≤ λ ≤ 1600 nm	NRC	GS-143, GS-262, F-176
1600 nm < λ ≤ 2500 nm	NBS	F-201

14.2 Description of measurement facility

A schematic of the measurement facility used for the spectroradiometric measurements is given in Figure 14-1.

Figure 14-1 NRC Spectroradiometer



14.2.1 Spectroradiometer

The spectroradiometer is composed of the monochromator, the sphere input optics, and the detectors.

14.2.1.1 Monochromator

A summary of the monochromator operating conditions is given in Table 14-2. The monochromator was a GCA McPherson Model 2051, which is a 1-metre focal length grating instrument with a Czerny-Turner optical design. On the input to this instrument was a GCA McPherson Model 608M1 (Suprasil) Prism Predisperser, which acts to reduce stray light and remove the unwanted higher orders of the diffracted light which would be present in the grating instrument. Three different gratings were used, depending upon the wavelength regions under measurement. The slit widths were adjusted in each of the three sets of measurements to produce an optimum signal size for each of the detectors (the maximum bandwidth available with the gratings used was approximately 3.3 nm). The bandwidths used were triangular in shape (the input and output slits were set to be equal), with the Full Width at Half Maximum (FWHM) as given in Table 14-2. The interior of the GCA-2051 was purged during all the measurements with a slight overpressure of air which had been cleaned of all water vapour and CO_2 using a Balston FT-IR Purge Gas Generator Model 75-62.

Table 14-2 Spectroradiometer Configurations for Wavelength regions used in Measurements

measurement set	wavelength range	detector	grating grooves/mm	grating blaze	coating	bandwidth FWHM
UV/VIS	250 nm ≤ λ ≤ 310 nm 320 nm ≤ λ ≤ 1150 nm	PMT Si	600	400 nm	Al	3.0 nm
NIR	1200 nm ≤ λ ≤ 1750 nm	Ge	600	1000 nm	Au	0.8 nm
IR	1800 nm ≤ λ ≤ 2500 nm	InSb	600	2700 nm	Au	3.3 nm

14.2.1.2 Monochromator Input Optics

The input optics used to define the irradiance area measured, and couple this radiation to the monochromator, was an integrating sphere as shown in Figure 14-1. The interior of the sphere was formed of pressed Halon (PTFE) with a final inside diameter of approximately 32 mm. The input port to the sphere was circular, 12 mm in diameter. This input port thus defines the region of the irradiance produced by the lamps which was measured. The output port of the sphere was rectangular in shape, design to provide optimum coupling to the input slits of the Predisperser unit. These two ports on the sphere are at 90 degrees to each other, so that region of the sphere wall seen by the monochromator does not overlap the region of the sphere wall irradiated by the input to the sphere. Note that the input port to this sphere defines the point from which the distance to the lamp filament must be measured.

There is also a small baffling unit attached to the input to this integrating sphere. The interior of this baffle unit is coated with black paint to reduce scattered light and the internal baffles are designed to reduce off-axis light which could enter the sphere. The smallest aperture in this baffle unit is an aperture of 26 mm diameter at approximately 60 mm from the input port. However, this aperture was not a limiting aperture of the input optics, as will be discussed in Section 14.2.2.1 describing the measurement configuration.

14.2.1.3 Detectors

Four different types of detectors were used to cover the wavelength region for these measurements. Although data was taken such that measurements were made with each detector to overlap the wavelengths taken with other detectors, the final wavelength regions used for each detector were determined by using the detector which gave the best run-to-run reproducibility for the measurements (as described in Section 14.6.1). The detectors and the wavelength regions in which they were used for the final data are summarized in Table 14-2.

PMT: The photomultiplier used was a Hamamatsu Model R6872, cooled to approximately –10 °C with a thermo-electric cooling unit. The operating high voltage was set to give an optimum signal over the wavelength range from 250 nm to 380 nm.

Si: The silicon detector used was a Hamamatsu S2387-66R, mounted into a thermoelectrically controlled unit operating at approximately 15 °C. The feedback resistor used in the amplifier unit for this detector was approximately 10 GΩ.

Ge: The germanium detector used was a North Coast Scientific Corporation Model EO-817L which was operated at a bias of 250 V and held in a liquid-nitrogen cooled assembly. The amplifier also operated within the cooled assembly and provided a very high gain, as evidenced by the smaller bandwidths used (Table 14-2) for these measurements.

InSb: The indium-antimonide detector used was a Cincinnati Electronics Corporation Model IDH-100. This detector and amplifier, together with a cold filter to remove IR radiation above 2.6 μm, also operated within a liquid-nitrogen-cooled unit. The signals obtained in this wavelength region were very small and required the use of chopping techniques. The chopping frequency was approximately 35 Hz, and the lockin amplifier used was a Stanford Research Systems SR810 DSP LIA.

14.2.2 Measurement Configuration

14.2.2.1 Optical Configuration

The basic optical configuration for the measurements is shown in Figure 14-1, which is approximately to scale. The specific configuration in Figure 14-1 is for the NIST-type of FEL lamps used as the NRC standards for the measurements (all four of the lamps listed in Table 14-1 above).

The apertures A1 and A2 are sized and placed to limit the field-of-view (FOV) of the input sphere to the desired portion of the lamp being measured. Aperture A1 is a 66 mm diameter aperture placed at approximately 275 mm from the sphere input port to define the measured region of the NRC standards. This is approximately as shown in Figure 14-1 of this report, and also Fig. 1 of reference [4]. Aperture A2 was added only for the measurement of the CCPR transfer lamps. It was a 40 mm diameter aperture, and was placed at approximately 326 mm from the sphere input port for the CCPR FEL Type I lamps and at approximately 377 mm from the sphere input port for the CCPR Polaron Type II lamps. Since A2 contains a smaller FOV than A1, it was not necessary to remove or move A1 when A2 was in place.

The shutter was basically a moveable blade inside an aperture of diameter approximately 63 mm. It was placed close enough to the baffle system of the input sphere that it did not impinge on the FOV of any of the other apertures.

The IR measurements performed using the InSb detector required the use of a chopper. This was a rotating blade chopper that was inserted (only for the IR measurements) in between the input sphere baffle assembly and the shutter. The shutter had to be moved slightly farther from the input sphere for this configuration.

The conical light trap was placed ‘behind’ the lamps, as indicated in Figure 14-1, to enclose the entire FOV of the input sphere as defined by the apertures A1 or A2. This was at approximately 1 m from the sphere input port for the NRC lamps and 1.5 m from the sphere input port for the CCPR lamps.

The optical axis was set up using a laser beam placed ‘behind’ the light sources as indicated, and incident upon the input sphere. This beam was placed co-linear with the photometric bench upon which the shutter, apertures, lamps, and conical light trap were placed. The input aperture plane of the monochromator input sphere was adjusted (by adjusting the position of the complete monochromator since the input sphere is firmly attached to the monochromator) such that the input aperture was centered on the optical axis and perpendicular to the optical axis.

A reference point for distance measurement along the optical axis was set using a telescope positioned as indicated. The axis of the telescope was set perpendicular to the optical axis and in a horizontal plane. The focal point of the telescope was set at the intersection of the telescope axis with the optical axis. The distance of this intersection from the input aperture (port) of the input sphere was set, using calibrated length rods, at 1.3 m. The distance of a lamp filament from the input sphere aperture could now be set by positioning the required point on the lamp filament at the telescope crosshair, and then moving the lamp assembly the required distance interval toward the input sphere using the distance scale on the photometric bench. (The lamp assembly contains a crosshair indexed to the scale on the photometric bench.)

14.2.2.2 Lamp Configuration

The NRC standard FEL lamps were aligned to the optical axis using the NIST-style alignment jig to position the lamp socket at the correct angles and positions for measurement.

The CCPR comparison lamps were aligned using the instructions received by email from E.R. Woolliams on 2002-May-28.

The electrical supply to the lamps was derived from high-stability (Kepco) DC power supplies operating in current control. The current supplied to the lamps was measured using calibrated standard resistors (0.01 Ω) in the standard 4-terminal measuring configuration. The voltage at the lamps was measured using the terminals supplied at the lamp assembly.

14.3 Laboratory Conditions

The ambient temperature in the measurement laboratory was 25 °C ± 1 °C.

The relative humidity in the measurement laboratory was between approximately 40 % and 50 % for the UV/VIS and NIR measurements, and between approximately 35 % and 45 % for the IR measurements.

14.4 Laboratory standards

Four FEL-type lamps, with the NIST type of bi-pin mounting socket, were used for calibrating the NRC spectroradiometer. The alignment of these lamps was done using the NIST type of alignment jig. The lamps are identified as GS-143, GS-262, F-176, and F-201 and these lamps hold the NRC spectral irradiance scale.

14.5 Measurement Procedure

The basic procedure used is a sequential method: Each lamp was measured completely through a given wavelength range, or set of wavelength ranges, before installing another lamp onto the optical axis to repeat the process. The spectroradiometer system was calibrated by measuring two NRC standard lamps at the beginning and at the end of each measurement day. Each measurement sequence was composed of two or more complete scans through the wavelength range. A typical measurement day for the UV/VIS wavelength range is summarized in Table 14-3. The arrows between columns indicate the time sequence for the measurements. The notation (240,400,10) indicates a measurement set from 240 nm to 400 nm with measurements every 10 nm.

Table 14-3 Measurement sequence for typical UV/VIS measurement day. The numbers given in the table are the number of repeat scans performed.

lamp	wavelength range and detector (240,400,10) PMT		(240,400,10) Si		(300,1200,50) Si	CCPR measurement number
GS-143	3	→	3	→	3	
F-176	3	←	3	←	3	
BN-9101-210	2	→	2	→	2	M1
BN-9101-218	2	←	2	←	2	M1
BN-9101-248	2	→	2	→	2	M1
F-201	2	←	2	←	2	
GS-262	2	→	2	→	2	

14.6 Data Analysis

14.6.1 Calibration of the spectroradiometer

The measurements taken permit various means of analysis of the data. However, for the purposes of expediency, only one method was adopted for the submission of the calibrations in this report. It was assumed (with some justification) that the spectroradiometer remained stable over the four to six days that encompassed the measurements for each of the three measurement regions (UV/VIS, NIR, and IR). Therefore, all the calibration measurements taken for each measurement region were averaged together to provide one 'spectroradiometer calibration factor' that would be used for all the measurements of the CCPR lamps during that same period of time. (The units of the calibration factor would be *spectral irradiance / signal voltage* for the particular spectroradiometer configuration in use.) The standard deviation of the data for this calibration factor for the different spectroradiometer configurations was evaluated, and, wherever there was a choice, the optimum (lowest fractional standard deviation of the calibration factor) spectroradiometer configuration was used to determine the particular configuration and calibration factor which would be used for the final calculation of the spectral irradiance of the CCPR lamps. The resulting configurations used for various wavelength regions were presented in Table 14-2 above.

14.6.2 Measurement Results

In each of these four wavelength regions (Table 14-2), the calibration of the CCPR lamps is simply determined as the product of the spectroradiometer calibration factor and the signal voltage measured for the particular lamp in the appropriate measurement configuration.

Note: As indicated in Section 14.2.1.3, measurements were taken to provide overlap between the different detectors and the different sets of measurements. In general, the agreement in these regions of overlap was reasonable. However, we did observe one group of measurements that did not overlap very well. This was for the overlap between the measurements taken using the Ge detector in the NIR set of measurements with the measurements taken using the InSb detector for the IR set of measurements. This overlap covered the range from 1500 nm to 1750 nm, and consisted of six wavelength datapoints, since I took data every 50 nm. Also, the effect was observed only for the CCPR Type II (Polaron) lamps. The agreement was fine for the CCPR Type I (FEL) lamps. The spectral irradiance values determined for the Polaron lamps by the InSb measurements were higher than the values originating from the Ge measurements by approximately 2 % to 4 %. I do not expect any of the usual sources of problems (bandwidth, linearity) to be the problem here, so at present I am unable to explain this difference. For the purposes of this report I have arbitrarily used the Ge detector data for this wavelength region. In addition, I have not accounted for this in my estimation of uncertainties. This implies that I believe the Ge data more than the InSb data for these measurements.

14.7 Uncertainty determination

All uncertainties as presented as one standard deviation (coverage factor $k = 1$). Note that all the uncertainties presented are given as fractional uncertainties. The uncertainties are given in Table 14-4. All uncertainties, except the standard deviations of the CCPR lamp reproducibility during repeat measurements during one lighting of the lamp ("Measurement repeatability"), are the same values for all lamps. The following uncertainties are presented:

14.7.1 Calibration of Standard Lamps

This is the uncertainty in the calibration of the NRC lamps we used as our standards for the calibration of the spectroradiometer. The standard lamps used, and the origin of the spectral irradiance scale, were discussed above in Sections 14.1 and 14.4. The uncertainties for the various scales were determined as follows:

1) CIE World Mean of 1975: The uncertainties presented are the same as those we used for the previous CCPR comparison [2], since the scale and standards are the same. These values are based upon the scatter in the data of the original comparison [1] and the scatter in the ten lamps upon which we maintain this scale. I think the values are pessimistic, particularly since they are based upon the scatter of the data, rather than the uncertainty of the mean of all this data. (The mean was used for the calibration of the standard lamps.) Within our present time constraints I am unable to return to the original data used by my predecessor and re-evaluate the data and the model fit to the original datapoints. I suspect the uncertainties in the 300 nm to 400 nm range could be reduced by a factor of two at least.
2) NRC Primary Realization: These uncertainties are presented in Table 1 of reference [4].
3) NBS Calibrations: The uncertainties used are taken from the calibration reports [5,6] of these two lamps.

14.7.2 Calibration of Spectroradiometer

The method of determining the calibration factor for the spectroradiometer was presented above in Section 14.5 and Section 14.6. This method of determining the uncertainties for the calibration of the spectroradiometer takes account of the behaviour of the complete system: the lamp stabilities, the lamp remount/realignment variation, any monochromator drift, and the noise in the detector signals. The uncertainties presented are the standard deviation of the calibration datasets (all the repeat measurements and the re-mount measurements performed with the various standard lamps), rather than the standard deviation of the mean. Since there are between 10 and 40 datasets which contribute (depending upon the wavelength region) to the spectroradiometer calibration factor, the uncertainty of the mean would be reduced considerably if it were assumed that this data sample was the distribution of one random variable. However, since only a limited number of standard lamps were used as a sample of the primary scale, and there are several different variables accounted for (as indicated above), I have chosen to leave the uncertainties as those of the sample, rather than the mean.

14.7.3 Detector Linearity

These figures are derived from measurements in our laboratory for similar detectors to the ones used in these measurements. They represent upper limits of uncertainty that can be expected.

14.7.4 Distance

The method of setting the lamp positions was described above in Section 14.2.2. A maximum uncertainty of 0.5 mm is estimated in setting the position of the filament. This results in the uncertainty given in the dataset.

14.7.5 Lamp Control

The uncertainty of all the components in the control and setting of the electrical parameters for the lamp control was less than 0.01 %. At maximum this would scale up to be less than the 0.1 % given on the dataset.

14.7.6 Wavelength

The wavelength accuracy of the monochromator was determined to be better than 0.05 nm. The reproducibility of the monochromator wavelength settings is approximately 0.005 nm. For the calibration of similar lamps as done in this comparison, it is the wavelength reproducibility that contributes the uncertainty due to wavelength uncertainty. The uncertainty expected from the reproducibility of this monochromator is negligible compared to the uncertainties which are already presented.

14.7.7 Correlation

Since NRC made measurements in only one round, the only correlations that need to be considered are the correlations within one round. In Table 14-4 correlation is indicated as “correlated” meaning a component that is correlated for all lamp measurements, or “uncorrelated” meaning a component that is uncorrelated for all the lamp measurements.

Table 14-4 Estimated fractional uncertainties (k = 1) for the NRC spectroradiometer used for the calibration of the CCPR transfer lamps. Note that this data does not include the uncertainties due to the reproducibility and repeatability of the CCPR transfer lamps. All uncertainties except "Measurement repeatability" are common for all lamps. As an example, "Measurement repeatability" is given for the calibration of FEL BN 9101 210.

TYPE: Correlation	B Correlated	A Uncorrelated	B Correlated	B Correlated	B Correlated	A Uncorrelated		
Wavelength / nm	Calibration of standard lamps	Calibration of spectro-radiometer	Detector linearity	Distance	Lamp control	Measurement repeatability (Example FEL 210)	Combined standard uncertainty	
250.0	0.0090	0.0275	0.0010	0.0020	0.0010	0.0221	0.0365	3.65%
260.0	0.0090	0.0209	0.0010	0.0020	0.0010	0.0076	0.0241	2.41%
270.0	0.0090	0.0175	0.0010	0.0020	0.0010	0.0044	0.0203	2.03%
280.0	0.0080	0.0139	0.0010	0.0020	0.0010	0.0026	0.0165	1.65%
290.0	0.0080	0.0114	0.0010	0.0020	0.0010	0.0025	0.0144	1.44%
300.0	0.1000	0.0106	0.0010	0.0020	0.0010	0.0021	0.1006	10.06%
310.0	0.0700	0.0111	0.0010	0.0020	0.0010	0.0019	0.0709	7.09%
320.0	0.0600	0.0092	0.0001	0.0020	0.0010	0.0030	0.0608	6.08%
330.0	0.0500	0.0066	0.0001	0.0020	0.0010	0.0032	0.0506	5.06%
340.0	0.0400	0.0063	0.0001	0.0020	0.0010	0.0009	0.0406	4.06%
350.0	0.0300	0.0062	0.0001	0.0020	0.0010	0.0008	0.0307	3.07%
360.0	0.0300	0.0058	0.0001	0.0020	0.0010	0.0004	0.0306	3.06%
370.0	0.0300	0.0056	0.0001	0.0020	0.0010	0.0001	0.0306	3.06%
380.0	0.0300	0.0057	0.0001	0.0020	0.0010	0.0003	0.0306	3.06%
390.0	0.0300	0.0053	0.0001	0.0020	0.0010	0.0003	0.0306	3.06%
400.0	0.0200	0.0053	0.0001	0.0020	0.0010	0.0004	0.0208	2.08%
450.0	0.0200	0.0056	0.0001	0.0020	0.0010	0.0022	0.0210	2.10%
500.0	0.0160	0.0055	0.0001	0.0020	0.0010	0.0026	0.0173	1.73%
550.0	0.0160	0.0053	0.0001	0.0020	0.0010	0.0028	0.0172	1.72%
600.0	0.0160	0.0053	0.0001	0.0020	0.0010	0.0027	0.0172	1.72%
650.0	0.0160	0.0051	0.0001	0.0020	0.0010	0.0024	0.0171	1.71%
700.0	0.0050	0.0055	0.0001	0.0020	0.0010	0.0024	0.0081	0.81%
750.0	0.0050	0.0054	0.0001	0.0020	0.0010	0.0022	0.0080	0.80%

800.0	0.0050	0.0055	0.0001	0.0020	0.0010	0.0021	0.0081	0.81%
850.0	0.0050	0.0056	0.0001	0.0020	0.0010	0.0022	0.0081	0.81%
900.0	0.0050	0.0055	0.0001	0.0020	0.0010	0.0020	0.0080	0.80%
950.0	0.0050	0.0054	0.0001	0.0020	0.0010	0.0019	0.0079	0.79%
1000.0	0.0050	0.0053	0.0001	0.0020	0.0010	0.0021	0.0079	0.79%
1100.0	0.0050	0.0047	0.0001	0.0020	0.0010	0.0002	0.0072	0.72%
1200.0	0.0050	0.0083	0.0020	0.0020	0.0010	0.0002	0.0102	1.02%
1300.0	0.0050	0.0084	0.0020	0.0020	0.0010	0.0004	0.0102	1.02%
1400.0	0.0050	0.0089	0.0020	0.0020	0.0010	0.0008	0.0107	1.07%
1500.0	0.0050	0.0083	0.0020	0.0020	0.0010	0.0016	0.0102	1.02%
1600.0	0.0050	0.0078	0.0020	0.0020	0.0010	0.0020	0.0099	0.99%
1700.0	0.0075	0.0103	0.0020	0.0020	0.0010	0.0007	0.0131	1.31%
1800.0	0.0087	0.0087	0.0020	0.0020	0.0010	0.0031	0.0130	1.30%
1900.0	0.0098	0.0155	0.0020	0.0020	0.0010	0.0009	0.0186	1.86%
2000.0	0.0110	0.0106	0.0020	0.0020	0.0010	0.0023	0.0157	1.57%
2100.0	0.0137	0.0114	0.0020	0.0020	0.0010	0.0016	0.0181	1.81%
2200.0	0.0164	0.0116	0.0020	0.0020	0.0010	0.0027	0.0205	2.05%
2300.0	0.0190	0.0117	0.0020	0.0020	0.0010	0.0066	0.0234	2.34%
2400.0	0.0217	0.0129	0.0020	0.0020	0.0010	0.0036	0.0257	2.57%
2500.0	0.0370	0.0121	0.0020	0.0020	0.0010	0.0128	0.0411	4.11%

14.8 NRC Results

NRC measured three Type I lamps and three Type II lamps. The results for FEL BN 9101 210 are given in Table 14-5 and the results for FEL BN 9101 248 are given in Table 14-6 and the results for FEL BN 9101 218 are given in Table 14-7. The results for P257c are given inTable 14-8, the results for P252c are given in Table 14-9 and the results for P250c are given in Table 14-10.

Table 14-5 NRC Results for FEL BN 9101 210. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 210	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.528E-04	3.52 %	0.93 %	0.00 %	3.65 %					
260	2.585E-04	2.22 %	0.93 %	0.00 %	2.41 %					
270	4.380E-04	1.80 %	0.93 %	0.00 %	2.03 %					
280	6.935E-04	1.42 %	0.84 %	0.00 %	1.65 %					
290	1.045E-03	1.17 %	0.84 %	0.00 %	1.44 %					
300	1.533E-03	1.08 %	10.00 %	0.00 %	10.06 %					
310	2.149E-03	1.12 %	7.00 %	0.00 %	7.09 %					
320	2.927E-03	0.97 %	6.00 %	0.00 %	6.08 %					
330	3.858E-03	0.73 %	5.01 %	0.00 %	5.06 %					
340	5.044E-03	0.64 %	4.01 %	0.00 %	4.06 %					
350	6.784E-03	0.62 %	3.01 %	0.00 %	3.07 %					
360	8.526E-03	0.58 %	3.01 %	0.00 %	3.06 %					
370	1.064E-02	0.56 %	3.01 %	0.00 %	3.06 %					
380	1.317E-02	0.57 %	3.01 %	0.00 %	3.06 %					
390	1.568E-02	0.53 %	3.01 %	0.00 %	3.06 %					
400	1.866E-02	0.53 %	2.01 %	0.00 %	2.08 %					
450	3.822E-02	0.60 %	2.01 %	0.00 %	2.10 %					
500	6.303E-02	0.61 %	1.62 %	0.00 %	1.73 %					
550	9.008E-02	0.60 %	1.62 %	0.00 %	1.72 %					
555										
600	1.185E-01	0.60 %	1.62 %	0.00 %	1.72 %					
650	1.417E-01	0.56 %	1.62 %	0.00 %	1.71 %					
700	1.638E-01	0.60 %	0.55 %	0.00 %	0.81 %					
750	1.791E-01	0.58 %	0.55 %	0.00 %	0.80 %					
800	1.895E-01	0.59 %	0.55 %	0.00 %	0.81 %					
850	1.956E-01	0.60 %	0.55 %	0.00 %	0.81 %					
900	1.977E-01	0.59 %	0.55 %	0.00 %	0.80 %					
950	1.966E-01	0.57 %	0.55 %	0.00 %	0.79 %					
1000	1.931E-01	0.57 %	0.55 %	0.00 %	0.79 %					
1100	1.809E-01	0.47 %	0.55 %	0.00 %	0.72 %					
1200	1.639E-01	0.83 %	0.58 %	0.00 %	1.02 %					
1300	1.466E-01	0.84 %	0.58 %	0.00 %	1.02 %					
1400	1.296E-01	0.90 %	0.58 %	0.00 %	1.07 %					
1500	1.136E-01	0.84 %	0.58 %	0.00 %	1.02 %					
1600	9.904E-02	0.80 %	0.58 %	0.00 %	0.99 %					
1700	8.612E-02	1.03 %	0.81 %	0.00 %	1.31 %					
1800	7.519E-02	0.92 %	0.92 %	0.00 %	1.30 %					
1900	6.510E-02	1.55 %	1.02 %	0.00 %	1.86 %					
2000	5.703E-02	1.08 %	1.14 %	0.00 %	1.57 %					
2100	4.971E-02	1.15 %	1.40 %	0.00 %	1.81 %					
2200	4.384E-02	1.19 %	1.67 %	0.00 %	2.05 %					
2300	3.851E-02	1.34 %	1.92 %	0.00 %	2.34 %					

2400	3.399E-02	1.34 %	2.19 %	0.00 %	2.57 %					
2500	3.005E-02	1.76 %	3.71 %	0.00 %	4.11 %					

Table 14-6 NRC Results for FEL BN 9101 248. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 248	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.290E-04	3.01 %	0.93 %	0.00 %	3.15 %					
260	2.235E-04	2.15 %	0.93 %	0.00 %	2.34 %					
270	3.788E-04	1.80 %	0.93 %	0.00 %	2.03 %					
280	5.875E-04	1.41 %	0.84 %	0.00 %	1.64 %					
290	9.211E-04	1.15 %	0.84 %	0.00 %	1.42 %					
300	1.367E-03	1.06 %	10.00 %	0.00 %	10.06 %					
310	1.941E-03	1.11 %	7.00 %	0.00 %	7.09 %					
320	2.633E-03	1.19 %	6.00 %	0.00 %	6.12 %					
330	3.505E-03	0.67 %	5.01 %	0.00 %	5.05 %					
340	4.614E-03	0.65 %	4.01 %	0.00 %	4.06 %					
350	6.245E-03	0.62 %	3.01 %	0.00 %	3.07 %					
360	7.881E-03	0.58 %	3.01 %	0.00 %	3.06 %					
370	9.881E-03	0.57 %	3.01 %	0.00 %	3.06 %					
380	1.229E-02	0.57 %	3.01 %	0.00 %	3.06 %					
390	1.469E-02	0.53 %	3.01 %	0.00 %	3.06 %					
400	1.755E-02	0.53 %	2.01 %	0.00 %	2.08 %					
450	3.654E-02	0.63 %	2.01 %	0.00 %	2.11 %					
500	6.099E-02	0.64 %	1.62 %	0.00 %	1.74 %					
550	8.802E-02	0.63 %	1.62 %	0.00 %	1.73 %					
555										
600	1.168E-01	0.62 %	1.62 %	0.00 %	1.73 %					
650	1.405E-01	0.59 %	1.62 %	0.00 %	1.72 %					
700	1.634E-01	0.62 %	0.55 %	0.00 %	0.83 %					
750	1.795E-01	0.59 %	0.55 %	0.00 %	0.81 %					
800	1.907E-01	0.60 %	0.55 %	0.00 %	0.81 %					
850	1.975E-01	0.61 %	0.55 %	0.00 %	0.82 %					
900	2.002E-01	0.60 %	0.55 %	0.00 %	0.82 %					
950	1.997E-01	0.59 %	0.55 %	0.00 %	0.81 %					
1000	1.966E-01	0.58 %	0.55 %	0.00 %	0.80 %					
1100	1.846E-01	0.47 %	0.55 %	0.00 %	0.72 %					
1200	1.684E-01	0.84 %	0.58 %	0.00 %	1.02 %					
1300	1.509E-01	0.84 %	0.58 %	0.00 %	1.02 %					
1400	1.337E-01	0.90 %	0.58 %	0.00 %	1.07 %					
1500	1.173E-01	0.84 %	0.58 %	0.00 %	1.02 %					
1600	1.024E-01	0.90 %	0.58 %	0.00 %	1.07 %					
1700	8.904E-02	1.03 %	0.81 %	0.00 %	1.31 %					
1800	7.760E-02	0.87 %	0.92 %	0.00 %	1.27 %					
1900	6.721E-02	1.56 %	1.02 %	0.00 %	1.86 %					
2000	5.890E-02	1.07 %	1.14 %	0.00 %	1.56 %					
2100	5.143E-02	1.15 %	1.40 %	0.00 %	1.82 %					
2200	4.532E-02	1.19 %	1.67 %	0.00 %	2.05 %					
2300	3.986E-02	1.24 %	1.92 %	0.00 %	2.29 %					
2400	3.519E-02	1.44 %	2.19 %	0.00 %	2.62 %					
2500	3.100E-02	2.32 %	3.71 %	0.00 %	4.38 %					

Table 14-7 NRC Results for FEL BN 9101 218. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 218	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.121E-04	3.03 %	0.93 %	0.00 %	3.17 %					
260	1.918E-04	2.19 %	0.93 %	0.00 %	2.38 %					
270	3.279E-04	1.84 %	0.93 %	0.00 %	2.07 %					
280	5.206E-04	1.43 %	0.84 %	0.00 %	1.66 %					
290	8.022E-04	1.19 %	0.84 %	0.00 %	1.46 %					
300	1.190E-03	1.12 %	10.00 %	0.00 %	10.07 %					
310	1.693E-03	1.12 %	7.00 %	0.00 %	7.09 %					
320	2.300E-03	1.12 %	6.00 %	0.00 %	6.11 %					
330	3.061E-03	0.66 %	5.01 %	0.00 %	5.05 %					
340	4.042E-03	0.65 %	4.01 %	0.00 %	4.06 %					
350	5.472E-03	0.62 %	3.01 %	0.00 %	3.07 %					
360	6.925E-03	0.58 %	3.01 %	0.00 %	3.06 %					
370	8.694E-03	0.56 %	3.01 %	0.00 %	3.06 %					
380	1.083E-02	0.58 %	3.01 %	0.00 %	3.06 %					
390	1.297E-02	0.54 %	3.01 %	0.00 %	3.06 %					
400	1.553E-02	0.53 %	2.01 %	0.00 %	2.08 %					
450	3.248E-02	0.56 %	2.01 %	0.00 %	2.09 %					
500	5.456E-02	0.56 %	1.62 %	0.00 %	1.71 %					
550	7.916E-02	0.53 %	1.62 %	0.00 %	1.70 %					
555										
600	1.055E-01	0.53 %	1.62 %	0.00 %	1.70 %					
650	1.274E-01	0.51 %	1.62 %	0.00 %	1.69 %					
700	1.486E-01	0.55 %	0.55 %	0.00 %	0.78 %					
750	1.637E-01	0.54 %	0.55 %	0.00 %	0.77 %					
800	1.745E-01	0.55 %	0.55 %	0.00 %	0.78 %					
850	1.810E-01	0.56 %	0.55 %	0.00 %	0.78 %					
900	1.839E-01	0.55 %	0.55 %	0.00 %	0.78 %					
950	1.837E-01	0.54 %	0.55 %	0.00 %	0.77 %					
1000	1.811E-01	0.53 %	0.55 %	0.00 %	0.77 %					
1100	1.709E-01	0.47 %	0.55 %	0.00 %	0.72 %					
1200	1.563E-01	0.83 %	0.58 %	0.00 %	1.02 %					
1300	1.403E-01	0.84 %	0.58 %	0.00 %	1.02 %					
1400	1.245E-01	0.90 %	0.58 %	0.00 %	1.07 %					
1500	1.093E-01	0.83 %	0.58 %	0.00 %	1.01 %					
1600	9.554E-02	0.78 %	0.58 %	0.00 %	0.97 %					
1700	8.292E-02	1.03 %	0.81 %	0.00 %	1.31 %					
1800	7.286E-02	0.88 %	0.92 %	0.00 %	1.27 %					
1900	6.340E-02	1.58 %	1.02 %	0.00 %	1.88 %					
2000	5.519E-02	1.06 %	1.14 %	0.00 %	1.56 %					
2100	4.811E-02	1.22 %	1.40 %	0.00 %	1.86 %					
2200	4.235E-02	1.43 %	1.67 %	0.00 %	2.20 %					
2300	3.725E-02	1.36 %	1.92 %	0.00 %	2.36 %					
2400	3.288E-02	1.47 %	2.19 %	0.00 %	2.64 %					
2500	2.881E-02	1.93 %	3.71 %	0.00 %	4.18 %					

Table 14-8 NRC Results for Polaron P257c. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

P257c	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	2.164E-05	6.87 %	0.93 %	0.00 %	6.93 %					
260	3.685E-05	3.34 %	0.93 %	0.00 %	3.46 %					
270	6.268E-05	2.13 %	0.93 %	0.00 %	2.33 %					
280	1.008E-04	1.52 %	0.84 %	0.00 %	1.73 %					
290	1.551E-04	1.21 %	0.84 %	0.00 %	1.47 %					
300	2.324E-04	1.08 %	10.00 %	0.00 %	10.06 %					
310	3.306E-04	1.12 %	7.00 %	0.00 %	7.09 %					
320	4.534E-04	5.25 %	6.00 %	0.00 %	7.97 %					
330	6.109E-04	1.25 %	5.01 %	0.00 %	5.16 %					
340	8.109E-04	0.70 %	4.01 %	0.00 %	4.07 %					
350	1.110E-03	0.62 %	3.01 %	0.00 %	3.07 %					
360	1.416E-03	0.74 %	3.01 %	0.00 %	3.10 %					
370	1.777E-03	0.60 %	3.01 %	0.00 %	3.07 %					
380	2.232E-03	0.68 %	3.01 %	0.00 %	3.08 %					
390	2.682E-03	0.55 %	3.01 %	0.00 %	3.06 %					
400	3.226E-03	0.53 %	2.01 %	0.00 %	2.08 %					
450	6.890E-03	0.62 %	2.01 %	0.00 %	2.11 %					
500	1.173E-02	0.63 %	1.62 %	0.00 %	1.73 %					
550	1.719E-02	0.61 %	1.62 %	0.00 %	1.73 %					
555										
600	2.307E-02	0.60 %	1.62 %	0.00 %	1.72 %					
650	2.800E-02	0.57 %	1.62 %	0.00 %	1.71 %					
700	3.277E-02	0.60 %	0.55 %	0.00 %	0.81 %					
750	3.615E-02	0.59 %	0.55 %	0.00 %	0.80 %					
800	3.849E-02	0.60 %	0.55 %	0.00 %	0.81 %					
850	3.994E-02	0.60 %	0.55 %	0.00 %	0.81 %					
900	4.061E-02	0.59 %	0.55 %	0.00 %	0.81 %					
950	4.050E-02	0.58 %	0.55 %	0.00 %	0.80 %					
1000	3.985E-02	0.58 %	0.55 %	0.00 %	0.80 %					
1100	3.741E-02	0.47 %	0.55 %	0.00 %	0.72 %					
1200	3.405E-02	0.84 %	0.58 %	0.00 %	1.02 %					
1300	3.035E-02	0.84 %	0.58 %	0.00 %	1.02 %					
1400	2.632E-02	0.90 %	0.58 %	0.00 %	1.07 %					
1500	2.327E-02	0.83 %	0.58 %	0.00 %	1.01 %					
1600	2.019E-02	0.78 %	0.58 %	0.00 %	0.97 %					
1700	1.749E-02	1.04 %	0.81 %	0.00 %	1.32 %					
1800	1.553E-02	1.00 %	0.92 %	0.00 %	1.36 %					
1900	1.331E-02	1.66 %	1.02 %	0.00 %	1.95 %					
2000	1.154E-02	1.53 %	1.14 %	0.00 %	1.91 %					
2100	9.960E-03	1.72 %	1.40 %	0.00 %	2.22 %					
2200	8.452E-03	3.58 %	1.67 %	0.00 %	3.95 %					
2300	7.265E-03	3.28 %	1.92 %	0.00 %	3.80 %					
2400	6.255E-03	4.50 %	2.19 %	0.00 %	5.00 %					
2500	5.152E-03	8.77 %	3.71 %	0.00 %	9.52 %					

Table 14-9 NRC Results for Polaron P252c. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

P252c	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	2.073E-05	4.77 %	0.93 %	0.00 %	4.86 %					
260	3.458E-05	2.28 %	0.93 %	0.00 %	2.47 %					
270	5.860E-05	2.06 %	0.93 %	0.00 %	2.26 %					
280	9.435E-05	1.54 %	0.84 %	0.00 %	1.76 %					
290	1.456E-04	1.23 %	0.84 %	0.00 %	1.48 %					
300	2.194E-04	1.06 %	10.00 %	0.00 %	10.06 %					
310	3.123E-04	1.12 %	7.00 %	0.00 %	7.09 %					
320	4.308E-04	4.11 %	6.00 %	0.00 %	7.27 %					
330	5.784E-04	1.25 %	5.01 %	0.00 %	5.16 %					
340	7.776E-04	1.19 %	4.01 %	0.00 %	4.18 %					
350	1.061E-03	0.76 %	3.01 %	0.00 %	3.10 %					
360	1.352E-03	0.73 %	3.01 %	0.00 %	3.10 %					
370	1.708E-03	0.65 %	3.01 %	0.00 %	3.08 %					
380	2.138E-03	0.60 %	3.01 %	0.00 %	3.07 %					
390	2.579E-03	0.56 %	3.01 %	0.00 %	3.06 %					
400	3.109E-03	0.53 %	2.01 %	0.00 %	2.08 %					
450	6.684E-03	0.65 %	2.01 %	0.00 %	2.12 %					
500	1.144E-02	0.63 %	1.62 %	0.00 %	1.73 %					
550	1.685E-02	0.63 %	1.62 %	0.00 %	1.73 %					
555										
600	2.269E-02	0.63 %	1.62 %	0.00 %	1.73 %					
650	2.761E-02	0.60 %	1.62 %	0.00 %	1.72 %					
700	3.240E-02	0.62 %	0.55 %	0.00 %	0.83 %					
750	3.581E-02	0.60 %	0.55 %	0.00 %	0.81 %					
800	3.820E-02	0.61 %	0.55 %	0.00 %	0.82 %					
850	3.971E-02	0.62 %	0.55 %	0.00 %	0.83 %					
900	4.043E-02	0.62 %	0.55 %	0.00 %	0.83 %					
950	4.038E-02	0.59 %	0.55 %	0.00 %	0.81 %					
1000	3.977E-02	0.59 %	0.55 %	0.00 %	0.80 %					
1100	3.738E-02	0.48 %	0.55 %	0.00 %	0.73 %					
1200	3.410E-02	0.84 %	0.58 %	0.00 %	1.02 %					
1300	3.042E-02	0.84 %	0.58 %	0.00 %	1.02 %					
1400	2.637E-02	0.90 %	0.58 %	0.00 %	1.07 %					
1500	2.336E-02	0.83 %	0.58 %	0.00 %	1.01 %					
1600	2.029E-02	0.78 %	0.58 %	0.00 %	0.97 %					
1700	1.757E-02	1.07 %	0.81 %	0.00 %	1.34 %					
1800	1.571E-02	1.13 %	0.92 %	0.00 %	1.46 %					
1900	1.344E-02	1.71 %	1.02 %	0.00 %	2.00 %					
2000	1.172E-02	1.36 %	1.14 %	0.00 %	1.77 %					
2100	1.006E-02	1.50 %	1.40 %	0.00 %	2.05 %					
2200	8.474E-03	2.91 %	1.67 %	0.00 %	3.35 %					
2300	7.283E-03	3.78 %	1.92 %	0.00 %	4.24 %					
2400	6.322E-03	4.36 %	2.19 %	0.00 %	4.88 %					
2500	4.903E-03	11.57 %	3.71 %	0.00 %	12.15 %					

Table 14-10 NRC Results for Polaron P250c. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

P250c	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	2.305E-05	4.62 %	0.93 %	0.00 %	4.71 %					
260	3.835E-05	2.88 %	0.93 %	0.00 %	3.02 %					
270	6.452E-05	1.79 %	0.93 %	0.00 %	2.02 %					
280	1.033E-04	1.55 %	0.84 %	0.00 %	1.76 %					
290	1.588E-04	1.16 %	0.84 %	0.00 %	1.43 %					
300	2.379E-04	1.16 %	10.00 %	0.00 %	10.07 %					
310	3.383E-04	1.13 %	7.00 %	0.00 %	7.10 %					
320	4.610E-04	2.04 %	6.00 %	0.00 %	6.34 %					
330	6.256E-04	1.30 %	5.01 %	0.00 %	5.17 %					
340	8.369E-04	0.73 %	4.01 %	0.00 %	4.07 %					
350	1.129E-03	0.66 %	3.01 %	0.00 %	3.08 %					
360	1.434E-03	0.66 %	3.01 %	0.00 %	3.08 %					
370	1.813E-03	0.62 %	3.01 %	0.00 %	3.07 %					
380	2.271E-03	0.59 %	3.01 %	0.00 %	3.07 %					
390	2.726E-03	0.54 %	3.01 %	0.00 %	3.06 %					
400	3.278E-03	0.54 %	2.01 %	0.00 %	2.08 %					
450	6.979E-03	0.60 %	2.01 %	0.00 %	2.10 %					
500	1.186E-02	0.59 %	1.62 %	0.00 %	1.72 %					
550	1.736E-02	0.59 %	1.62 %	0.00 %	1.72 %					
555										
600	2.326E-02	0.59 %	1.62 %	0.00 %	1.72 %					
650	2.819E-02	0.57 %	1.62 %	0.00 %	1.71 %					
700	3.296E-02	0.59 %	0.55 %	0.00 %	0.81 %					
750	3.633E-02	0.58 %	0.55 %	0.00 %	0.79 %					
800	3.866E-02	0.58 %	0.55 %	0.00 %	0.80 %					
850	4.011E-02	0.59 %	0.55 %	0.00 %	0.80 %					
900	4.075E-02	0.58 %	0.55 %	0.00 %	0.80 %					
950	4.063E-02	0.56 %	0.55 %	0.00 %	0.79 %					
1000	3.996E-02	0.56 %	0.55 %	0.00 %	0.78 %					
1100	3.749E-02	0.48 %	0.55 %	0.00 %	0.73 %					
1200	3.410E-02	0.84 %	0.58 %	0.00 %	1.02 %					
1300	3.040E-02	0.84 %	0.58 %	0.00 %	1.02 %					
1400	2.639E-02	0.90 %	0.58 %	0.00 %	1.07 %					
1500	2.330E-02	0.83 %	0.58 %	0.00 %	1.01 %					
1600	2.020E-02	0.78 %	0.58 %	0.00 %	0.98 %					
1700	1.748E-02	1.04 %	0.81 %	0.00 %	1.32 %					
1800	1.563E-02	0.94 %	0.92 %	0.00 %	1.31 %					
1900	1.326E-02	1.87 %	1.02 %	0.00 %	2.13 %					
2000	1.167E-02	1.16 %	1.14 %	0.00 %	1.63 %					
2100	9.966E-03	1.22 %	1.40 %	0.00 %	1.86 %					
2200	8.549E-03	3.37 %	1.67 %	0.00 %	3.76 %					
2300	7.272E-03	3.38 %	1.92 %	0.00 %	3.89 %					
2400	6.266E-03	4.66 %	2.19 %	0.00 %	5.15 %					
2500	5.343E-03	11.63 %	3.71 %	0.00 %	12.21 %					

14.9 Pilot Results

NPL's results for FEL BN 9101 210 are given in Table 14-11 and the results for FEL BN 9101 248 are given in Table 14-12 and the results for FEL BN 9101 218 are given in Table 14-13. NPL's results for P257c are given in Table 14-14, the results for P252c are given in Table 14-15, and the results for P250c are given in Table 14-16.

Table 14-11 NPL Results for FEL BN 9101 210. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 210	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.540E-04	0.54 %	0.32 %	2.06 %	2.15 %	1.540E-04	0.75 %	0.00 %	2.06 %	2.19 %
260	2.681E-04	0.38 %	0.32 %	2.05 %	2.11 %	2.695E-04	0.47 %	0.00 %	2.05 %	2.11 %
270	4.430E-04	0.29 %	0.31 %	2.05 %	2.09 %	4.464E-04	0.37 %	0.00 %	2.05 %	2.08 %
280	6.993E-04	0.24 %	0.29 %	1.56 %	1.60 %	7.050E-04	0.33 %	0.00 %	1.56 %	1.60 %
290	1.060E-03	0.21 %	0.27 %	1.08 %	1.13 %	1.068E-03	0.32 %	0.00 %	1.08 %	1.13 %
300	1.551E-03	0.20 %	0.33 %	0.45 %	0.59 %	1.561E-03	0.30 %	0.15 %	0.45 %	0.56 %
310	2.197E-03	0.18 %	0.38 %	0.43 %	0.60 %	2.208E-03	0.27 %	0.20 %	0.43 %	0.55 %
320	3.026E-03	0.17 %	0.43 %	0.37 %	0.60 %	3.036E-03	0.25 %	0.25 %	0.37 %	0.51 %
330	4.062E-03	0.15 %	0.47 %	0.36 %	0.61 %	4.069E-03	0.24 %	0.28 %	0.36 %	0.52 %
340	5.329E-03	0.08 %	0.53 %	0.35 %	0.64 %	5.331E-03	0.23 %	0.33 %	0.35 %	0.53 %
350	6.847E-03	0.16 %	0.58 %	0.34 %	0.69 %	6.843E-03	0.23 %	0.36 %	0.34 %	0.55 %
360	8.635E-03	0.15 %	0.67 %	0.33 %	0.77 %	8.622E-03	0.24 %	0.43 %	0.33 %	0.59 %
370	1.071E-02	0.15 %	0.72 %	0.32 %	0.80 %	1.068E-02	0.25 %	0.46 %	0.32 %	0.61 %
380	1.307E-02	0.14 %	0.81 %	0.31 %	0.88 %	1.304E-02	0.25 %	0.52 %	0.31 %	0.66 %
390	1.573E-02	0.14 %	0.78 %	0.31 %	0.85 %	1.569E-02	0.26 %	0.50 %	0.31 %	0.64 %
400	1.869E-02	0.14 %	0.72 %	0.30 %	0.79 %	1.864E-02	0.26 %	0.46 %	0.30 %	0.61 %
450	3.776E-02	0.13 %	0.31 %	0.27 %	0.43 %	3.776E-02	0.24 %	0.10 %	0.27 %	0.37 %
500	6.254E-02	0.12 %	0.31 %	0.24 %	0.41 %	6.271E-02	0.22 %	0.00 %	0.24 %	0.32 %
550	9.021E-02	0.12 %	0.33 %	0.22 %	0.42 %	9.059E-02	0.19 %	0.00 %	0.22 %	0.29 %
555	9.302E-02	0.12 %	0.33 %	0.22 %	0.41 %	9.342E-02	0.18 %	0.00 %	0.22 %	0.28 %
600	1.178E-01	0.11 %	0.33 %	0.20 %	0.40 %	1.183E-01	0.17 %	0.00 %	0.20 %	0.26 %
650	1.428E-01	0.03 %	0.32 %	0.18 %	0.37 %	1.432E-01	0.17 %	0.00 %	0.18 %	0.25 %
700	1.637E-01	0.13 %	0.31 %	0.17 %	0.38 %	1.640E-01	0.18 %	0.00 %	0.17 %	0.25 %
750	1.796E-01	0.11 %	0.30 %	0.16 %	0.36 %	1.798E-01	0.17 %	0.00 %	0.16 %	0.23 %
800	1.906E-01	0.10 %	0.29 %	0.15 %	0.34 %	1.907E-01	0.15 %	0.00 %	0.15 %	0.21 %
850	1.971E-01	0.09 %	0.28 %	0.14 %	0.32 %	1.971E-01	0.12 %	0.00 %	0.14 %	0.18 %
900	1.995E-01	0.09 %	0.26 %	0.13 %	0.31 %	1.995E-01	0.10 %	0.00 %	0.13 %	0.17 %
950	1.987E-01	0.09 %	0.25 %	0.13 %	0.30 %	1.986E-01	0.09 %	0.00 %	0.13 %	0.16 %
1000	1.953E-01	0.08 %	0.25 %	0.12 %	0.29 %	1.950E-01	0.10 %	0.00 %	0.12 %	0.16 %
1100	1.830E-01	0.08 %	0.25 %	0.11 %	0.29 %	1.826E-01	0.13 %	0.00 %	0.11 %	0.17 %
1200	1.667E-01	0.07 %	0.28 %	0.10 %	0.31 %	1.664E-01	0.12 %	0.00 %	0.10 %	0.16 %
1300	1.492E-01	0.07 %	0.32 %	0.09 %	0.34 %	1.491E-01	0.13 %	0.00 %	0.09 %	0.16 %
1400	1.321E-01	0.07 %	0.33 %	0.09 %	0.35 %	1.320E-01	0.14 %	0.00 %	0.09 %	0.17 %
1500	1.161E-01	0.08 %	0.30 %	0.08 %	0.32 %	1.159E-01	0.14 %	0.00 %	0.08 %	0.16 %
1600	1.015E-01	0.07 %	0.26 %	0.08 %	0.28 %	1.013E-01	0.13 %	0.00 %	0.08 %	0.15 %
1700	8.849E-02	0.08 %	0.23 %	0.08 %	0.25 %	8.843E-02	0.18 %	0.00 %	0.08 %	0.19 %
1800	7.710E-02	0.15 %	0.21 %	0.08 %	0.27 %	7.725E-02	0.24 %	0.00 %	0.08 %	0.25 %
1900	6.722E-02	0.25 %	0.23 %	0.07 %	0.35 %	6.754E-02	0.29 %	0.00 %	0.07 %	0.30 %
2000	5.861E-02	0.28 %	0.29 %	0.08 %	0.42 %	5.900E-02	0.33 %	0.00 %	0.08 %	0.34 %
2100	5.115E-02	0.32 %	0.38 %	0.07 %	0.50 %	5.152E-02	0.31 %	0.00 %	0.07 %	0.32 %
2200	4.495E-02	0.37 %	0.45 %	0.06 %	0.59 %	4.508E-02	0.36 %	0.00 %	0.06 %	0.36 %
2300	3.980E-02	0.58 %	0.45 %	0.06 %	0.74 %	3.963E-02	0.42 %	0.00 %	0.06 %	0.42 %
2400	3.459E-02	0.61 %	0.76 %	0.09 %	0.97 %	3.499E-02	0.53 %	0.00 %	0.09 %	0.54 %

2500	3.091E-02	0.71 %	1.46 %	0.08 %	1.63 %	3.089E-02	0.42 %	0.00 %	0.08 %	0.43 %

Table 14-12 NPL Results for FEL BN 9101 248. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 248	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.329E-04	0.64 %	0.32 %	2.06 %	2.18 %	1.312E-04	0.74 %	0.00 %	2.06 %	2.18 %
260	2.331E-04	0.48 %	0.32 %	2.05 %	2.13 %	2.308E-04	0.55 %	0.00 %	2.05 %	2.12 %
270	3.881E-04	0.37 %	0.31 %	2.05 %	2.10 %	3.850E-04	0.42 %	0.00 %	2.05 %	2.09 %
280	6.172E-04	0.30 %	0.29 %	1.56 %	1.61 %	6.130E-04	0.34 %	0.00 %	1.56 %	1.60 %
290	9.424E-04	0.24 %	0.27 %	1.08 %	1.14 %	9.366E-04	0.29 %	0.00 %	1.08 %	1.12 %
300	1.388E-03	0.21 %	0.33 %	0.45 %	0.60 %	1.380E-03	0.26 %	0.15 %	0.45 %	0.54 %
310	1.980E-03	0.19 %	0.38 %	0.43 %	0.61 %	1.968E-03	0.24 %	0.20 %	0.43 %	0.53 %
320	2.744E-03	0.17 %	0.43 %	0.37 %	0.60 %	2.727E-03	0.22 %	0.25 %	0.37 %	0.50 %
330	3.706E-03	0.16 %	0.47 %	0.36 %	0.61 %	3.682E-03	0.21 %	0.28 %	0.36 %	0.50 %
340	4.890E-03	0.09 %	0.53 %	0.35 %	0.65 %	4.856E-03	0.20 %	0.33 %	0.35 %	0.52 %
350	6.318E-03	0.17 %	0.58 %	0.34 %	0.69 %	6.270E-03	0.19 %	0.36 %	0.34 %	0.53 %
360	8.008E-03	0.16 %	0.67 %	0.33 %	0.77 %	7.944E-03	0.18 %	0.43 %	0.33 %	0.57 %
370	9.976E-03	0.15 %	0.72 %	0.32 %	0.80 %	9.892E-03	0.17 %	0.46 %	0.32 %	0.59 %
380	1.223E-02	0.15 %	0.81 %	0.31 %	0.88 %	1.212E-02	0.17 %	0.52 %	0.31 %	0.63 %
390	1.479E-02	0.14 %	0.78 %	0.31 %	0.85 %	1.465E-02	0.16 %	0.50 %	0.31 %	0.61 %
400	1.764E-02	0.14 %	0.72 %	0.30 %	0.80 %	1.747E-02	0.16 %	0.46 %	0.30 %	0.57 %
450	3.622E-02	0.13 %	0.31 %	0.27 %	0.43 %	3.585E-02	0.15 %	0.10 %	0.27 %	0.32 %
500	6.069E-02	0.13 %	0.31 %	0.24 %	0.42 %	6.010E-02	0.14 %	0.00 %	0.24 %	0.28 %
550	8.833E-02	0.12 %	0.33 %	0.22 %	0.42 %	8.756E-02	0.12 %	0.00 %	0.22 %	0.25 %
555	9.116E-02	0.12 %	0.33 %	0.22 %	0.42 %	9.037E-02	0.12 %	0.00 %	0.22 %	0.24 %
600	1.162E-01	0.12 %	0.33 %	0.20 %	0.40 %	1.153E-01	0.11 %	0.00 %	0.20 %	0.23 %
650	1.418E-01	0.04 %	0.32 %	0.18 %	0.37 %	1.409E-01	0.11 %	0.00 %	0.18 %	0.21 %
700	1.634E-01	0.13 %	0.31 %	0.17 %	0.38 %	1.625E-01	0.10 %	0.00 %	0.17 %	0.20 %
750	1.801E-01	0.12 %	0.30 %	0.16 %	0.36 %	1.793E-01	0.10 %	0.00 %	0.16 %	0.19 %
800	1.919E-01	0.11 %	0.29 %	0.15 %	0.34 %	1.911E-01	0.09 %	0.00 %	0.15 %	0.18 %
850	1.990E-01	0.10 %	0.28 %	0.14 %	0.33 %	1.982E-01	0.09 %	0.00 %	0.14 %	0.17 %
900	2.019E-01	0.09 %	0.26 %	0.13 %	0.31 %	2.012E-01	0.08 %	0.00 %	0.13 %	0.16 %
950	2.016E-01	0.09 %	0.25 %	0.13 %	0.30 %	2.009E-01	0.08 %	0.00 %	0.13 %	0.15 %
1000	1.985E-01	0.08 %	0.25 %	0.12 %	0.29 %	1.979E-01	0.08 %	0.00 %	0.12 %	0.15 %
1100	1.867E-01	0.08 %	0.25 %	0.11 %	0.29 %	1.863E-01	0.10 %	0.00 %	0.11 %	0.15 %
1200	1.707E-01	0.08 %	0.28 %	0.10 %	0.31 %	1.703E-01	0.12 %	0.00 %	0.10 %	0.16 %
1300	1.531E-01	0.08 %	0.32 %	0.09 %	0.34 %	1.527E-01	0.14 %	0.00 %	0.09 %	0.17 %
1400	1.357E-01	0.08 %	0.33 %	0.09 %	0.35 %	1.352E-01	0.16 %	0.00 %	0.09 %	0.19 %
1500	1.194E-01	0.08 %	0.30 %	0.08 %	0.32 %	1.189E-01	0.16 %	0.00 %	0.08 %	0.18 %
1600	1.047E-01	0.08 %	0.26 %	0.08 %	0.28 %	1.042E-01	0.16 %	0.00 %	0.08 %	0.17 %
1700	9.154E-02	0.10 %	0.23 %	0.08 %	0.26 %	9.134E-02	0.21 %	0.00 %	0.08 %	0.22 %
1800	7.997E-02	0.18 %	0.21 %	0.08 %	0.29 %	7.992E-02	0.27 %	0.00 %	0.08 %	0.28 %
1900	6.982E-02	0.29 %	0.23 %	0.07 %	0.38 %	6.976E-02	0.34 %	0.00 %	0.07 %	0.35 %
2000	6.094E-02	0.36 %	0.29 %	0.08 %	0.47 %	6.081E-02	0.39 %	0.00 %	0.08 %	0.40 %
2100	5.321E-02	0.41 %	0.38 %	0.07 %	0.56 %	5.313E-02	0.39 %	0.00 %	0.07 %	0.40 %
2200	4.654E-02	0.51 %	0.45 %	0.06 %	0.68 %	4.672E-02	0.40 %	0.00 %	0.06 %	0.41 %
2300	4.077E-02	0.55 %	0.45 %	0.06 %	0.72 %	4.125E-02	0.46 %	0.00 %	0.06 %	0.46 %
2400	3.563E-02	0.78 %	0.76 %	0.09 %	1.09 %	3.620E-02	0.82 %	0.00 %	0.09 %	0.83 %
2500	3.198E-02	0.93 %	1.46 %	0.08 %	1.73 %	3.192E-02	0.70 %	0.00 %	0.08 %	0.70 %

Table 14-13 NPL Results for FEL BN 9101 218. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

FEL 218	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.237E-04	0.82 %	0.32 %	2.06 %	2.24 %	1.107E-04	0.77 %	0.00 %	2.06 %	2.19 %
260	2.179E-04	0.56 %	0.32 %	2.05 %	2.15 %	1.951E-04	0.56 %	0.00 %	2.05 %	2.13 %
270	3.640E-04	0.41 %	0.31 %	2.05 %	2.11 %	3.264E-04	0.44 %	0.00 %	2.05 %	2.09 %
280	5.802E-04	0.32 %	0.29 %	1.56 %	1.62 %	5.212E-04	0.38 %	0.00 %	1.56 %	1.61 %
290	8.878E-04	0.28 %	0.27 %	1.08 %	1.15 %	7.990E-04	0.36 %	0.00 %	1.08 %	1.14 %
300	1.310E-03	0.24 %	0.33 %	0.45 %	0.61 %	1.181E-03	0.35 %	0.15 %	0.45 %	0.59 %
310	1.871E-03	0.22 %	0.38 %	0.43 %	0.62 %	1.691E-03	0.34 %	0.20 %	0.43 %	0.59 %
320	2.596E-03	0.20 %	0.43 %	0.37 %	0.60 %	2.351E-03	0.33 %	0.25 %	0.37 %	0.56 %
330	3.510E-03	0.18 %	0.47 %	0.36 %	0.62 %	3.186E-03	0.32 %	0.28 %	0.36 %	0.56 %
340	4.635E-03	0.11 %	0.53 %	0.35 %	0.65 %	4.216E-03	0.31 %	0.33 %	0.35 %	0.57 %
350	5.994E-03	0.17 %	0.58 %	0.34 %	0.69 %	5.463E-03	0.30 %	0.36 %	0.34 %	0.58 %
360	7.604E-03	0.16 %	0.67 %	0.33 %	0.77 %	6.945E-03	0.28 %	0.43 %	0.33 %	0.61 %
370	9.481E-03	0.16 %	0.72 %	0.32 %	0.80 %	8.675E-03	0.27 %	0.46 %	0.32 %	0.62 %
380	1.164E-02	0.15 %	0.81 %	0.31 %	0.88 %	1.067E-02	0.26 %	0.52 %	0.31 %	0.66 %
390	1.408E-02	0.15 %	0.78 %	0.31 %	0.85 %	1.293E-02	0.25 %	0.50 %	0.31 %	0.64 %
400	1.681E-02	0.14 %	0.72 %	0.30 %	0.80 %	1.546E-02	0.24 %	0.46 %	0.30 %	0.60 %
450	3.470E-02	0.14 %	0.31 %	0.27 %	0.43 %	3.208E-02	0.21 %	0.10 %	0.27 %	0.35 %
500	5.844E-02	0.13 %	0.31 %	0.24 %	0.42 %	5.420E-02	0.18 %	0.00 %	0.24 %	0.30 %
550	8.547E-02	0.12 %	0.33 %	0.22 %	0.42 %	7.940E-02	0.15 %	0.00 %	0.22 %	0.26 %
555	8.824E-02	0.12 %	0.33 %	0.22 %	0.42 %	8.198E-02	0.14 %	0.00 %	0.22 %	0.26 %
600	1.129E-01	0.12 %	0.33 %	0.20 %	0.40 %	1.049E-01	0.13 %	0.00 %	0.20 %	0.24 %
650	1.381E-01	0.04 %	0.32 %	0.18 %	0.37 %	1.286E-01	0.14 %	0.00 %	0.18 %	0.23 %
700	1.596E-01	0.13 %	0.31 %	0.17 %	0.38 %	1.486E-01	0.13 %	0.00 %	0.17 %	0.22 %
750	1.764E-01	0.12 %	0.30 %	0.16 %	0.36 %	1.644E-01	0.12 %	0.00 %	0.16 %	0.20 %
800	1.882E-01	0.11 %	0.29 %	0.15 %	0.34 %	1.755E-01	0.11 %	0.00 %	0.15 %	0.19 %
850	1.956E-01	0.10 %	0.28 %	0.14 %	0.33 %	1.824E-01	0.10 %	0.00 %	0.14 %	0.17 %
900	1.989E-01	0.09 %	0.26 %	0.13 %	0.31 %	1.856E-01	0.09 %	0.00 %	0.13 %	0.16 %
950	1.988E-01	0.09 %	0.25 %	0.13 %	0.30 %	1.855E-01	0.09 %	0.00 %	0.13 %	0.16 %
1000	1.960E-01	0.08 %	0.25 %	0.12 %	0.29 %	1.830E-01	0.10 %	0.00 %	0.12 %	0.16 %
1100	1.847E-01	0.08 %	0.25 %	0.11 %	0.29 %	1.727E-01	0.12 %	0.00 %	0.11 %	0.17 %
1200	1.691E-01	0.08 %	0.28 %	0.10 %	0.31 %	1.582E-01	0.14 %	0.00 %	0.10 %	0.18 %
1300	1.518E-01	0.08 %	0.32 %	0.09 %	0.35 %	1.422E-01	0.15 %	0.00 %	0.09 %	0.18 %
1400	1.348E-01	0.08 %	0.33 %	0.09 %	0.35 %	1.261E-01	0.17 %	0.00 %	0.09 %	0.19 %
1500	1.187E-01	0.08 %	0.30 %	0.08 %	0.32 %	1.111E-01	0.16 %	0.00 %	0.08 %	0.18 %
1600	1.039E-01	0.08 %	0.26 %	0.08 %	0.28 %	9.746E-02	0.16 %	0.00 %	0.08 %	0.18 %
1700	9.069E-02	0.09 %	0.23 %	0.08 %	0.26 %	8.541E-02	0.22 %	0.00 %	0.08 %	0.24 %
1800	7.928E-02	0.19 %	0.21 %	0.08 %	0.29 %	7.477E-02	0.31 %	0.00 %	0.08 %	0.32 %
1900	6.948E-02	0.32 %	0.23 %	0.07 %	0.40 %	6.536E-02	0.39 %	0.00 %	0.07 %	0.40 %
2000	6.087E-02	0.36 %	0.29 %	0.08 %	0.47 %	5.707E-02	0.45 %	0.00 %	0.08 %	0.46 %
2100	5.317E-02	0.45 %	0.38 %	0.07 %	0.60 %	4.991E-02	0.44 %	0.00 %	0.07 %	0.45 %
2200	4.647E-02	0.53 %	0.45 %	0.06 %	0.70 %	4.383E-02	0.48 %	0.00 %	0.06 %	0.48 %
2300	4.091E-02	0.78 %	0.45 %	0.06 %	0.90 %	3.865E-02	0.54 %	0.00 %	0.06 %	0.55 %
2400	3.582E-02	0.92 %	0.76 %	0.09 %	1.19 %	3.404E-02	0.81 %	0.00 %	0.09 %	0.82 %
2500	3.190E-02	1.13 %	1.46 %	0.08 %	1.85 %	2.997E-02	0.69 %	0.00 %	0.08 %	0.69 %

Table 14-14 NPL Results for P257c. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

P257c	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	2.350E-04	0.59 %	0.33 %	0.42 %	0.80 %	2.437E-04	1.40 %	0.15 %	0.42 %	1.47 %
310	3.386E-04	0.36 %	0.38 %	0.41 %	0.67 %	3.477E-04	0.99 %	0.20 %	0.41 %	1.09 %
320	4.738E-04	0.25 %	0.43 %	0.35 %	0.61 %	4.826E-04	0.69 %	0.25 %	0.35 %	0.82 %
330	6.455E-04	0.20 %	0.47 %	0.34 %	0.61 %	6.533E-04	0.49 %	0.28 %	0.34 %	0.66 %
340	8.586E-04	0.18 %	0.53 %	0.33 %	0.65 %	8.645E-04	0.37 %	0.33 %	0.33 %	0.60 %
350	1.118E-03	0.17 %	0.58 %	0.32 %	0.68 %	1.121E-03	0.32 %	0.36 %	0.32 %	0.58 %
360	1.427E-03	0.16 %	0.67 %	0.31 %	0.76 %	1.427E-03	0.30 %	0.43 %	0.31 %	0.61 %
370	1.790E-03	0.15 %	0.72 %	0.30 %	0.79 %	1.785E-03	0.30 %	0.46 %	0.30 %	0.63 %
380	2.209E-03	0.15 %	0.81 %	0.30 %	0.87 %	2.199E-03	0.30 %	0.52 %	0.30 %	0.67 %
390	2.686E-03	0.14 %	0.78 %	0.29 %	0.84 %	2.671E-03	0.30 %	0.50 %	0.29 %	0.65 %
400	3.223E-03	0.13 %	0.72 %	0.28 %	0.79 %	3.202E-03	0.30 %	0.46 %	0.28 %	0.62 %
450	6.789E-03	0.12 %	0.31 %	0.26 %	0.42 %	6.737E-03	0.30 %	0.10 %	0.26 %	0.41 %
500	1.161E-02	0.11 %	0.31 %	0.23 %	0.40 %	1.153E-02	0.30 %	0.00 %	0.23 %	0.37 %
550	1.718E-02	0.10 %	0.33 %	0.20 %	0.40 %	1.708E-02	0.26 %	0.00 %	0.20 %	0.33 %
555	1.775E-02	0.10 %	0.33 %	0.20 %	0.40 %	1.765E-02	0.25 %	0.00 %	0.20 %	0.33 %
600	2.288E-02	0.10 %	0.33 %	0.19 %	0.39 %	2.277E-02	0.23 %	0.00 %	0.19 %	0.29 %
650	2.817E-02	0.10 %	0.32 %	0.17 %	0.38 %	2.805E-02	0.23 %	0.00 %	0.17 %	0.28 %
700	3.269E-02	0.10 %	0.31 %	0.16 %	0.37 %	3.255E-02	0.23 %	0.00 %	0.16 %	0.28 %
750	3.622E-02	0.10 %	0.30 %	0.15 %	0.35 %	3.608E-02	0.22 %	0.00 %	0.15 %	0.26 %
800	3.872E-02	0.10 %	0.29 %	0.14 %	0.34 %	3.858E-02	0.19 %	0.00 %	0.14 %	0.24 %
850	4.024E-02	0.09 %	0.28 %	0.13 %	0.32 %	4.010E-02	0.17 %	0.00 %	0.13 %	0.22 %
900	4.089E-02	0.09 %	0.26 %	0.13 %	0.31 %	4.077E-02	0.16 %	0.00 %	0.13 %	0.20 %
950	4.082E-02	0.09 %	0.25 %	0.12 %	0.29 %	4.072E-02	0.15 %	0.00 %	0.12 %	0.20 %
1000	4.016E-02	0.09 %	0.25 %	0.11 %	0.29 %	4.009E-02	0.16 %	0.00 %	0.11 %	0.19 %
1100	3.760E-02	0.10 %	0.25 %	0.12 %	0.29 %	3.765E-02	0.21 %	0.00 %	0.12 %	0.24 %
1200	3.414E-02	0.10 %	0.28 %	0.10 %	0.32 %	3.429E-02	0.27 %	0.00 %	0.10 %	0.29 %
1300	3.043E-02	0.11 %	0.32 %	0.09 %	0.35 %	3.061E-02	0.32 %	0.00 %	0.09 %	0.33 %
1400	2.683E-02	0.11 %	0.33 %	0.09 %	0.36 %	2.698E-02	0.36 %	0.00 %	0.09 %	0.37 %
1500	2.345E-02	0.11 %	0.30 %	0.12 %	0.34 %	2.360E-02	0.36 %	0.00 %	0.12 %	0.38 %
1600	2.036E-02	0.11 %	0.26 %	0.07 %	0.29 %	2.058E-02	0.35 %	0.00 %	0.07 %	0.36 %
1700	1.763E-02	0.17 %	0.23 %	0.10 %	0.30 %	1.791E-02	0.49 %	0.00 %	0.10 %	0.50 %
1800	1.530E-02	0.29 %	0.21 %	0.10 %	0.38 %	1.558E-02	0.68 %	0.00 %	0.10 %	0.69 %
1900	1.336E-02	0.40 %	0.23 %	0.07 %	0.47 %	1.354E-02	0.84 %	0.00 %	0.07 %	0.84 %
2000	1.167E-02	0.43 %	0.29 %	0.11 %	0.53 %	1.177E-02	0.97 %	0.00 %	0.11 %	0.97 %
2100	1.016E-02	0.50 %	0.38 %	0.09 %	0.64 %	1.028E-02	0.95 %	0.00 %	0.09 %	0.96 %
2200	8.891E-03	0.60 %	0.45 %	0.06 %	0.75 %	9.022E-03	1.01 %	0.00 %	0.06 %	1.01 %
2300	7.879E-03	0.82 %	0.45 %	0.06 %	0.94 %	7.949E-03	1.17 %	0.00 %	0.06 %	1.17 %
2400	6.813E-03	0.96 %	0.76 %	0.08 %	1.22 %	6.981E-03	1.72 %	0.00 %	0.08 %	1.72 %
2500	6.081E-03	1.18 %	1.46 %	0.08 %	1.88 %	6.158E-03	1.48 %	0.00 %	0.08 %	1.49 %

Table 14-15 NPL Results for P252c. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

P252c	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	2.211E-04	0.41 %	0.33 %	0.42 %	0.67 %	2.351E-04	1.91 %	0.15 %	0.42 %	1.96 %
310	3.186E-04	0.30 %	0.38 %	0.41 %	0.63 %	3.353E-04	1.51 %	0.20 %	0.41 %	1.58 %
320	4.460E-04	0.22 %	0.43 %	0.35 %	0.60 %	4.655E-04	1.18 %	0.25 %	0.35 %	1.26 %
330	6.083E-04	0.18 %	0.47 %	0.34 %	0.61 %	6.304E-04	0.92 %	0.28 %	0.34 %	1.02 %
340	8.105E-04	0.16 %	0.53 %	0.33 %	0.65 %	8.349E-04	0.70 %	0.33 %	0.33 %	0.84 %
350	1.057E-03	0.14 %	0.58 %	0.32 %	0.67 %	1.084E-03	0.54 %	0.36 %	0.32 %	0.72 %
360	1.352E-03	0.14 %	0.67 %	0.31 %	0.76 %	1.381E-03	0.42 %	0.43 %	0.31 %	0.68 %
370	1.700E-03	0.14 %	0.72 %	0.30 %	0.79 %	1.730E-03	0.34 %	0.46 %	0.30 %	0.65 %
380	2.102E-03	0.13 %	0.81 %	0.30 %	0.87 %	2.134E-03	0.30 %	0.52 %	0.30 %	0.67 %
390	2.562E-03	0.13 %	0.78 %	0.29 %	0.84 %	2.596E-03	0.29 %	0.50 %	0.29 %	0.64 %
400	3.080E-03	0.13 %	0.72 %	0.28 %	0.79 %	3.117E-03	0.29 %	0.46 %	0.28 %	0.61 %
450	6.544E-03	0.11 %	0.31 %	0.26 %	0.42 %	6.605E-03	0.28 %	0.10 %	0.26 %	0.40 %
500	1.125E-02	0.10 %	0.31 %	0.23 %	0.40 %	1.137E-02	0.22 %	0.00 %	0.23 %	0.32 %
550	1.671E-02	0.10 %	0.33 %	0.20 %	0.40 %	1.692E-02	0.18 %	0.00 %	0.20 %	0.27 %
555	1.727E-02	0.10 %	0.33 %	0.20 %	0.40 %	1.749E-02	0.18 %	0.00 %	0.20 %	0.27 %
600	2.231E-02	0.10 %	0.33 %	0.19 %	0.39 %	2.262E-02	0.17 %	0.00 %	0.19 %	0.25 %
650	2.755E-02	0.10 %	0.32 %	0.17 %	0.38 %	2.794E-02	0.16 %	0.00 %	0.17 %	0.24 %
700	3.204E-02	0.10 %	0.31 %	0.16 %	0.36 %	3.249E-02	0.16 %	0.00 %	0.16 %	0.23 %
750	3.559E-02	0.10 %	0.30 %	0.15 %	0.35 %	3.608E-02	0.15 %	0.00 %	0.15 %	0.22 %
800	3.812E-02	0.09 %	0.29 %	0.14 %	0.33 %	3.863E-02	0.15 %	0.00 %	0.14 %	0.21 %
850	3.968E-02	0.09 %	0.28 %	0.13 %	0.32 %	4.020E-02	0.14 %	0.00 %	0.13 %	0.20 %
900	4.037E-02	0.09 %	0.26 %	0.13 %	0.31 %	4.090E-02	0.14 %	0.00 %	0.13 %	0.18 %
950	4.032E-02	0.09 %	0.25 %	0.12 %	0.29 %	4.087E-02	0.13 %	0.00 %	0.12 %	0.18 %
1000	3.969E-02	0.09 %	0.25 %	0.11 %	0.29 %	4.025E-02	0.14 %	0.00 %	0.11 %	0.18 %
1100	3.721E-02	0.09 %	0.25 %	0.12 %	0.29 %	3.780E-02	0.18 %	0.00 %	0.12 %	0.21 %
1200	3.386E-02	0.10 %	0.28 %	0.10 %	0.31 %	3.446E-02	0.22 %	0.00 %	0.10 %	0.24 %
1300	3.023E-02	0.10 %	0.32 %	0.09 %	0.35 %	3.080E-02	0.28 %	0.00 %	0.09 %	0.29 %
1400	2.666E-02	0.10 %	0.33 %	0.09 %	0.36 %	2.720E-02	0.32 %	0.00 %	0.09 %	0.33 %
1500	2.329E-02	0.10 %	0.30 %	0.12 %	0.34 %	2.382E-02	0.31 %	0.00 %	0.12 %	0.34 %
1600	2.022E-02	0.11 %	0.26 %	0.07 %	0.29 %	2.075E-02	0.34 %	0.00 %	0.07 %	0.35 %
1700	1.747E-02	0.16 %	0.23 %	0.10 %	0.30 %	1.802E-02	0.57 %	0.00 %	0.10 %	0.58 %
1800	1.509E-02	0.23 %	0.21 %	0.10 %	0.33 %	1.563E-02	0.89 %	0.00 %	0.10 %	0.90 %
1900	1.309E-02	0.30 %	0.23 %	0.07 %	0.38 %	1.358E-02	1.20 %	0.00 %	0.07 %	1.21 %
2000	1.142E-02	0.33 %	0.29 %	0.11 %	0.45 %	1.184E-02	1.49 %	0.00 %	0.11 %	1.50 %
2100	1.001E-02	0.35 %	0.38 %	0.09 %	0.53 %	1.035E-02	1.74 %	0.00 %	0.09 %	1.74 %
2200	8.794E-03	0.47 %	0.45 %	0.06 %	0.65 %	9.081E-03	1.79 %	0.00 %	0.06 %	1.79 %
2300	7.714E-03	0.55 %	0.45 %	0.06 %	0.71 %	7.965E-03	1.89 %	0.00 %	0.06 %	1.89 %
2400	6.750E-03	0.82 %	0.76 %	0.08 %	1.12 %	6.961E-03	2.48 %	0.00 %	0.08 %	2.48 %
2500	6.009E-03	1.07 %	1.46 %	0.08 %	1.82 %	6.059E-03	2.99 %	0.00 %	0.08 %	2.99 %

Table 14-16 NPL Results for P250c. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1.

P250c	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250										
260										
270										
280										
290										
300	2.426E-04	0.51 %	0.33 %	0.42 %	0.74 %	2.376E-04	0.83 %	0.15 %	0.42 %	0.95 %
310	3.479E-04	0.37 %	0.38 %	0.41 %	0.67 %	3.424E-04	0.51 %	0.20 %	0.41 %	0.69 %
320	4.851E-04	0.27 %	0.43 %	0.35 %	0.62 %	4.791E-04	0.34 %	0.25 %	0.35 %	0.55 %
330	6.593E-04	0.22 %	0.47 %	0.34 %	0.62 %	6.528E-04	0.27 %	0.28 %	0.34 %	0.52 %
340	8.756E-04	0.18 %	0.53 %	0.33 %	0.65 %	8.684E-04	0.24 %	0.33 %	0.33 %	0.53 %
350	1.139E-03	0.17 %	0.58 %	0.32 %	0.68 %	1.131E-03	0.23 %	0.36 %	0.32 %	0.53 %
360	1.453E-03	0.16 %	0.67 %	0.31 %	0.76 %	1.443E-03	0.22 %	0.43 %	0.31 %	0.57 %
370	1.821E-03	0.16 %	0.72 %	0.30 %	0.80 %	1.810E-03	0.20 %	0.46 %	0.30 %	0.59 %
380	2.247E-03	0.15 %	0.81 %	0.30 %	0.87 %	2.234E-03	0.19 %	0.52 %	0.30 %	0.63 %
390	2.732E-03	0.15 %	0.78 %	0.29 %	0.84 %	2.717E-03	0.18 %	0.50 %	0.29 %	0.60 %
400	3.278E-03	0.14 %	0.72 %	0.28 %	0.79 %	3.260E-03	0.17 %	0.46 %	0.28 %	0.56 %
450	6.900E-03	0.12 %	0.31 %	0.26 %	0.42 %	6.863E-03	0.15 %	0.10 %	0.26 %	0.32 %
500	1.178E-02	0.11 %	0.31 %	0.23 %	0.40 %	1.172E-02	0.13 %	0.00 %	0.23 %	0.26 %
550	1.737E-02	0.11 %	0.33 %	0.20 %	0.41 %	1.732E-02	0.12 %	0.00 %	0.20 %	0.24 %
555	1.795E-02	0.11 %	0.33 %	0.20 %	0.40 %	1.790E-02	0.12 %	0.00 %	0.20 %	0.24 %
600	2.308E-02	0.10 %	0.33 %	0.19 %	0.40 %	2.304E-02	0.11 %	0.00 %	0.19 %	0.22 %
650	2.837E-02	0.10 %	0.32 %	0.17 %	0.38 %	2.833E-02	0.12 %	0.00 %	0.17 %	0.21 %
700	3.290E-02	0.10 %	0.31 %	0.16 %	0.37 %	3.282E-02	0.12 %	0.00 %	0.16 %	0.20 %
750	3.645E-02	0.10 %	0.30 %	0.15 %	0.35 %	3.633E-02	0.11 %	0.00 %	0.15 %	0.19 %
800	3.897E-02	0.10 %	0.29 %	0.14 %	0.34 %	3.881E-02	0.11 %	0.00 %	0.14 %	0.18 %
850	4.050E-02	0.09 %	0.28 %	0.13 %	0.32 %	4.032E-02	0.10 %	0.00 %	0.13 %	0.17 %
900	4.113E-02	0.09 %	0.26 %	0.13 %	0.31 %	4.096E-02	0.10 %	0.00 %	0.13 %	0.16 %
950	4.103E-02	0.09 %	0.25 %	0.12 %	0.29 %	4.087E-02	0.09 %	0.00 %	0.12 %	0.15 %
1000	4.033E-02	0.09 %	0.25 %	0.11 %	0.29 %	4.019E-02	0.10 %	0.00 %	0.11 %	0.15 %
1100	3.771E-02	0.10 %	0.25 %	0.12 %	0.30 %	3.758E-02	0.11 %	0.00 %	0.12 %	0.16 %
1200	3.425E-02	0.10 %	0.28 %	0.10 %	0.32 %	3.409E-02	0.12 %	0.00 %	0.10 %	0.15 %
1300	3.055E-02	0.11 %	0.32 %	0.09 %	0.35 %	3.039E-02	0.13 %	0.00 %	0.09 %	0.16 %
1400	2.692E-02	0.11 %	0.33 %	0.09 %	0.36 %	2.681E-02	0.13 %	0.00 %	0.09 %	0.16 %
1500	2.349E-02	0.11 %	0.30 %	0.12 %	0.34 %	2.342E-02	0.12 %	0.00 %	0.12 %	0.17 %
1600	2.033E-02	0.11 %	0.26 %	0.07 %	0.29 %	2.025E-02	0.12 %	0.00 %	0.07 %	0.14 %
1700	1.750E-02	0.15 %	0.23 %	0.10 %	0.29 %	1.740E-02	0.19 %	0.00 %	0.10 %	0.21 %
1800	1.508E-02	0.26 %	0.21 %	0.10 %	0.35 %	1.502E-02	0.48 %	0.00 %	0.10 %	0.49 %
1900	1.309E-02	0.42 %	0.23 %	0.07 %	0.48 %	1.313E-02	0.85 %	0.00 %	0.07 %	0.86 %
2000	1.148E-02	0.51 %	0.29 %	0.11 %	0.59 %	1.154E-02	0.95 %	0.00 %	0.11 %	0.96 %
2100	1.014E-02	0.53 %	0.38 %	0.09 %	0.66 %	1.008E-02	0.97 %	0.00 %	0.09 %	0.98 %
2200	8.942E-03	0.71 %	0.45 %	0.06 %	0.84 %	8.766E-03	1.08 %	0.00 %	0.06 %	1.08 %
2300	7.814E-03	0.83 %	0.45 %	0.06 %	0.95 %	7.738E-03	1.42 %	0.00 %	0.06 %	1.42 %
2400	6.785E-03	1.26 %	0.76 %	0.08 %	1.47 %	6.790E-03	1.69 %	0.00 %	0.08 %	1.69 %
2500	6.133E-03	1.65 %	1.46 %	0.08 %	2.21 %	6.044E-03	2.08 %	0.00 %	0.08 %	2.08 %

14.10 Lamp Behaviour

14.10.1 NRC lamps

The following Type I lamps were supplied to NRC by NPL:

FEL BN 9101 210 FEL BN 9101 248 FEL BN 9101 218

The following Type II lamps were supplied to NRC by NPL:

P257c P252c P250c

NRC measured all intercomparison wavelengths except 555 nm. NRC only measured the lamps on one occasion. NPL only measured the Type II lamps at wavelengths above 300 nm (as indicated in the protocol) and therefore the comparison of Type II lamps can only be at the longer wavelengths.

14.10.2 Lamp history

Table 14-17 Lamp history for FEL BN 9101 210

Date period	Activity	Burn hours:minutes
June – Nov. 2001	First round measurement at NPL	17:16
November 2001	Air-freight shipment to NRC	
Aug. – Sept. 2002	First round measurement at NRC	11:00
September 2002	Air-freight shipment to NPL	
Jan. – May 2003	Second round measurement at NPL	13:55
June 2003	Air-freight shipment to NRC	

Table 14-18 Lamp history for FEL BN 9101 248

Date period	Activity	Burn hours:minutes
June – Nov. 2001	First round measurement at NPL	11:26
November 2001	Air-freight shipment to NRC	
Aug. – Sept. 2002	First round measurement at NRC	11:06
September 2002	Air-freight shipment to NPL	
Jan. – May 2003	Second round measurement at NPL	10:26
June 2003	Air-freight shipment to NRC	

Table 14-19 Lamp history for FEL BN 9101 218

Date period	Activity	Burn hours:minutes
June – Nov. 2001	First round measurement at NPL	10:00
November 2001	Air-freight shipment to NRC	
Aug. – Sept. 2002	First round measurement at NRC	13:06
September 2002	Air-freight shipment to NPL	
Jan. – May 2003	Second round measurement at NPL	14:25
June 2003	Air-freight shipment to NRC	

Table 14-20 Lamp history for P257c

Date period	Activity	Burn hours:minutes
June – Nov. 2001	First round measurement at NPL	8:09
November 2001	Air-freight shipment to NRC	
Aug. – Sept. 2002	First round measurement at NRC	12:36
September 2002	Air-freight shipment to NPL	
Jan. – May 2003	Second round measurement at NPL	12:57
June 2003	Air-freight shipment to NRC	

Table 14-21 Lamp history for P252c

Date period	Activity	Burn hours:minutes
June – Nov. 2001	First round measurement at NPL	6:39
November 2001	Air-freight shipment to NRC	
Aug. – Sept. 2002	First round measurement at NRC	12:30
September 2002	Air-freight shipment to NPL	
Jan. – May 2003	Second round measurement at NPL	11:59
June 2003	Air-freight shipment to NRC	

Table 14-22 Lamp history for P250c

Date period	Activity	Burn hours:minutes
June – Nov. 2001	First round measurement at NPL	6:54
November 2001	Air-freight shipment to NRC	
Aug. – Sept. 2002	First round measurement at NRC	12:42
September 2002	Air-freight shipment to NPL	
Jan. – May 2003	Second round measurement at NPL	10:23
June 2003	Air-freight shipment to NRC	

14.10.3 Lamp electrical stability

The Type I lamps were operated at 8.100 A at both laboratories, the lamp voltage measured was:

Lamp	Potential first NPL measurement	Potential first NRC measurement	Potential second NPL measurement
FEL BN 9101 210	105.2 V	105.368 V	105.4 V
FEL BN 9101 248	105.4 V	105.555 V	105.6 V
FEL BN 9101 218	105.4 V	106.007 V	106.1 V

The Type II lamps were operated at 27.200 A at both laboratories, the lamp voltage measured was:

Lamp	Potential first NPL measurement	Potential first NRC measurement	Potential second NPL measurement
P257c	15.22 V	15.285 V	15.25 V
P252c	15.17 V	15.489 V	15.61 V
P250c	15.57 V	15.740 V	15.72 V

14.10.4 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the NRC lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

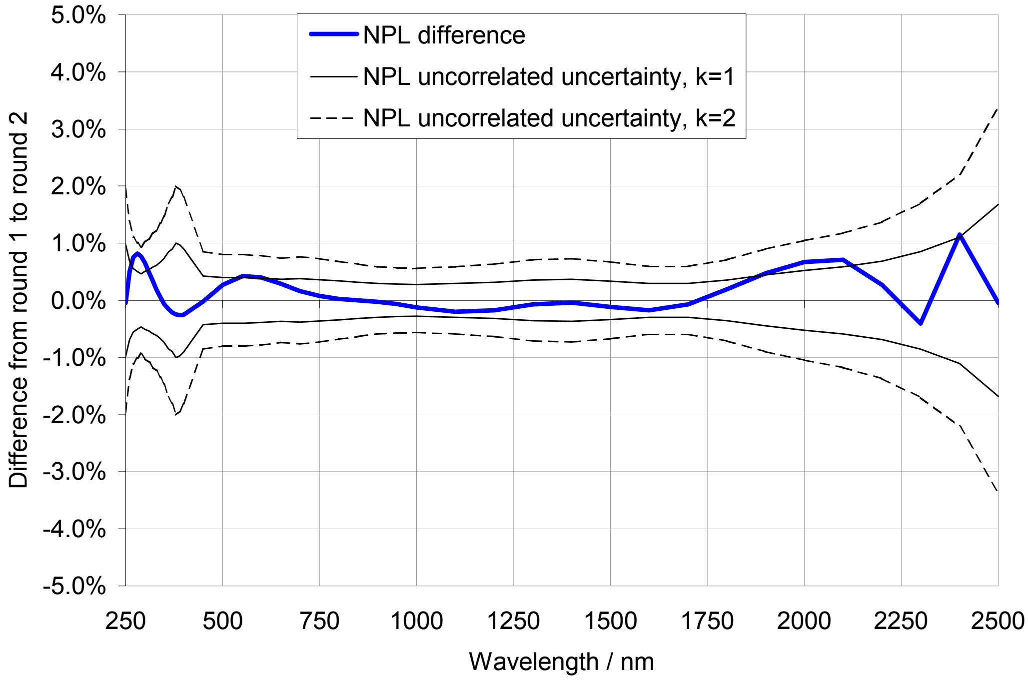


Figure 14-2 Difference between first and second round measurements of FEL BN 9101 210 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

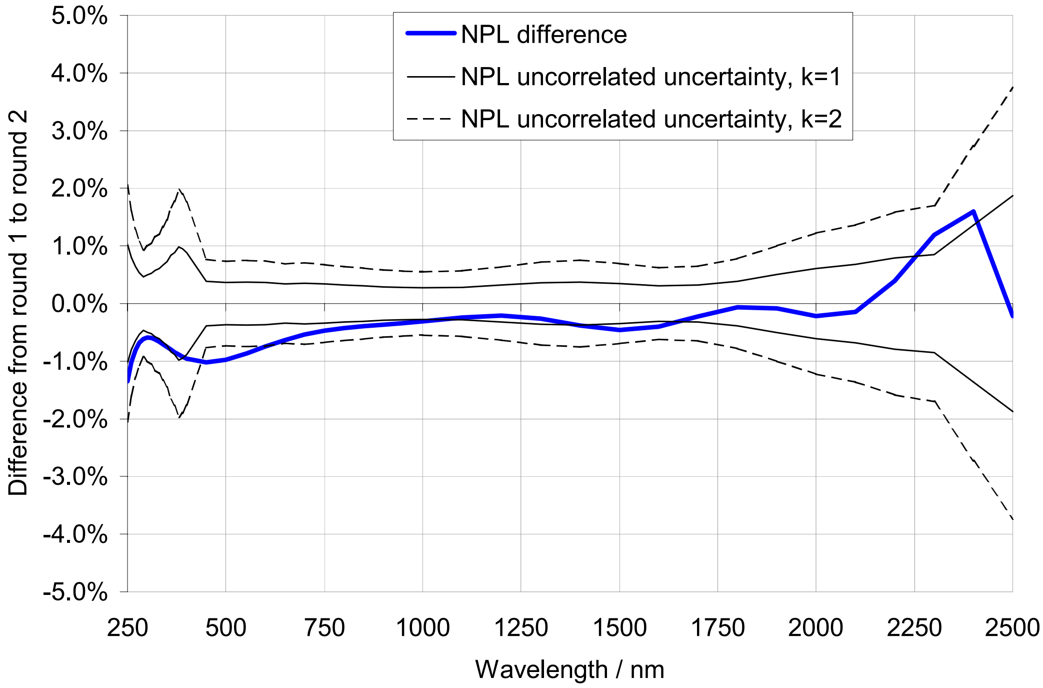


Figure 14-3 Difference between first and second round measurements of FEL BN 9101 248 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

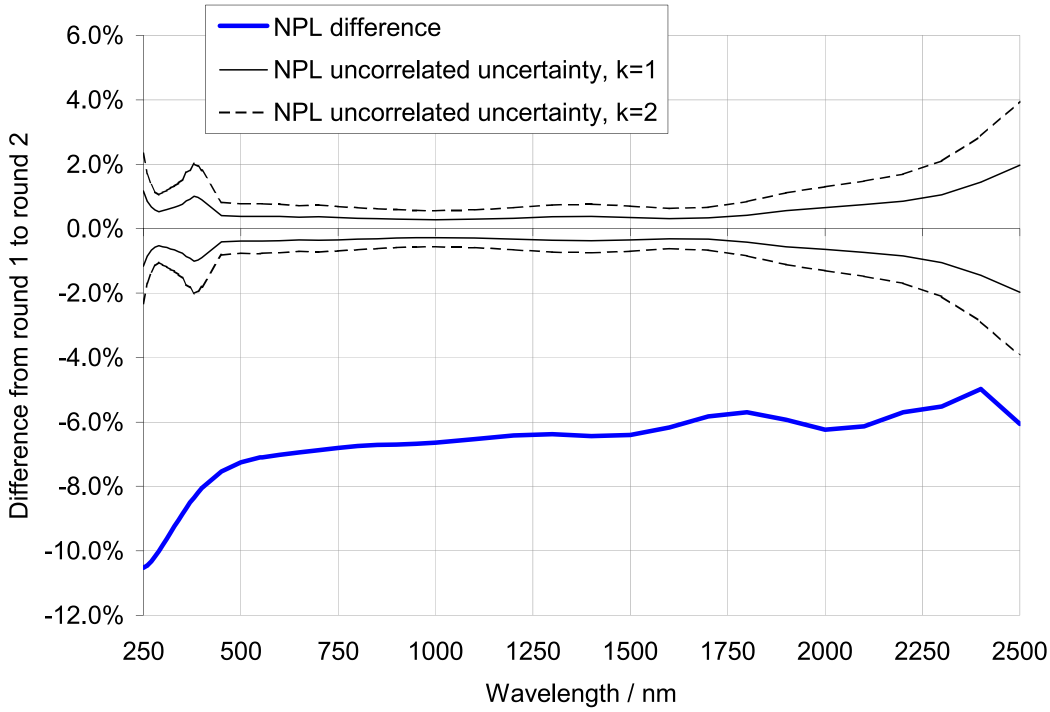


Figure 14-4 Difference between first and second round measurements of FEL BN 9101 218 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

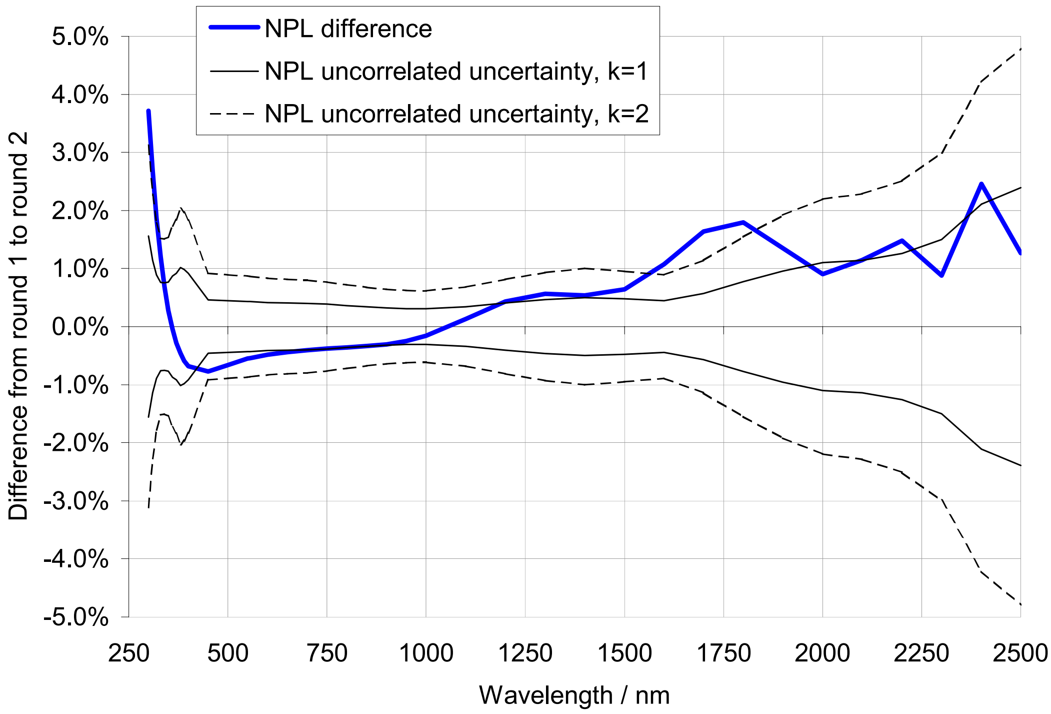


Figure 14-5 Difference between first and second round measurements of P257c by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

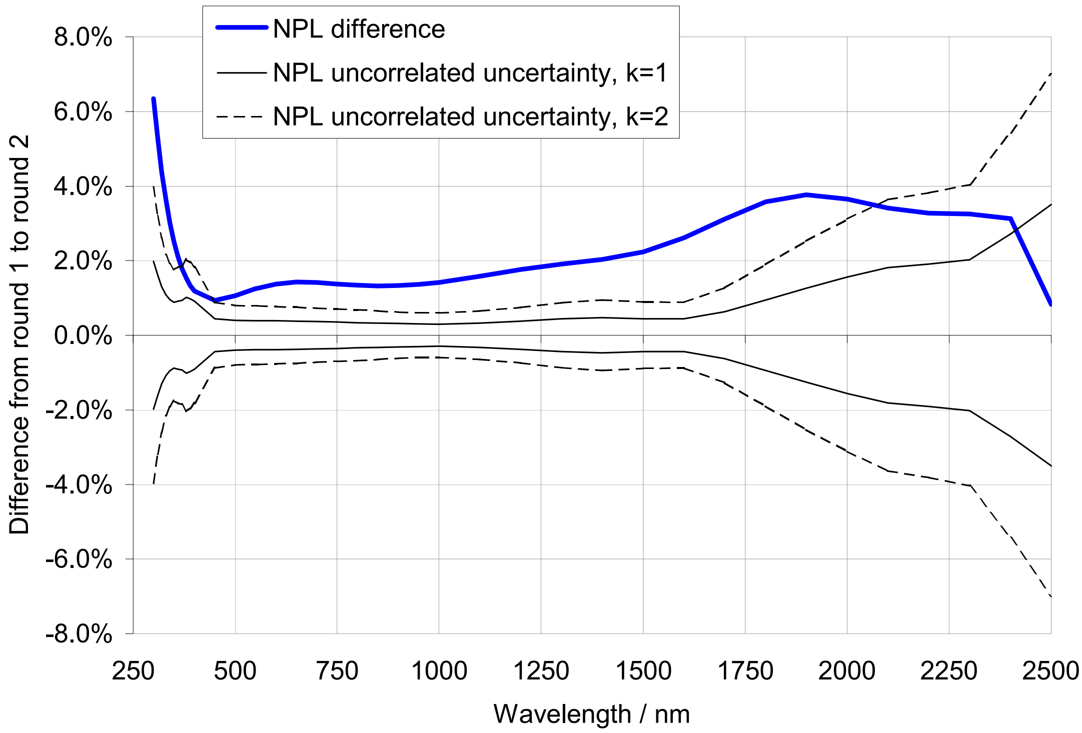


Figure 14-6 Difference between first and second round measurements of P252c by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

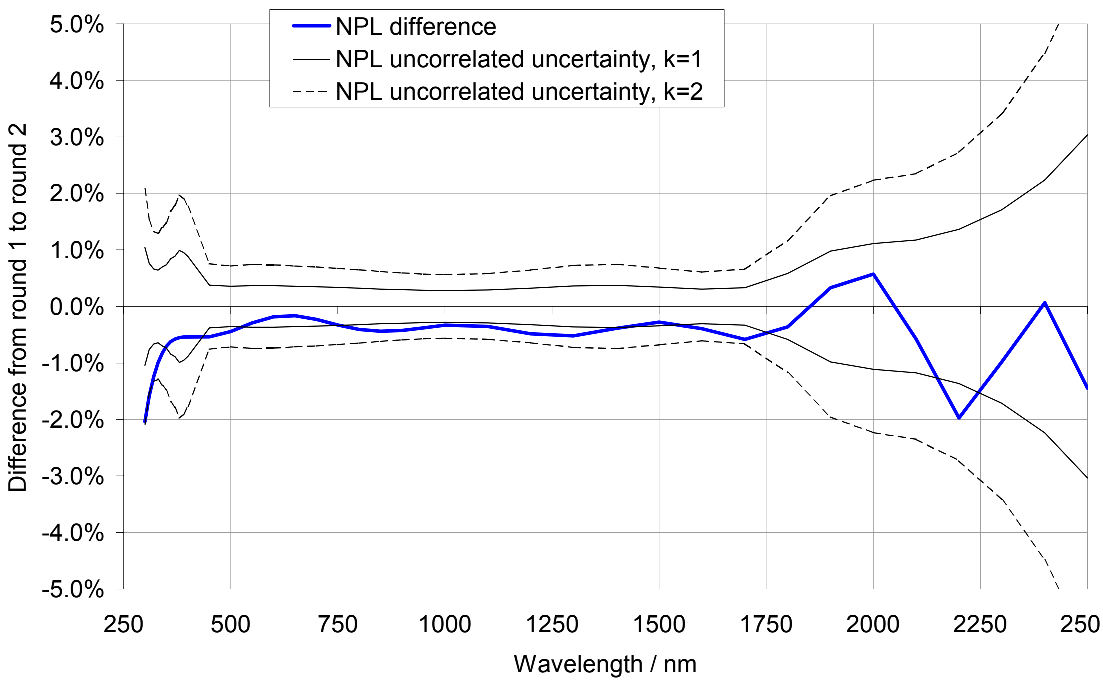


Figure 14-7 Difference between first and second round measurements of P250c by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

14.10.5 Lamp stability from NRC measurements

Because NRC measured the lamps on only one occasion, it is not possible to comment on the stability of these lamps from the NRC measurements.

14.11 Bilateral comparison between NRC and the comparison scale

These graphs show the difference between the NRC and NPL measurements of the NRC lamps. Versions of these graphs normalised to show the relative difference between the lamps, but not the absolute difference between the measurements were used to assist in choosing which lamp measurements to use.

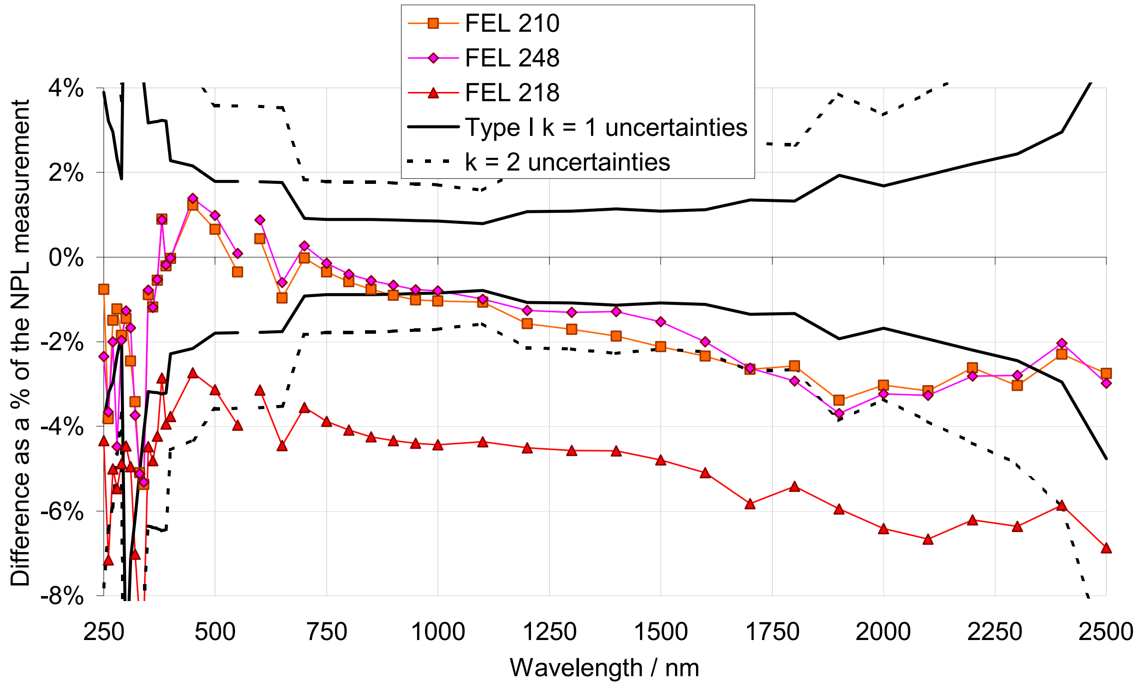


Figure 14-8 Bilateral comparisons of the NRC Type I lamps

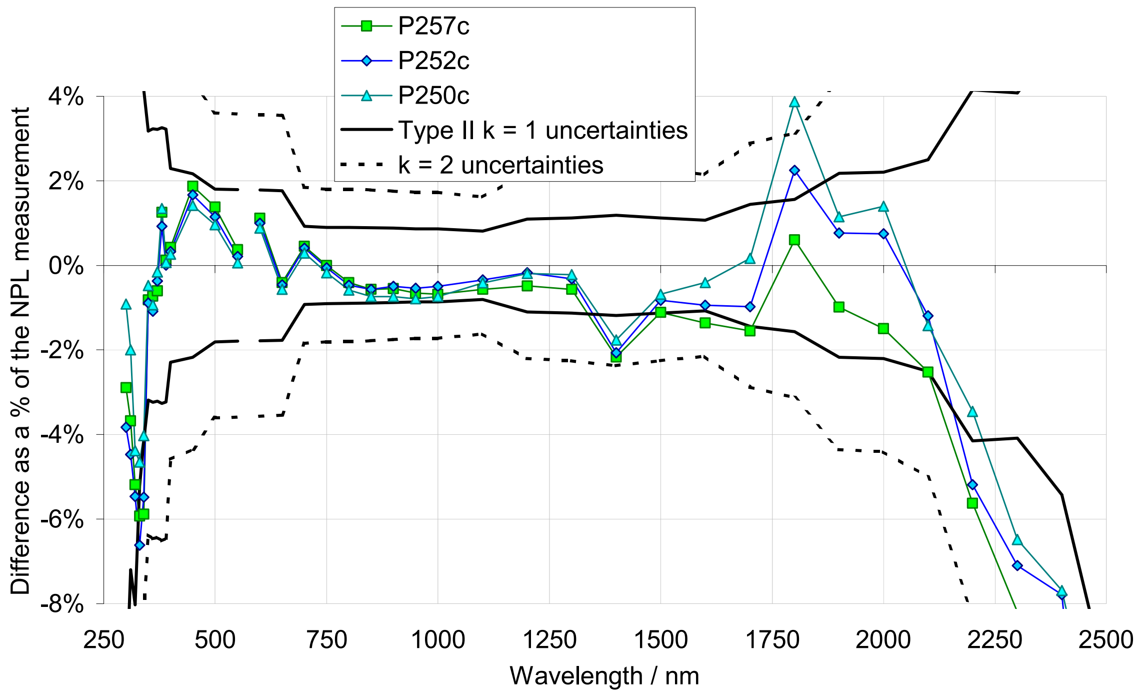


Figure 14-9 Bilateral comparisons of the NRC Type II lamps

14.12 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to NRC the information in the graphs Figure 14-2 to Figure 14-9. The decision was made to use all the data for FEL BN 9101 210 and FEL BN 9101 248, but to ignore the measurements of FEL BN 9101 218 completely because of its large change as measured at NPL, a change that was also seen in the voltage measurements. For the Type II lamps, all the data for P257c and P250c will be used, but the measurements of P252c will not be included in the analysis.

14.13 References

[1] M. Suzuki and N. Ooba, An International Intercomparison of Spectral Irradiance Scales, *Metrologia* **12**, 123–128 (1976).

[2] James H. Walker, Robert D. Saunders, John K. Jackson, and Klaus D. Mielenz, Results of a CCPR Intercomparison of Spectral Irradiance Measurements by National Laboratories, *J. Res. NIST* **96**, 647–668 (1991).

[3] L. P. Boivin and A. A. Gaertner, Analysis of the Uncertainties Involved in the Realization of a Spectral Irradiance Scale in the Infrared at the NRC, *Metrologia* **28**, 129–134 (1991).

[4] L. P. Boivin and A. A. Gaertner, Realization of a spectral irradiance scale in the near infrared at the National Research Council of Canada, *Applied Optics* **31**, 6082–6095 (1992).

[5] NBS Report of Calibration of One Standard of Spectral Irradiance, NBS Test Number 534/235034-85-1, dated June 6, 1985.

[6] NBS Report of Calibration of One Standard of Spectral Irradiance, NBS Test Number 534/235034-85-2, dated February 20, 1987.

15 Measurements at PTB

15.1 Primary scale realisation

The spectral irradiance scale at the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig is realised, maintained and disseminated [1] using a high temperature black-body radiator of type BB3200pg [2]. The various radiometric parameters of this black-body have been characterised in detail, including modifications to improve performance as well as operating and safety conditions, and it has been found very suitable for use as a primary standard of spectral irradiance [3-5].

The main parameter of a black-body, the temperature, has to be determined very accurately. At the PTB in Braunschweig, broadband-filter detectors are well established for the detector-based determination of the so-called radiometric temperature [3]. Improvements of this procedure and comparisons with other methods have been carried out and published [5,6].

For this comparison, the black-body was used at different distances of about 880 mm and at different temperatures between 2960 K and 3090 K. The measuring aperture P-MB-11 with a diameter of 7.557 mm ± 3 µm was used to define the source area of the black-body. The spectral irradiance at the reference plane of the spectroradiometer was then calculated according to Planck's law using the geometric parameters and the measured radiometric temperatures of the black-body. The measurement procedure is described in the PTB quality-management system in document QM-AA-4.11-01 (spectral irradiance scale realisation).

15.2 Description of measurement facility

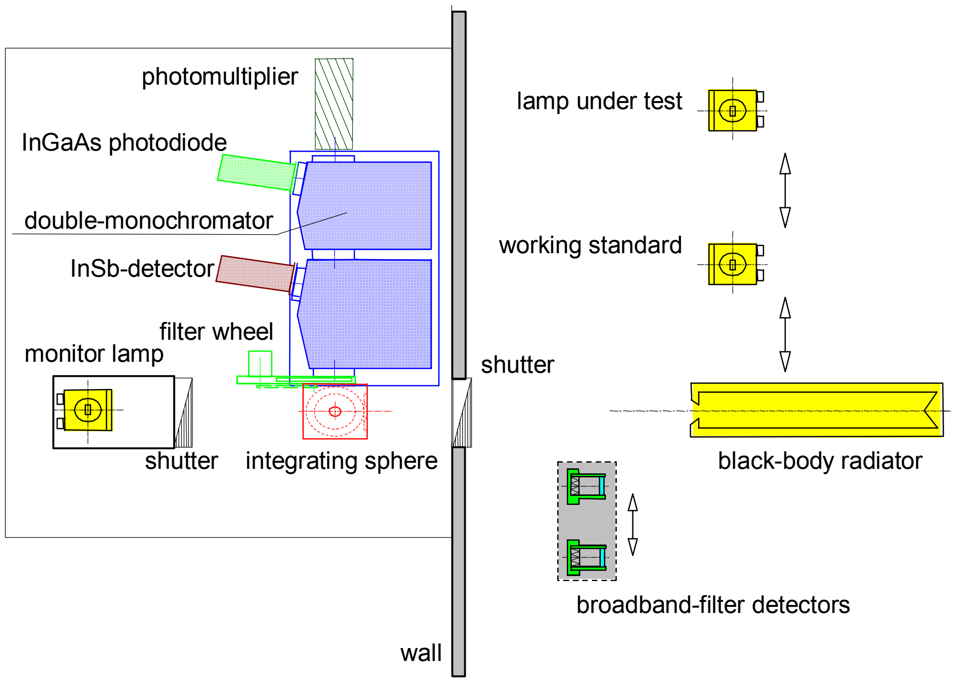


Figure 15-1 Schematic diagram of the PTB's spectral irradiance facility

The PTB's spectroradiometer, shown schematically in Figure 15-1, for spectral irradiance calibrations consists of an integrating sphere as entrance optics, a Bentham DTM300 double monochromator with triple grating turrets and three detectors to cover the spectral range from 250 nm to 2500 nm [5]. The entrance port of the integrating sphere is formed by a precision aperture that defines the reference plane for spectral irradiance measurements. The monochromator system has a focal length of 300 mm and a numerical aperture of *f* / 4.1. Three pairs of gratings are used as shown in Table 15-1.

Table 15-1 Grating types used in the PTB double-monochromator

Grating type	Lines / mm^{-1}	Useable spectral range	Blaze Wavelength	Dispersion / nm mm^{-1}
I - T312R0µ3	1200	200 nm – 700 nm	300 nm	1.35
II - T306R1µ0	600	600 nm – 1500 nm	1000 nm	2.7
III - T303R2µ0	300	1400 nm – 3000 nm	2000 nm	5.4

The detectors at the exit ports of the monochromator are a photomultiplier tube for the spectral range from 250 nm to 800 nm, an InGaAs photodiode (850 nm to 1650 nm) and an InSb detector used with the lock-in technique (1700 nm to 2500 nm).

15.3 Laboratory conditions

Throughout the calibration the laboratory was stabilised at a temperature of 21 ± 0.5 ºC. The humidity was not controlled.

15.4 Laboratory standards

The comparison lamps were calibrated directly against the black-body source.

A set of working standards was calibrated against the black-body measurements within the same group as the lamps for the comparison. This ensured that lamps for customers, which are calibrated against the PTB working standards, are linked to the same scale realisation as the standards for the CCPR-K1.a intercomparison. The laboratory standards used for customer calibrations are 4.11-0204, 4.11-0205, 4.11-4206 and 4.11-0207 as documented in the PTB quality-management system.

15.5 Measurement procedure

The black-body, working standards, or the lamps under test, were measured in the same optical path of the system in different successive measurement cycles, each covering the whole recommended wavelength range. The stability of the system was controlled using a monitor lamp during each measurement cycle such that the signal of the black-body source, the standard lamp or the test lamp was compared with the signal of a monitor lamp, at each wavelength, by opening two different entrance ports of the integrating sphere. The stability of the monitor lamp was known to be better than $1 \cdot 10^{-3}\,h^{-1}$ even in the UV spectral region and was additionally recorded using a temperature-stabilised monitor detector.

During each of the two measurement campaigns at the PTB, the standards for the CCPR-K1.a intercomparison were measured three times with black-body measurements and measurements of the PTB working standards in turn. The spectral irradiance scale used was averaged over up to six black-body calibrations for each measuring round and was compared to earlier scale realisations using additionally selected standard lamps. The calibration procedure is documented in the PTB quality-management system in document QM-AA-4.11-02 (spectral irradiance calibrations).

15.6 Uncertainty determination

In this document, the mathematical functions and the input quantities as well as their associated uncertainties are presented. Due to its complexity, the derivation and detailed description of all components of the mathematical models is not described in this document.

The complete measurement uncertainty budgets for the black-body radiator temperature measurement, the spectral irradiance scale realisation and the calibration procedure are described in detail in [5] and in the PTB quality-management system in documents QM-AA-4.11-01 and QM-AA-4.11-02.

15.6.1 Black-body radiator temperature measurements

The broadband-filter detectors measure the irradiance of the black-body radiator weighted according to their spectral responsivity. Their photosignal is a measure for the temperature of the black-body radiator.

This relationship can be described as follows:

$$U_{\mathrm{FD}}(T_{\mathrm{BB}}) = \varepsilon \cdot \left(V_{\mathrm{iU}} + \delta V_{\mathrm{iU}}\right) \cdot \cos\varepsilon_1 \cos\varepsilon_2 \cdot \frac{A_{\mathrm{BB}} + \delta A_{\mathrm{BB}}}{d_{\mathrm{FD}}^2} \cdot \left(s_{\mathrm{abs}} + \delta s_{\mathrm{abs}}\right) \int s_{\mathrm{rel}}(\lambda) \frac{c_1}{\pi\lambda^5} \frac{1}{\exp(c_2/\lambda T_{\mathrm{BB}}) - 1} \cdot d\lambda \quad (15\text{-}1)$$

The quantities used in this equation are

U_{FD}	photosignal of the broadband-filter detector measured
ε	effective emissivity of the black-body radiator
V_{iU}, δV_{iU}	gain of the electrical measurements and its drift
$\cos\varepsilon_1$, $\cos\varepsilon_2$	misalignment of filter detector to the optical axis of the black-body
A_{BB}, δA_{BB}	size of the black-body opening aperture and its drift
d_{FD}	distance of the filter detector to the black-body aperture
s_{abs}, δs_{abs}	absolute spectral responsivity of the filter detector and its drift
s_{rel}	relative spectral responsivity distribution of the filter detector
λ	wavelength used for calculation
T_{BB}	radiometric temperature of the black-body radiator
c_1,c_2	Planck constants

Table 15-2 Standard measurement uncertainties for black-body radiator temperature measurements

Quantity		Type A Uncertainty	Type B Uncertainty	Uncertainty in Temperature / K @ 3090 K
Effective black-body emissivity	ε		0.01 %	0.04
Black-body alignment	$\cos\varepsilon_1$		1°	0.06
Detector alignment	$\cos\varepsilon_2$		1°	0.06
Black-body aperture	A_{BB}		1 µm	0.10
Aperture contamination during operation	A_{BB}		0.06 %	0.20
Distance detector to black-body	d_{FD}		0.05 mm	0.04
Absolute detector responsivity	s_{abs}		0.1 %	0.38
Relative detector responsivity	s_{rel}		0.01 %	0.04
Responsivity drift between calibrations	δs_{abs}		0.05 %	0.19
Detector signal readings	U_{FD}	0.01 %		0.04
Gain and drift of electrical measurements	V_{iU}, δV_{iU}		0.001 %	< 0.01
Total standard measurement uncertainty				0.50
Expanded uncertainty (k = 2)				1.00

15.6.2 Primary spectral irradiance scale realisation

With the temperature of the black-body radiator known, its spectral irradiance can directly be calculated as follows:

$$E(\lambda,T_{\mathrm{P}}) = \varepsilon \cdot \cos\varepsilon_{\mathrm{diff1}} \cdot \cos\varepsilon_{\mathrm{diff2}} \cdot \frac{A_{\mathrm{BB}} + \delta A_{\mathrm{BB}}}{d_{\mathrm{diff}}^2} \cdot \frac{c_1}{\pi \lambda^5} \cdot \frac{1}{\exp\left(c_2/\lambda T_{\mathrm{P}}\right) - 1} + \delta E(\lambda,T) \quad (15\text{-}2)$$

The quantities used in this equation are:

E_{BB}	calculated spectral irradiance of the black-body radiator
ε	emissivity of the black-body radiator
$\cos\varepsilon_{\mathrm{diff1}}$,$\cos\varepsilon_{\mathrm{diff2}}$	misalignment of the integrating sphere opening to the optical axis of the black-body
A_{BB}, δA_{BB}	size and drift of the black-body opening aperture
d_{diff}	distance of the integrating sphere opening to the black-body aperture
λ	calculated wavelength
T_{P}	radiometric temperature of the black-body radiator determined by the filter detectors
δE	correction for black-body temperature non-uniformity
c_1,c_2	Planck constants

The wavelength λ has no associated uncertainty because it is used as an exact calculation parameter. The emissivity ε, the size of the black-body opening aperture A_{BB} and its drift δA_{BB} in the mathematical model for the spectral irradiance are strongly correlated with the same input quantities that were used to determine the black-body radiator temperature T_{BB}. The correlation slightly reduces the associated uncertainty for the temperature T_{P} used to calculate the spectral irradiance.

The effect of this uncertainty at different wavelengths is shown in Table 15-3.

Table 15-3 Standard measurement uncertainties for primary spectral irradiance scale realisation

Quantity		Uncertainty	Uncertainty in Spectral Irradiance 250 nm	260 nm - 300 nm	310 nm - 350 nm	360 nm - 400 nm	450 nm - 600 nm	650 nm - 800 nm	850 nm - 1000 nm	1100 nm - 1300 nm	1350 nm - 2000 nm	2000 nm - 2500 nm
Black-body alignment	cos ε_2	1 °	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %
Spectroradiometer alignment	cos ε_1	1 °	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %
Distance: diffuser to black-body	d_{diff}	0.05 mm	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %
Effective black-body emissivity*	ε	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %	0.00 %	0.00 %	0.00 %	0.01 %	0.01 %
Black-body aperture (diameter)*	A_{BB}	1 µm	0.03 %	0.03 %	0.02 %	0.02 %	0.01 %	0.00 %	0.01 %	0.01 %	0.02 %	0.02 %
Aperture contamination during operation*	δA_{BB}	0.05 %	0.07 %	0.07 %	0.05 %	0.04 %	0.01 %	0.01 %	0.02 %	0.03 %	0.03 %	0.04 %
Temperature determination*	T_{P}	0.43 K	0.26 %	0.25 %	0.21 %	0.18 %	0.15 %	0.10 %	0.08 %	0.06 %	0.05 %	0.04 %
Black-body temperature non-uniformity	δE	0.15 K	0.06 %	0.06 %	0.05 %	0.04 %	0.04 %	0.02 %	0.02 %	0.01 %	0.01 %	0.01 %
Total standard measurement uncertainty			0.28 %	0.27 %	0.23 %	0.20 %	0.17 %	0.11 %	0.08 %	0.08 %	0.07 %	0.07 %

* The uncertainty values for black-body emissivity, aperture and aperture contamination are strongly correlated with the temperature determination. Therefore the uncertainty for the temperature determination is slightly reduced by these parts and the correlation is taken into account in this uncertainty budget.
For details see [5].

15.6.3 Calibration procedure

The mathematical model of the calibration procedure considers that separate measurements of the monitor lamp against the working standard B (at the time t_1) and the transfer standard S (at the time t_2) have to be combined. The form factor f of the spectroradiometer and several correction factors κ have to be considered under varying conditions. The spectral irradiance of the transfer standard can be expressed as follows:

$$E_S(\lambda,t_2,T_S) = \frac{v_S(\lambda_2,b,t_2,T_S)}{v_M(\lambda_2,b,t_2,T_M)} \cdot \kappa_{\lambda,S,M}(\lambda,\lambda_2,t_2) \cdot \kappa_{L,S,M}(t_2) \cdot \kappa_{\varepsilon,S}(t_2) \cdot \kappa_{d,S}(t_2) \cdot \frac{\kappa_{I,S}(t_1)}{\kappa_{I,M}(t_1)} \cdot \frac{1}{\kappa_{t,M}(\lambda,t_2,t_1)} \cdot$$
$$\frac{v_M(\lambda_1,b,t_1,T_M)}{v_B(\lambda_1,b,t_1,T_B)} \cdot \kappa_{\lambda,M,B}(\lambda,\lambda_1,t_1) \cdot \kappa_{L,M,B}(t_1) \cdot \frac{1}{\kappa_{\varepsilon,B}(t_1) \cdot \kappa_{d,B}(t_1)} \cdot \frac{\kappa_{I,M}(t_1)}{\kappa_{I,B}(t_1)} \cdot \frac{1}{\kappa_{t,B}(\lambda,t_1,t_0)} \quad (15\text{-}3)$$

The quantities used in this equation are:

E_S	calibrated spectral irradiance of the transfer standard
t_0, t_1, t_2	times of measurements/calibrations
λ	calculated wavelength
λ_1, λ_2	wavelengths set at the spectroradiometer at times t_1 and t_2
T_S, T_B, T_M	calculated distribution temperatures of the transfer standard, the working standard and the monitor lamp
b	spectral bandwidth of the spectroradiometer
v_S, v_B, v_M	photosignals of the lamps
$\kappa_{\lambda,S,M}$, $\kappa_{\lambda,B,M}$	combined correction factor for wavelength settings at times t_1 and t_2
$\kappa_{L,S,M}$, $\kappa_{L,B,M}$	combined correction factor for nonlinearity of the measurement electronics settings at times t_1 and t_2
$\kappa_{d,S}$, $\kappa_{d,B}$	correction factor for distance settings of the transfer standard and the working standard
$\kappa_{\varepsilon,S}$, $\kappa_{\varepsilon,B}$	correction factor for alignment of the transfer standard and the working standard
$\kappa_{I,S}$, $\kappa_{I,B}$, $\kappa_{I,M}$	correction factor for electrical current settings of any of the lamps
$\kappa_{t,B}$, $\kappa_{t,M}$	correction factor for the drift of the working standard and the monitor lamp / measurement facility since the last measurement or calibration
E_B	spectral irradiance of the working standard

All correction factors and form factors are selected to be unity under the ideal conditions of the defined calibration procedures. Their associated uncertainties are considered for these conditions.

The combined correction factors take into account that a misadjustment of a quantity (e.g. the wavelength λ) has the same effect on the monitor lamp and the other lamp measured at the same time*. Therefore, the associated measurement uncertainty of this quantity for the spectral irradiance calibration can be significantly lower than usually assumed.

The effect of these uncertainties on the spectral irradiance calibration is given in Table 15-4.

* If, for instance, the distribution temperatures of the two lamps are similar, a misadjustment of the wavelength has a negligible effect on the ratio of photosignals measured at the same time.

Table 15-4 Standard measurement uncertainties for spectral irradiance calibrations

Parameter		Type A Uncertainty	Type B Uncertainty	Uncertainty in Spectral Irradiance % 250 nm	260 nm - 300 nm	310 nm - 350 nm	360 nm - 400 nm	450 nm - 600 nm	650 nm - 800 nm	850 nm - 1000 nm	1100 nm - 1300 nm	1350 nm - 2000 nm	2000 nm - 2500 nm
Primary black-body scale realisation	E_B		0.5 K	0.28 %	0.27 %	0.23 %	0.20 %	0.17 %	0.11 %	0.08 %	0.08 %	0.07 %	0.06 %
Distance of transfer standard	$\kappa_{d,S}$		0.05 mm	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %
Distance of working standard	$\kappa_{d,S}$		0.05 mm	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %	0.04 %
Alignment of transfer standard	$\kappa_{\varepsilon,S}$		0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %
Alignment of working standard	$\kappa_{\varepsilon,S}$		0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %
Electrical current of transfer standard	$\kappa_{I,S}$		0.001 A	0.07 %	0.06 %	0.06 %	0.05 %	0.04 %	0.03 %	0.02 %	0.02 %	0.01 %	0.01 %
Electrical current of monitor lamp	$\kappa_{I,M}$		0.001 A	0.07 %	0.06 %	0.06 %	0.05 %	0.04 %	0.03 %	0.02 %	0.02 %	0.01 %	0.01 %
Wavelength for transfer standard	$\kappa_{\lambda,S,M}$		0.2 nm	0.08 %	0.08 %	0.06 %	0.04 %	0.03 %	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %
Wavelength for working standard	$\kappa_{\lambda,B,M}$		0.2 nm	0.08 %	0.08 %	0.06 %	0.04 %	0.03 %	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %
Stability of facility and monitor lamp	$\kappa_{t,M}$	0.04 % - 0.28 %		0.28 %	0.28 %	0.23 %	0.20 %	0.18 %	0.12 %	0.09 %	0.07 %	0.05 %	0.04 %
Repeatability of working standard	v_B	0.03 % - 0.4 %		0.13 %	0.13 %	0.08 %	0.08 %	0.06 %	0.05 %	0.04 %	0.03 %	0.40 %	0.40 %
Repeatability of transfer standard	v_S	0.03 % - 0.4 %		0.13 %	0.13 %	0.08 %	0.08 %	0.06 %	0.05 %	0.04 %	0.03 %	0.40 %	0.40 %
Reproducibility of transfer standard	E_S	0.17 % - 1.04 %		0.35 %	0.35 %	0.29 %	0.23 %	0.17 %	0.29 %	0.23 %	0.40 %	0.81 %	1.04 %
Total standard measurement uncertainty				0.6 %	0.6 %	0.5 %	0.4 %	0.3 %	0.4 %	0.3 %	0.4 %	1.0 %	1.2 %
Expanded uncertainty ($k = 2$)				1.2 %	1.2 %	0.9 %	0.8 %	0.7 %	0.7 %	0.6 %	0.9 %	2.0 %	2.4 %

15.6.4 Correlation

Of the effects described in Table 15-4, only the wavelength accuracy for the transfer standard and working standard are correlated for all measurements of all lamps in both rounds. The primary black-body scale realisation is correlated for all measurements within a round, but was independently realised for the two rounds. All other effects are entirely uncorrelated between all measurements of the lamps.

15.7 PTB Results

PTB measured three lamps. The results for FEL BN 9101 240 are given in Table 15-5, the results for FEL BN 9101 227 are given in Table 15-6 and the results for FEL BN 9101 198 are given in Table 15-7.

Table 15-5 PTB Results for FEL BN 9101 240. Uncertainties have been split according to correlation between lamps and between rounds.

FEL 240	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.687E-04	0.51 %	0.28 %	0.11 %	0.60 %	1.688E-04	0.51 %	0.28 %	0.11 %	0.60 %
260	2.955E-04	0.50 %	0.27 %	0.11 %	0.58 %	2.956E-04	0.50 %	0.27 %	0.11 %	0.58 %
270	4.911E-04	0.50 %	0.27 %	0.11 %	0.58 %	4.902E-04	0.50 %	0.27 %	0.11 %	0.58 %
280	7.518E-04	0.50 %	0.27 %	0.11 %	0.58 %	7.537E-04	0.50 %	0.27 %	0.11 %	0.58 %
290	1.163E-03	0.50 %	0.27 %	0.11 %	0.58 %	1.162E-03	0.50 %	0.27 %	0.11 %	0.58 %
300	1.693E-03	0.49 %	0.27 %	0.11 %	0.57 %	1.691E-03	0.49 %	0.27 %	0.11 %	0.57 %
310	2.400E-03	0.41 %	0.23 %	0.08 %	0.48 %	2.403E-03	0.41 %	0.23 %	0.08 %	0.48 %
320	3.275E-03	0.41 %	0.23 %	0.08 %	0.48 %	3.276E-03	0.41 %	0.23 %	0.08 %	0.48 %
330	4.388E-03	0.41 %	0.23 %	0.08 %	0.47 %	4.385E-03	0.41 %	0.23 %	0.08 %	0.47 %
340	5.746E-03	0.41 %	0.23 %	0.08 %	0.47 %	5.748E-03	0.41 %	0.23 %	0.08 %	0.47 %
350	7.391E-03	0.41 %	0.23 %	0.08 %	0.47 %	7.387E-03	0.41 %	0.23 %	0.08 %	0.47 %
360	9.325E-03	0.35 %	0.20 %	0.06 %	0.40 %	9.303E-03	0.35 %	0.20 %	0.06 %	0.40 %
370	1.156E-02	0.34 %	0.20 %	0.06 %	0.40 %	1.154E-02	0.34 %	0.20 %	0.06 %	0.40 %
380	1.413E-02	0.34 %	0.20 %	0.06 %	0.40 %	1.408E-02	0.34 %	0.20 %	0.06 %	0.40 %
390	1.701E-02	0.34 %	0.20 %	0.06 %	0.40 %	1.696E-02	0.34 %	0.20 %	0.06 %	0.40 %
400	2.022E-02	0.34 %	0.20 %	0.06 %	0.40 %	2.015E-02	0.34 %	0.20 %	0.06 %	0.40 %
450	4.081E-02	0.30 %	0.17 %	0.04 %	0.35 %	4.079E-02	0.30 %	0.17 %	0.04 %	0.35 %
500	6.763E-02	0.29 %	0.17 %	0.04 %	0.34 %	6.753E-02	0.29 %	0.17 %	0.04 %	0.34 %
550	9.755E-02	0.29 %	0.17 %	0.04 %	0.34 %	9.734E-02	0.29 %	0.17 %	0.04 %	0.34 %
555	1.006E-01	0.29 %	0.17 %	0.04 %	0.34 %	1.003E-01	0.29 %	0.17 %	0.04 %	0.34 %
600	1.272E-01	0.29 %	0.17 %	0.04 %	0.34 %	1.270E-01	0.29 %	0.17 %	0.04 %	0.34 %
650	1.540E-01	0.34 %	0.11 %	0.01 %	0.36 %	1.536E-01	0.34 %	0.11 %	0.01 %	0.36 %
700	1.761E-01	0.34 %	0.11 %	0.01 %	0.35 %	1.759E-01	0.34 %	0.11 %	0.01 %	0.35 %
750	1.927E-01	0.34 %	0.11 %	0.01 %	0.35 %	1.927E-01	0.34 %	0.11 %	0.01 %	0.35 %
800	2.040E-01	0.34 %	0.11 %	0.01 %	0.36 %	2.042E-01	0.34 %	0.11 %	0.01 %	0.36 %
850	2.110E-01	0.27 %	0.08 %	0.01 %	0.28 %	2.107E-01	0.27 %	0.08 %	0.01 %	0.28 %
900	2.130E-01	0.27 %	0.08 %	0.01 %	0.28 %	2.128E-01	0.27 %	0.08 %	0.01 %	0.28 %
950	2.124E-01	0.27 %	0.08 %	0.01 %	0.28 %	2.123E-01	0.27 %	0.08 %	0.01 %	0.28 %
1000	2.079E-01	0.27 %	0.08 %	0.01 %	0.28 %	2.083E-01	0.27 %	0.08 %	0.01 %	0.28 %
1100	1.947E-01	0.42 %	0.08 %	0.01 %	0.43 %	1.946E-01	0.42 %	0.08 %	0.01 %	0.43 %
1200	1.781E-01	0.42 %	0.08 %	0.01 %	0.43 %	1.778E-01	0.42 %	0.08 %	0.01 %	0.43 %
1300	1.581E-01	0.42 %	0.08 %	0.01 %	0.43 %	1.582E-01	0.42 %	0.08 %	0.01 %	0.43 %
1400	1.398E-01	0.99 %	0.07 %	0.01 %	1.00 %	1.421E-01	0.99 %	0.07 %	0.01 %	1.00 %
1500	1.225E-01	0.99 %	0.07 %	0.01 %	1.00 %	1.226E-01	0.99 %	0.07 %	0.01 %	1.00 %
1600	1.070E-01	0.99 %	0.07 %	0.01 %	1.00 %	1.075E-01	0.99 %	0.07 %	0.01 %	1.00 %
1700	9.328E-02	1.00 %	0.07 %	0.01 %	1.00 %	9.368E-02	1.00 %	0.07 %	0.01 %	1.00 %
1800	8.187E-02	1.00 %	0.07 %	0.01 %	1.00 %	8.204E-02	1.00 %	0.07 %	0.01 %	1.00 %
1900	7.183E-02	1.01 %	0.07 %	0.01 %	1.02 %	7.252E-02	1.01 %	0.07 %	0.01 %	1.02 %
2000	6.197E-02	1.01 %	0.07 %	0.01 %	1.02 %	6.225E-02	1.01 %	0.07 %	0.01 %	1.02 %
2100	5.404E-02	1.21 %	0.06 %	0.01 %	1.21 %	5.448E-02	1.21 %	0.06 %	0.01 %	1.21 %
2200	4.711E-02	1.22 %	0.06 %	0.01 %	1.22 %	4.749E-02	1.22 %	0.06 %	0.01 %	1.22 %
2300	4.173E-02	1.21 %	0.06 %	0.01 %	1.21 %	4.176E-02	1.21 %	0.06 %	0.01 %	1.21 %
2400	3.675E-02	1.19 %	0.06 %	0.01 %	1.19 %	3.672E-02	1.19 %	0.06 %	0.01 %	1.19 %
2500	3.221E-02	1.21 %	0.06 %	0.01 %	1.21 %	3.258E-02	1.21 %	0.06 %	0.01 %	1.21 %

Table 15-6 PTB Results for FEL BN 9101 227. Uncertainties have been split according to correlation between lamps and between rounds.

FEL 227	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.293E-04	0.51 %	0.28 %	0.11 %	0.59 %	1.288E-04	0.51 %	0.28 %	0.11 %	0.59 %
260	2.289E-04	0.50 %	0.27 %	0.11 %	0.58 %	2.277E-04	0.50 %	0.27 %	0.11 %	0.58 %
270	3.835E-04	0.50 %	0.27 %	0.11 %	0.58 %	3.809E-04	0.50 %	0.27 %	0.11 %	0.58 %
280	6.064E-04	0.50 %	0.27 %	0.11 %	0.58 %	6.041E-04	0.50 %	0.27 %	0.11 %	0.58 %
290	9.233E-04	0.50 %	0.27 %	0.11 %	0.58 %	9.186E-04	0.50 %	0.27 %	0.11 %	0.58 %
300	1.352E-03	0.49 %	0.27 %	0.11 %	0.57 %	1.346E-03	0.49 %	0.27 %	0.11 %	0.57 %
310	1.922E-03	0.41 %	0.23 %	0.08 %	0.48 %	1.918E-03	0.41 %	0.23 %	0.08 %	0.48 %
320	2.651E-03	0.41 %	0.23 %	0.08 %	0.48 %	2.645E-03	0.41 %	0.23 %	0.08 %	0.48 %
330	3.576E-03	0.41 %	0.23 %	0.08 %	0.48 %	3.562E-03	0.41 %	0.23 %	0.08 %	0.48 %
340	4.711E-03	0.41 %	0.23 %	0.08 %	0.48 %	4.697E-03	0.41 %	0.23 %	0.08 %	0.48 %
350	6.091E-03	0.40 %	0.23 %	0.08 %	0.47 %	6.066E-03	0.40 %	0.23 %	0.08 %	0.47 %
360	7.732E-03	0.34 %	0.20 %	0.06 %	0.40 %	7.684E-03	0.34 %	0.20 %	0.06 %	0.40 %
370	9.628E-03	0.35 %	0.20 %	0.06 %	0.40 %	9.569E-03	0.35 %	0.20 %	0.06 %	0.40 %
380	1.183E-02	0.35 %	0.20 %	0.06 %	0.40 %	1.174E-02	0.35 %	0.20 %	0.06 %	0.40 %
390	1.430E-02	0.34 %	0.20 %	0.06 %	0.40 %	1.420E-02	0.34 %	0.20 %	0.06 %	0.40 %
400	1.708E-02	0.34 %	0.20 %	0.06 %	0.40 %	1.696E-02	0.34 %	0.20 %	0.06 %	0.40 %
450	3.509E-02	0.30 %	0.17 %	0.04 %	0.35 %	3.492E-02	0.30 %	0.17 %	0.04 %	0.35 %
500	5.908E-02	0.29 %	0.17 %	0.04 %	0.34 %	5.874E-02	0.29 %	0.17 %	0.04 %	0.34 %
550	8.622E-02	0.29 %	0.17 %	0.04 %	0.34 %	8.576E-02	0.29 %	0.17 %	0.04 %	0.34 %
555	8.896E-02	0.29 %	0.17 %	0.04 %	0.34 %	8.849E-02	0.29 %	0.17 %	0.04 %	0.34 %
600	1.136E-01	0.29 %	0.17 %	0.04 %	0.34 %	1.130E-01	0.29 %	0.17 %	0.04 %	0.34 %
650	1.385E-01	0.34 %	0.11 %	0.01 %	0.36 %	1.378E-01	0.34 %	0.11 %	0.01 %	0.36 %
700	1.596E-01	0.34 %	0.11 %	0.01 %	0.35 %	1.589E-01	0.34 %	0.11 %	0.01 %	0.35 %
750	1.759E-01	0.34 %	0.11 %	0.01 %	0.35 %	1.754E-01	0.34 %	0.11 %	0.01 %	0.35 %
800	1.874E-01	0.34 %	0.11 %	0.01 %	0.36 %	1.867E-01	0.34 %	0.11 %	0.01 %	0.36 %
850	1.946E-01	0.27 %	0.08 %	0.01 %	0.28 %	1.936E-01	0.27 %	0.08 %	0.01 %	0.28 %
900	1.974E-01	0.27 %	0.08 %	0.01 %	0.28 %	1.967E-01	0.27 %	0.08 %	0.01 %	0.28 %
950	1.976E-01	0.27 %	0.08 %	0.01 %	0.28 %	1.970E-01	0.27 %	0.08 %	0.01 %	0.28 %
1000	1.942E-01	0.27 %	0.08 %	0.01 %	0.28 %	1.939E-01	0.27 %	0.08 %	0.01 %	0.28 %
1100	1.829E-01	0.42 %	0.08 %	0.01 %	0.43 %	1.824E-01	0.42 %	0.08 %	0.01 %	0.43 %
1200	1.678E-01	0.42 %	0.08 %	0.01 %	0.43 %	1.673E-01	0.42 %	0.08 %	0.01 %	0.43 %
1300	1.500E-01	0.42 %	0.08 %	0.01 %	0.43 %	1.498E-01	0.42 %	0.08 %	0.01 %	0.43 %
1400	1.332E-01	0.99 %	0.07 %	0.01 %	1.00 %	1.350E-01	0.99 %	0.07 %	0.01 %	1.00 %
1500	1.170E-01	0.99 %	0.07 %	0.01 %	1.00 %	1.168E-01	0.99 %	0.07 %	0.01 %	1.00 %
1600	1.026E-01	0.99 %	0.07 %	0.01 %	1.00 %	1.025E-01	0.99 %	0.07 %	0.01 %	1.00 %
1700	8.983E-02	1.00 %	0.07 %	0.01 %	1.00 %	8.958E-02	1.00 %	0.07 %	0.01 %	1.00 %
1800	7.880E-02	1.00 %	0.07 %	0.01 %	1.00 %	7.872E-02	1.00 %	0.07 %	0.01 %	1.00 %
1900	6.913E-02	1.03 %	0.07 %	0.01 %	1.03 %	6.974E-02	1.03 %	0.07 %	0.01 %	1.03 %
2000	5.953E-02	1.00 %	0.07 %	0.01 %	1.00 %	5.993E-02	1.00 %	0.07 %	0.01 %	1.00 %
2100	5.257E-02	1.20 %	0.06 %	0.01 %	1.20 %	5.246E-02	1.20 %	0.06 %	0.01 %	1.20 %
2200	4.556E-02	1.22 %	0.06 %	0.01 %	1.22 %	4.590E-02	1.22 %	0.06 %	0.01 %	1.22 %
2300	4.027E-02	1.20 %	0.06 %	0.01 %	1.21 %	4.026E-02	1.20 %	0.06 %	0.01 %	1.21 %
2400	3.567E-02	1.19 %	0.06 %	0.01 %	1.19 %	3.551E-02	1.19 %	0.06 %	0.01 %	1.19 %
2500	3.120E-02	1.21 %	0.06 %	0.01 %	1.22 %	3.163E-02	1.21 %	0.06 %	0.01 %	1.22 %

Table 15-7 PTB Results for FEL BN 9101 198. Uncertainties have been split according to correlation between lamps and between rounds.

FEL 198	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.177E-04	0.52 %	0.28 %	0.11 %	0.60 %	1.154E-04	0.52 %	0.28 %	0.11 %	0.60 %
260	2.082E-04	0.50 %	0.27 %	0.11 %	0.58 %	2.044E-04	0.50 %	0.27 %	0.11 %	0.58 %
270	3.491E-04	0.50 %	0.27 %	0.11 %	0.58 %	3.422E-04	0.50 %	0.27 %	0.11 %	0.58 %
280	5.545E-04	0.50 %	0.27 %	0.11 %	0.58 %	5.447E-04	0.50 %	0.27 %	0.11 %	0.58 %
290	8.433E-04	0.50 %	0.27 %	0.11 %	0.58 %	8.295E-04	0.50 %	0.27 %	0.11 %	0.58 %
300	1.238E-03	0.49 %	0.27 %	0.11 %	0.58 %	1.219E-03	0.49 %	0.27 %	0.11 %	0.58 %
310	1.761E-03	0.41 %	0.23 %	0.08 %	0.48 %	1.737E-03	0.41 %	0.23 %	0.08 %	0.48 %
320	2.438E-03	0.41 %	0.23 %	0.08 %	0.48 %	2.406E-03	0.41 %	0.23 %	0.08 %	0.48 %
330	3.290E-03	0.41 %	0.23 %	0.08 %	0.48 %	3.249E-03	0.41 %	0.23 %	0.08 %	0.48 %
340	4.338E-03	0.41 %	0.23 %	0.08 %	0.47 %	4.293E-03	0.41 %	0.23 %	0.08 %	0.47 %
350	5.622E-03	0.41 %	0.23 %	0.08 %	0.47 %	5.559E-03	0.41 %	0.23 %	0.08 %	0.47 %
360	7.149E-03	0.35 %	0.20 %	0.06 %	0.40 %	7.058E-03	0.35 %	0.20 %	0.06 %	0.40 %
370	8.921E-03	0.34 %	0.20 %	0.06 %	0.40 %	8.812E-03	0.34 %	0.20 %	0.06 %	0.40 %
380	1.099E-02	0.35 %	0.20 %	0.06 %	0.40 %	1.083E-02	0.35 %	0.20 %	0.06 %	0.40 %
390	1.330E-02	0.34 %	0.20 %	0.06 %	0.40 %	1.312E-02	0.34 %	0.20 %	0.06 %	0.40 %
400	1.591E-02	0.34 %	0.20 %	0.06 %	0.40 %	1.570E-02	0.34 %	0.20 %	0.06 %	0.40 %
450	3.293E-02	0.30 %	0.17 %	0.04 %	0.35 %	3.258E-02	0.30 %	0.17 %	0.04 %	0.35 %
500	5.580E-02	0.29 %	0.17 %	0.04 %	0.34 %	5.510E-02	0.29 %	0.17 %	0.04 %	0.34 %
550	8.188E-02	0.29 %	0.17 %	0.04 %	0.34 %	8.098E-02	0.29 %	0.17 %	0.04 %	0.34 %
555	8.454E-02	0.29 %	0.17 %	0.04 %	0.34 %	8.357E-02	0.29 %	0.17 %	0.04 %	0.34 %
600	1.082E-01	0.29 %	0.17 %	0.04 %	0.34 %	1.072E-01	0.29 %	0.17 %	0.04 %	0.34 %
650	1.327E-01	0.34 %	0.11 %	0.01 %	0.36 %	1.312E-01	0.34 %	0.11 %	0.01 %	0.36 %
700	1.533E-01	0.34 %	0.11 %	0.01 %	0.35 %	1.518E-01	0.34 %	0.11 %	0.01 %	0.35 %
750	1.694E-01	0.34 %	0.11 %	0.01 %	0.36 %	1.679E-01	0.34 %	0.11 %	0.01 %	0.36 %
800	1.807E-01	0.34 %	0.11 %	0.01 %	0.35 %	1.794E-01	0.34 %	0.11 %	0.01 %	0.35 %
850	1.881E-01	0.27 %	0.08 %	0.01 %	0.29 %	1.864E-01	0.27 %	0.08 %	0.01 %	0.29 %
900	1.913E-01	0.27 %	0.08 %	0.01 %	0.28 %	1.894E-01	0.27 %	0.08 %	0.01 %	0.28 %
950	1.917E-01	0.27 %	0.08 %	0.01 %	0.28 %	1.900E-01	0.27 %	0.08 %	0.01 %	0.28 %
1000	1.887E-01	0.27 %	0.08 %	0.01 %	0.28 %	1.874E-01	0.27 %	0.08 %	0.01 %	0.28 %
1100	1.781E-01	0.42 %	0.08 %	0.01 %	0.43 %	1.765E-01	0.42 %	0.08 %	0.01 %	0.43 %
1200	1.639E-01	0.42 %	0.08 %	0.01 %	0.43 %	1.622E-01	0.42 %	0.08 %	0.01 %	0.43 %
1300	1.464E-01	0.42 %	0.08 %	0.01 %	0.43 %	1.453E-01	0.42 %	0.08 %	0.01 %	0.43 %
1400	1.298E-01	0.99 %	0.07 %	0.01 %	1.00 %	1.322E-01	0.99 %	0.07 %	0.01 %	1.00 %
1500	1.144E-01	0.99 %	0.07 %	0.01 %	1.00 %	1.136E-01	0.99 %	0.07 %	0.01 %	1.00 %
1600	1.002E-01	0.99 %	0.07 %	0.01 %	1.00 %	1.000E-01	0.99 %	0.07 %	0.01 %	1.00 %
1700	8.782E-02	1.00 %	0.07 %	0.01 %	1.00 %	8.752E-02	1.00 %	0.07 %	0.01 %	1.00 %
1800	7.713E-02	1.00 %	0.07 %	0.01 %	1.00 %	7.671E-02	1.00 %	0.07 %	0.01 %	1.00 %
1900	6.762E-02	1.02 %	0.07 %	0.01 %	1.03 %	6.766E-02	1.02 %	0.07 %	0.01 %	1.03 %
2000	5.865E-02	1.03 %	0.07 %	0.01 %	1.03 %	5.845E-02	1.03 %	0.07 %	0.01 %	1.03 %
2100	5.115E-02	1.24 %	0.06 %	0.01 %	1.25 %	5.130E-02	1.24 %	0.06 %	0.01 %	1.25 %
2200	4.474E-02	1.22 %	0.06 %	0.01 %	1.22 %	4.478E-02	1.22 %	0.06 %	0.01 %	1.22 %
2300	3.958E-02	1.23 %	0.06 %	0.01 %	1.23 %	3.926E-02	1.23 %	0.06 %	0.01 %	1.23 %
2400	3.496E-02	1.20 %	0.06 %	0.01 %	1.20 %	3.470E-02	1.20 %	0.06 %	0.01 %	1.20 %
2500	3.091E-02	1.20 %	0.06 %	0.01 %	1.20 %	3.079E-02	1.20 %	0.06 %	0.01 %	1.20 %

15.8 Pilot Results

NPL's results for FEL BN 9101 240 are given in Table 15-8 and the results for FEL BN 9101 227 are given in Table 15-9, the results for FEL BN 9101 198 are given in Table 15-10.

Table 15-8 NPL Results for FEL BN 9101 240. Uncertainties have been split according to correlation between lamps and between rounds.

FEL 240	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.699E-04	0.40 %	0.48 %	2.00 %	2.10 %	1.696E-04	1.06 %	0.45 %	2.00 %	2.31 %
260	2.940E-04	0.31 %	0.46 %	2.00 %	2.08 %	2.938E-04	0.80 %	0.43 %	2.00 %	2.20 %
270	4.835E-04	0.25 %	0.44 %	2.00 %	2.06 %	4.836E-04	0.61 %	0.41 %	2.00 %	2.13 %
280	7.606E-04	0.21 %	0.43 %	1.50 %	1.57 %	7.610E-04	0.47 %	0.40 %	1.50 %	1.62 %
290	1.150E-03	0.19 %	0.41 %	1.00 %	1.10 %	1.151E-03	0.38 %	0.38 %	1.00 %	1.14 %
300	1.679E-03	0.17 %	0.40 %	0.25 %	0.50 %	1.680E-03	0.32 %	0.37 %	0.25 %	0.55 %
310	2.376E-03	0.16 %	0.39 %	0.28 %	0.51 %	2.377E-03	0.28 %	0.36 %	0.28 %	0.54 %
320	3.268E-03	0.15 %	0.37 %	0.25 %	0.48 %	3.270E-03	0.26 %	0.35 %	0.25 %	0.50 %
330	4.385E-03	0.15 %	0.36 %	0.28 %	0.48 %	4.386E-03	0.23 %	0.34 %	0.28 %	0.50 %
340	5.750E-03	0.14 %	0.35 %	0.33 %	0.50 %	5.750E-03	0.22 %	0.33 %	0.33 %	0.51 %
350	7.387E-03	0.14 %	0.34 %	0.36 %	0.51 %	7.386E-03	0.20 %	0.32 %	0.36 %	0.52 %
360	9.315E-03	0.13 %	0.33 %	0.43 %	0.56 %	9.311E-03	0.19 %	0.31 %	0.43 %	0.56 %
370	1.155E-02	0.13 %	0.32 %	0.46 %	0.58 %	1.154E-02	0.18 %	0.30 %	0.46 %	0.58 %
380	1.410E-02	0.12 %	0.31 %	0.52 %	0.62 %	1.409E-02	0.18 %	0.29 %	0.52 %	0.62 %
390	1.697E-02	0.12 %	0.31 %	0.50 %	0.60 %	1.696E-02	0.17 %	0.29 %	0.50 %	0.60 %
400	2.017E-02	0.12 %	0.30 %	0.46 %	0.56 %	2.015E-02	0.17 %	0.28 %	0.46 %	0.57 %
450	4.076E-02	0.12 %	0.27 %	0.10 %	0.31 %	4.071E-02	0.17 %	0.25 %	0.10 %	0.32 %
500	6.746E-02	0.11 %	0.24 %	0.01 %	0.26 %	6.738E-02	0.16 %	0.22 %	0.01 %	0.27 %
550	9.721E-02	0.10 %	0.22 %	0.00 %	0.24 %	9.715E-02	0.14 %	0.20 %	0.00 %	0.24 %
555	1.002E-01	0.10 %	0.22 %	0.00 %	0.24 %	1.002E-01	0.14 %	0.20 %	0.00 %	0.24 %
600	1.268E-01	0.09 %	0.20 %	0.00 %	0.22 %	1.268E-01	0.12 %	0.19 %	0.00 %	0.22 %
650	1.536E-01	0.09 %	0.18 %	0.00 %	0.20 %	1.538E-01	0.12 %	0.17 %	0.00 %	0.21 %
700	1.760E-01	0.09 %	0.17 %	0.00 %	0.19 %	1.763E-01	0.12 %	0.16 %	0.00 %	0.20 %
750	1.931E-01	0.08 %	0.16 %	0.01 %	0.18 %	1.936E-01	0.11 %	0.15 %	0.01 %	0.19 %
800	2.049E-01	0.08 %	0.15 %	0.00 %	0.17 %	2.055E-01	0.11 %	0.14 %	0.00 %	0.17 %
850	2.117E-01	0.07 %	0.14 %	0.00 %	0.16 %	2.124E-01	0.10 %	0.13 %	0.00 %	0.17 %
900	2.142E-01	0.07 %	0.13 %	0.00 %	0.15 %	2.150E-01	0.10 %	0.12 %	0.00 %	0.16 %
950	2.132E-01	0.07 %	0.13 %	0.01 %	0.14 %	2.141E-01	0.10 %	0.12 %	0.01 %	0.16 %
1000	2.094E-01	0.07 %	0.12 %	0.01 %	0.14 %	2.103E-01	0.10 %	0.11 %	0.01 %	0.15 %
1100	1.962E-01	0.07 %	0.11 %	0.01 %	0.13 %	1.971E-01	0.12 %	0.10 %	0.01 %	0.16 %
1200	1.788E-01	0.09 %	0.10 %	0.02 %	0.13 %	1.797E-01	0.13 %	0.09 %	0.02 %	0.16 %
1300	1.600E-01	0.10 %	0.09 %	0.00 %	0.14 %	1.609E-01	0.13 %	0.09 %	0.00 %	0.16 %
1400	1.414E-01	0.11 %	0.09 %	0.01 %	0.14 %	1.422E-01	0.14 %	0.08 %	0.01 %	0.16 %
1500	1.241E-01	0.11 %	0.08 %	0.01 %	0.14 %	1.247E-01	0.13 %	0.08 %	0.01 %	0.15 %
1600	1.085E-01	0.10 %	0.08 %	0.01 %	0.13 %	1.089E-01	0.12 %	0.07 %	0.01 %	0.14 %
1700	9.476E-02	0.13 %	0.07 %	0.01 %	0.15 %	9.504E-02	0.15 %	0.07 %	0.01 %	0.17 %
1800	8.267E-02	0.17 %	0.07 %	0.02 %	0.19 %	8.291E-02	0.20 %	0.07 %	0.02 %	0.21 %
1900	7.205E-02	0.21 %	0.07 %	0.02 %	0.22 %	7.235E-02	0.24 %	0.06 %	0.02 %	0.25 %
2000	6.280E-02	0.24 %	0.07 %	0.05 %	0.25 %	6.317E-02	0.27 %	0.06 %	0.05 %	0.28 %
2100	5.486E-02	0.23 %	0.06 %	0.02 %	0.24 %	5.525E-02	0.25 %	0.06 %	0.02 %	0.26 %
2200	4.815E-02	0.25 %	0.06 %	0.00 %	0.26 %	4.845E-02	0.23 %	0.06 %	0.00 %	0.24 %
2300	4.240E-02	0.28 %	0.06 %	0.01 %	0.29 %	4.262E-02	0.31 %	0.06 %	0.01 %	0.31 %
2400	3.725E-02	0.43 %	0.06 %	0.07 %	0.44 %	3.749E-02	0.34 %	0.05 %	0.07 %	0.35 %
2500	3.290E-02	0.37 %	0.06 %	0.05 %	0.37 %	3.294E-02	0.20 %	0.05 %	0.05 %	0.22 %

Table 15-9 NPL Results for FEL BN 9101 227. Uncertainties have been split according to correlation between lamps and between rounds.

FEL 227	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.311E-04	0.84 %	0.48 %	2.00 %	2.22 %	1.307E-04	1.31 %	0.45 %	2.00 %	2.43 %
260	2.289E-04	0.63 %	0.46 %	2.00 %	2.15 %	2.285E-04	0.97 %	0.43 %	2.00 %	2.26 %
270	3.798E-04	0.48 %	0.44 %	2.00 %	2.10 %	3.794E-04	0.74 %	0.41 %	2.00 %	2.17 %
280	6.022E-04	0.38 %	0.43 %	1.50 %	1.60 %	6.019E-04	0.58 %	0.40 %	1.50 %	1.66 %
290	9.176E-04	0.31 %	0.41 %	1.00 %	1.13 %	9.172E-04	0.47 %	0.38 %	1.00 %	1.17 %
300	1.349E-03	0.27 %	0.40 %	0.25 %	0.54 %	1.349E-03	0.40 %	0.37 %	0.25 %	0.60 %
310	1.922E-03	0.24 %	0.39 %	0.28 %	0.53 %	1.921E-03	0.36 %	0.36 %	0.28 %	0.58 %
320	2.661E-03	0.21 %	0.37 %	0.25 %	0.50 %	2.659E-03	0.32 %	0.35 %	0.25 %	0.54 %
330	3.591E-03	0.20 %	0.36 %	0.28 %	0.50 %	3.587E-03	0.30 %	0.34 %	0.28 %	0.53 %
340	4.736E-03	0.19 %	0.35 %	0.33 %	0.52 %	4.730E-03	0.27 %	0.33 %	0.33 %	0.54 %
350	6.117E-03	0.17 %	0.34 %	0.36 %	0.53 %	6.107E-03	0.25 %	0.32 %	0.36 %	0.54 %
360	7.752E-03	0.17 %	0.33 %	0.43 %	0.57 %	7.738E-03	0.24 %	0.31 %	0.43 %	0.58 %
370	9.657E-03	0.16 %	0.32 %	0.46 %	0.58 %	9.638E-03	0.23 %	0.30 %	0.46 %	0.59 %
380	1.184E-02	0.16 %	0.31 %	0.52 %	0.63 %	1.182E-02	0.22 %	0.29 %	0.52 %	0.64 %
390	1.432E-02	0.15 %	0.31 %	0.50 %	0.61 %	1.429E-02	0.21 %	0.29 %	0.50 %	0.61 %
400	1.708E-02	0.15 %	0.30 %	0.46 %	0.57 %	1.705E-02	0.21 %	0.28 %	0.46 %	0.58 %
450	3.513E-02	0.15 %	0.27 %	0.10 %	0.32 %	3.507E-02	0.21 %	0.25 %	0.10 %	0.34 %
500	5.895E-02	0.14 %	0.24 %	0.01 %	0.28 %	5.891E-02	0.20 %	0.22 %	0.01 %	0.30 %
550	8.591E-02	0.12 %	0.22 %	0.00 %	0.25 %	8.595E-02	0.16 %	0.20 %	0.00 %	0.26 %
555	8.866E-02	0.12 %	0.22 %	0.00 %	0.24 %	8.872E-02	0.16 %	0.20 %	0.00 %	0.26 %
600	1.131E-01	0.11 %	0.20 %	0.00 %	0.23 %	1.133E-01	0.15 %	0.19 %	0.00 %	0.24 %
650	1.382E-01	0.10 %	0.18 %	0.00 %	0.21 %	1.385E-01	0.15 %	0.17 %	0.00 %	0.23 %
700	1.594E-01	0.10 %	0.17 %	0.00 %	0.20 %	1.598E-01	0.14 %	0.16 %	0.00 %	0.21 %
750	1.760E-01	0.09 %	0.16 %	0.01 %	0.19 %	1.765E-01	0.14 %	0.15 %	0.01 %	0.20 %
800	1.877E-01	0.09 %	0.15 %	0.00 %	0.17 %	1.882E-01	0.13 %	0.14 %	0.00 %	0.19 %
850	1.948E-01	0.09 %	0.14 %	0.00 %	0.17 %	1.954E-01	0.13 %	0.13 %	0.00 %	0.19 %
900	1.980E-01	0.08 %	0.13 %	0.00 %	0.16 %	1.985E-01	0.13 %	0.12 %	0.00 %	0.18 %
950	1.978E-01	0.08 %	0.13 %	0.01 %	0.15 %	1.982E-01	0.14 %	0.12 %	0.01 %	0.18 %
1000	1.950E-01	0.09 %	0.12 %	0.01 %	0.15 %	1.952E-01	0.15 %	0.11 %	0.01 %	0.19 %
1100	1.837E-01	0.11 %	0.11 %	0.01 %	0.15 %	1.837E-01	0.19 %	0.10 %	0.01 %	0.21 %
1200	1.683E-01	0.14 %	0.10 %	0.02 %	0.17 %	1.680E-01	0.22 %	0.09 %	0.02 %	0.24 %
1300	1.512E-01	0.17 %	0.09 %	0.00 %	0.19 %	1.508E-01	0.23 %	0.09 %	0.00 %	0.24 %
1400	1.342E-01	0.19 %	0.09 %	0.01 %	0.21 %	1.338E-01	0.23 %	0.08 %	0.01 %	0.24 %
1500	1.182E-01	0.18 %	0.08 %	0.01 %	0.20 %	1.179E-01	0.21 %	0.08 %	0.01 %	0.23 %
1600	1.038E-01	0.18 %	0.08 %	0.01 %	0.20 %	1.036E-01	0.20 %	0.07 %	0.01 %	0.21 %
1700	9.091E-02	0.24 %	0.07 %	0.01 %	0.25 %	9.072E-02	0.24 %	0.07 %	0.01 %	0.25 %
1800	7.955E-02	0.31 %	0.07 %	0.02 %	0.32 %	7.924E-02	0.30 %	0.07 %	0.02 %	0.31 %
1900	6.953E-02	0.39 %	0.07 %	0.02 %	0.39 %	6.910E-02	0.34 %	0.06 %	0.02 %	0.35 %
2000	6.076E-02	0.44 %	0.07 %	0.05 %	0.45 %	6.031E-02	0.40 %	0.06 %	0.05 %	0.40 %
2100	5.316E-02	0.43 %	0.06 %	0.02 %	0.43 %	5.291E-02	0.37 %	0.06 %	0.02 %	0.37 %
2200	4.668E-02	0.46 %	0.06 %	0.00 %	0.47 %	4.671E-02	0.36 %	0.06 %	0.00 %	0.37 %
2300	4.110E-02	0.53 %	0.06 %	0.01 %	0.53 %	4.122E-02	0.50 %	0.06 %	0.01 %	0.51 %
2400	3.618E-02	0.84 %	0.06 %	0.07 %	0.85 %	3.599E-02	0.60 %	0.05 %	0.07 %	0.61 %
2500	3.215E-02	0.92 %	0.06 %	0.05 %	0.93 %	3.190E-02	0.30 %	0.05 %	0.05 %	0.31 %

Table 15-10 NPL Results for FEL BN 9101 198. Uncertainties have been split according to correlation between lamps and between rounds.

FEL 198	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.173E-04	0.78 %	0.48 %	2.00 %	2.20 %	1.166E-04	0.78 %	0.45 %	2.00 %	2.19 %
260	2.052E-04	0.58 %	0.46 %	2.00 %	2.13 %	2.039E-04	0.58 %	0.43 %	2.00 %	2.13 %
270	3.412E-04	0.45 %	0.44 %	2.00 %	2.10 %	3.389E-04	0.45 %	0.41 %	2.00 %	2.09 %
280	5.423E-04	0.35 %	0.43 %	1.50 %	1.60 %	5.387E-04	0.35 %	0.40 %	1.50 %	1.59 %
290	8.283E-04	0.29 %	0.41 %	1.00 %	1.12 %	8.229E-04	0.29 %	0.38 %	1.00 %	1.11 %
300	1.221E-03	0.25 %	0.40 %	0.25 %	0.53 %	1.213E-03	0.25 %	0.37 %	0.25 %	0.51 %
310	1.744E-03	0.22 %	0.39 %	0.28 %	0.53 %	1.733E-03	0.22 %	0.36 %	0.28 %	0.51 %
320	2.420E-03	0.20 %	0.37 %	0.25 %	0.49 %	2.405E-03	0.20 %	0.35 %	0.25 %	0.47 %
330	3.274E-03	0.19 %	0.36 %	0.28 %	0.50 %	3.255E-03	0.19 %	0.34 %	0.28 %	0.48 %
340	4.328E-03	0.18 %	0.35 %	0.33 %	0.51 %	4.304E-03	0.18 %	0.33 %	0.33 %	0.50 %
350	5.603E-03	0.17 %	0.34 %	0.36 %	0.52 %	5.574E-03	0.17 %	0.32 %	0.36 %	0.51 %
360	7.118E-03	0.16 %	0.33 %	0.43 %	0.57 %	7.083E-03	0.16 %	0.31 %	0.43 %	0.55 %
370	8.886E-03	0.15 %	0.32 %	0.46 %	0.58 %	8.847E-03	0.15 %	0.30 %	0.46 %	0.57 %
380	1.092E-02	0.15 %	0.31 %	0.52 %	0.63 %	1.088E-02	0.15 %	0.29 %	0.52 %	0.62 %
390	1.323E-02	0.15 %	0.31 %	0.50 %	0.60 %	1.318E-02	0.15 %	0.29 %	0.50 %	0.59 %
400	1.582E-02	0.15 %	0.30 %	0.46 %	0.57 %	1.577E-02	0.15 %	0.28 %	0.46 %	0.56 %
450	3.282E-02	0.15 %	0.27 %	0.10 %	0.32 %	3.277E-02	0.15 %	0.25 %	0.10 %	0.31 %
500	5.549E-02	0.14 %	0.24 %	0.01 %	0.28 %	5.547E-02	0.14 %	0.22 %	0.01 %	0.26 %
550	8.134E-02	0.12 %	0.22 %	0.00 %	0.25 %	8.138E-02	0.12 %	0.20 %	0.00 %	0.24 %
555	8.399E-02	0.12 %	0.22 %	0.00 %	0.25 %	8.404E-02	0.12 %	0.20 %	0.00 %	0.23 %
600	1.076E-01	0.11 %	0.20 %	0.00 %	0.23 %	1.077E-01	0.11 %	0.19 %	0.00 %	0.22 %
650	1.320E-01	0.11 %	0.18 %	0.00 %	0.21 %	1.322E-01	0.11 %	0.17 %	0.00 %	0.20 %
700	1.528E-01	0.11 %	0.17 %	0.00 %	0.20 %	1.530E-01	0.11 %	0.16 %	0.00 %	0.19 %
750	1.692E-01	0.10 %	0.16 %	0.01 %	0.19 %	1.695E-01	0.10 %	0.15 %	0.01 %	0.18 %
800	1.810E-01	0.09 %	0.15 %	0.00 %	0.18 %	1.813E-01	0.09 %	0.14 %	0.00 %	0.17 %
850	1.884E-01	0.09 %	0.14 %	0.00 %	0.17 %	1.886E-01	0.09 %	0.13 %	0.00 %	0.16 %
900	1.920E-01	0.08 %	0.13 %	0.00 %	0.16 %	1.920E-01	0.08 %	0.12 %	0.00 %	0.15 %
950	1.922E-01	0.08 %	0.13 %	0.01 %	0.15 %	1.921E-01	0.08 %	0.12 %	0.01 %	0.14 %
1000	1.898E-01	0.08 %	0.12 %	0.01 %	0.15 %	1.896E-01	0.08 %	0.11 %	0.01 %	0.14 %
1100	1.794E-01	0.09 %	0.11 %	0.01 %	0.14 %	1.790E-01	0.09 %	0.10 %	0.01 %	0.14 %
1200	1.646E-01	0.11 %	0.10 %	0.02 %	0.15 %	1.641E-01	0.11 %	0.09 %	0.02 %	0.15 %
1300	1.481E-01	0.13 %	0.09 %	0.00 %	0.16 %	1.476E-01	0.13 %	0.09 %	0.00 %	0.16 %
1400	1.316E-01	0.15 %	0.09 %	0.01 %	0.17 %	1.311E-01	0.15 %	0.08 %	0.01 %	0.17 %
1500	1.160E-01	0.14 %	0.08 %	0.01 %	0.17 %	1.155E-01	0.14 %	0.08 %	0.01 %	0.16 %
1600	1.018E-01	0.14 %	0.08 %	0.01 %	0.16 %	1.014E-01	0.14 %	0.07 %	0.01 %	0.16 %
1700	8.911E-02	0.19 %	0.07 %	0.01 %	0.20 %	8.881E-02	0.19 %	0.07 %	0.01 %	0.20 %
1800	7.789E-02	0.25 %	0.07 %	0.02 %	0.26 %	7.781E-02	0.25 %	0.07 %	0.02 %	0.26 %
1900	6.801E-02	0.31 %	0.07 %	0.02 %	0.32 %	6.821E-02	0.31 %	0.06 %	0.02 %	0.32 %
2000	5.938E-02	0.36 %	0.07 %	0.05 %	0.37 %	5.976E-02	0.36 %	0.06 %	0.05 %	0.37 %
2100	5.196E-02	0.35 %	0.06 %	0.02 %	0.36 %	5.230E-02	0.35 %	0.06 %	0.02 %	0.36 %
2200	4.566E-02	0.36 %	0.06 %	0.00 %	0.36 %	4.573E-02	0.36 %	0.06 %	0.00 %	0.36 %
2300	4.025E-02	0.40 %	0.06 %	0.01 %	0.40 %	4.009E-02	0.40 %	0.06 %	0.01 %	0.40 %
2400	3.544E-02	0.60 %	0.06 %	0.07 %	0.61 %	3.539E-02	0.60 %	0.05 %	0.07 %	0.61 %
2500	3.142E-02	0.51 %	0.06 %	0.05 %	0.52 %	3.143E-02	0.51 %	0.05 %	0.05 %	0.52 %

15.9 Lamp Behaviour

15.9.1 PTB Lamps

The following lamps were supplied to PTB by NPL:

FEL BN 9101 240 FEL BN 9101 227 FEL BN 9101 198

Measurements were made in the sequence: PTB – NPL – PTB – NPL. There was an initial measurement of the lamps at NPL prior to this sequence, however the decision was made to ignore those results in light of the improvements made subsequently to the facility and hence to the measurement accuracy at NPL.

PTB measured all intercomparison wavelengths.

15.9.2 Lamp history

Table 15-11 Lamp history for FEL BN 9101 240

Date period	Activity	Burn hours:minutes
August 2000	0th round measurements at NPL (not used)	7:13
September 2000	Hand-carried to PTB	
Nov. – Dec. 2000	1st round measurements at PTB	12:00
April 2001	Hand-carried to NPL	
Feb. – July 2002	1st round measurements at NPL	10:40
July 2002	Hand-carried to PTB	
Aug. – Sept. 2002	2nd round measurements at PTB	9:49
March 2003	Hand-carried to NPL	
June – Aug. 2003	2nd round measurements at NPL	14:47
October 2003	Hand-carried to PTB	

Table 15-12 Lamp history for FEL BN 9101 227

Date period	Activity	Burn hours:minutes
August 2000	0th round measurements at NPL (not used)	7:00
September 2000	Hand-carried to PTB	
Nov. – Dec. 2000	1st round measurements at PTB	8:24
April 2001	Hand-carried to NPL	
Feb. – July 2002	1st round measurements at NPL	7:26
July 2002	Hand-carried to PTB	
Aug. – Sept. 2002	2nd round measurements at PTB	10:38
March 2003	Hand-carried to NPL	
June – Aug. 2003	2nd round measurements at NPL	12:06
October 2003	Hand-carried to PTB	

Table 15-13 Lamp history for FEL BN 9101 198

Date period	Activity	Burn hours:minutes
August 2000	0th round measurements at NPL (not used)	6:53
September 2000	Hand-carried to PTB	
Nov. – Dec. 2000	1st round measurements at PTB	15:48
April 2001	Hand-carried to NPL	
Feb. – July 2002	1st round measurements at NPL	10:40
July 2002	Hand-carried to PTB	
Aug. – Sept. 2002	2nd round measurements at PTB	10:35
March 2003	Hand-carried to NPL	
June – Aug. 2003	2nd round measurements at NPL	14:58
October 2003	Hand-carried to PTB	

15.9.3 Lamp electrical stability

The lamp was operated at 8.100 A at both laboratories, the lamp voltage measured was:

Table 15-14 Electrical Potential across lamp as measured by both laboratories

Lamp	Potential first PTB measurement	Potential first NPL measurement	Potential second PTB measurement	Potential second NPL measurement
FEL BN 9101 240	110.75 V	110.8 V	110.85 V	110.9 V
FEL BN 9101 227	104.43 V	104.5 V	104.43 V	104.5 V
FEL BN 9101 198	100.7 – 102.2 V	100.8 – 101.7 V	100.7 – 102.1 V	100.8 V

15.9.4 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the PTB lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

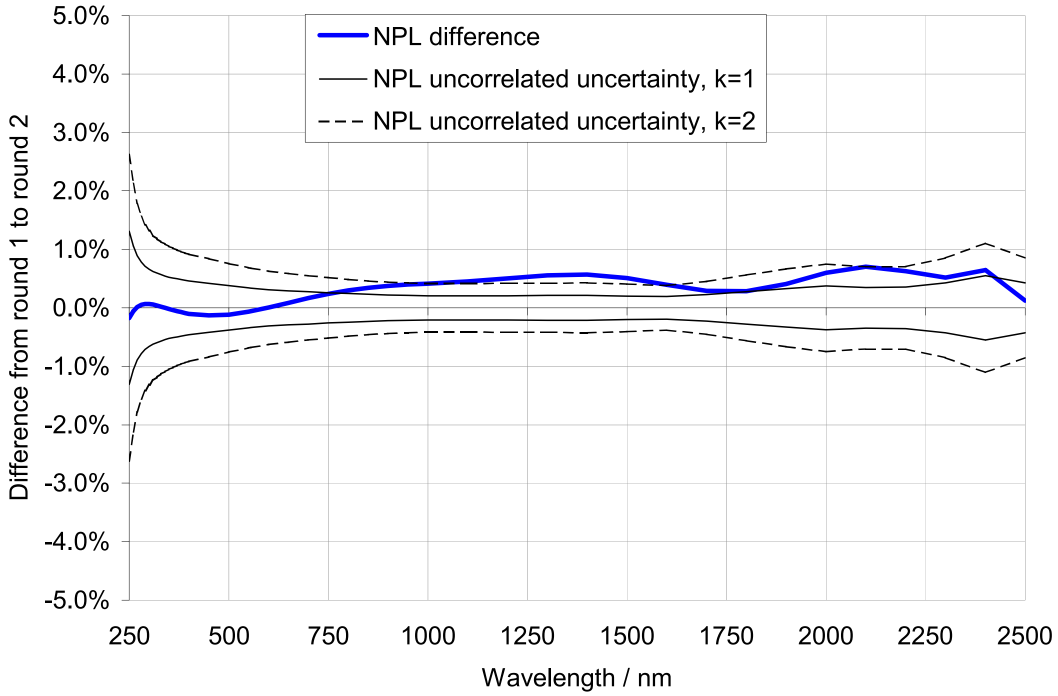


Figure 15-2 Difference between first and second round measurements of FEL BN 9101 240 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

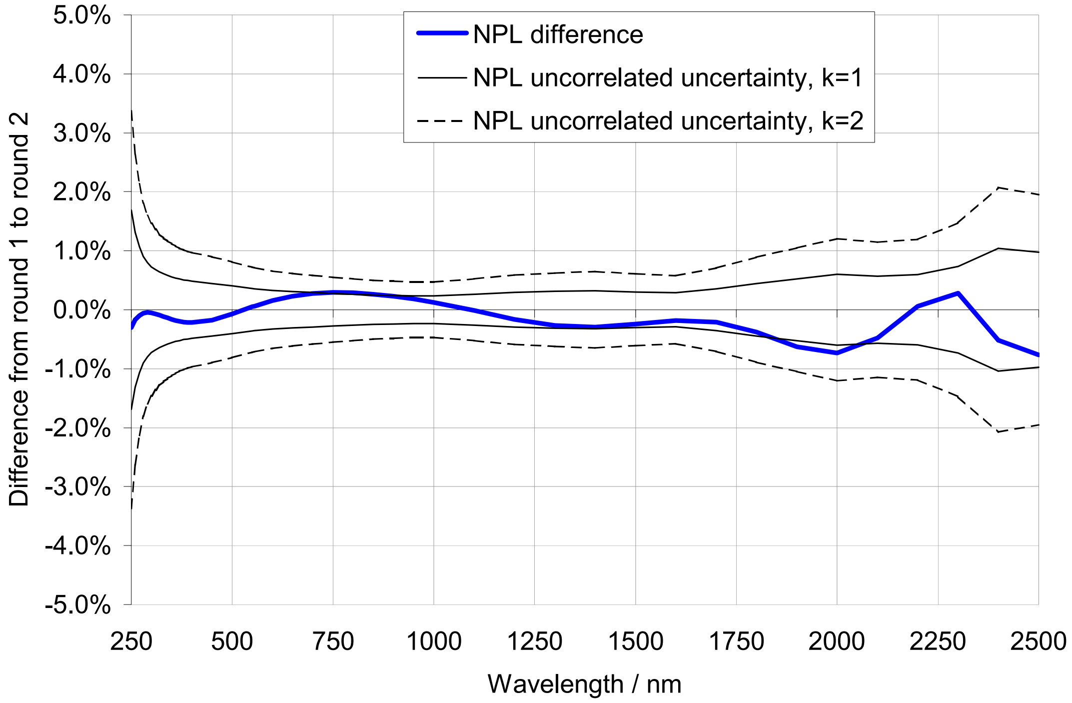


Figure 15-3 Difference between first and second round measurements of FEL BN 9101 227 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

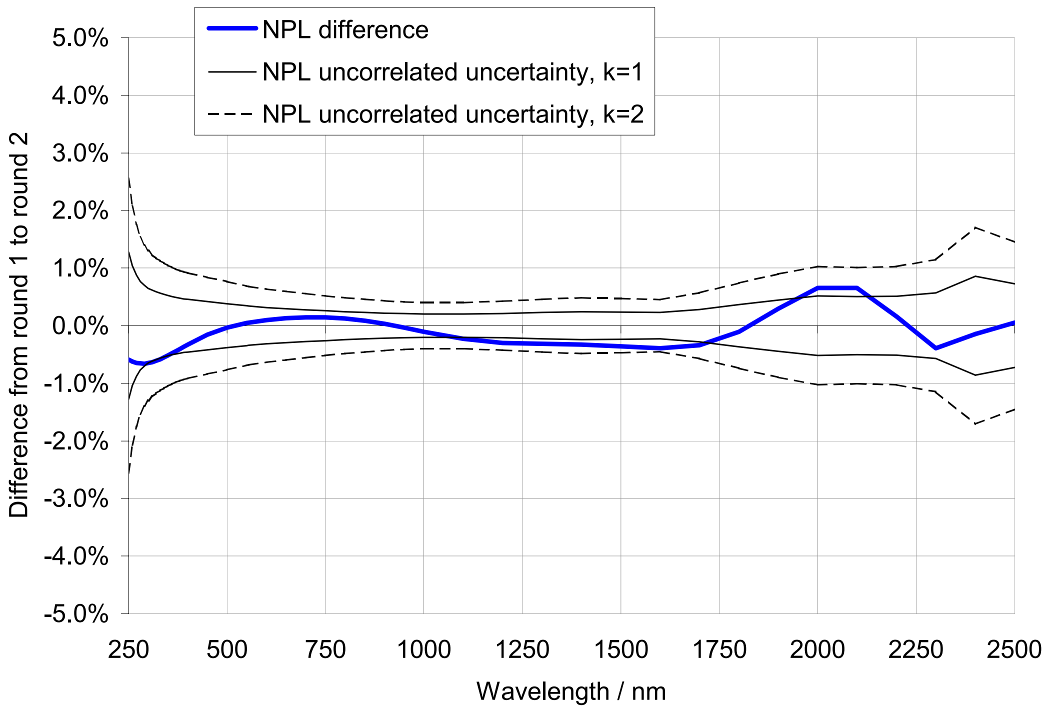


Figure 15-4 Difference between first and second round measurements of FEL BN 9101 198 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

15.9.5 Lamp stability from PTB measurements

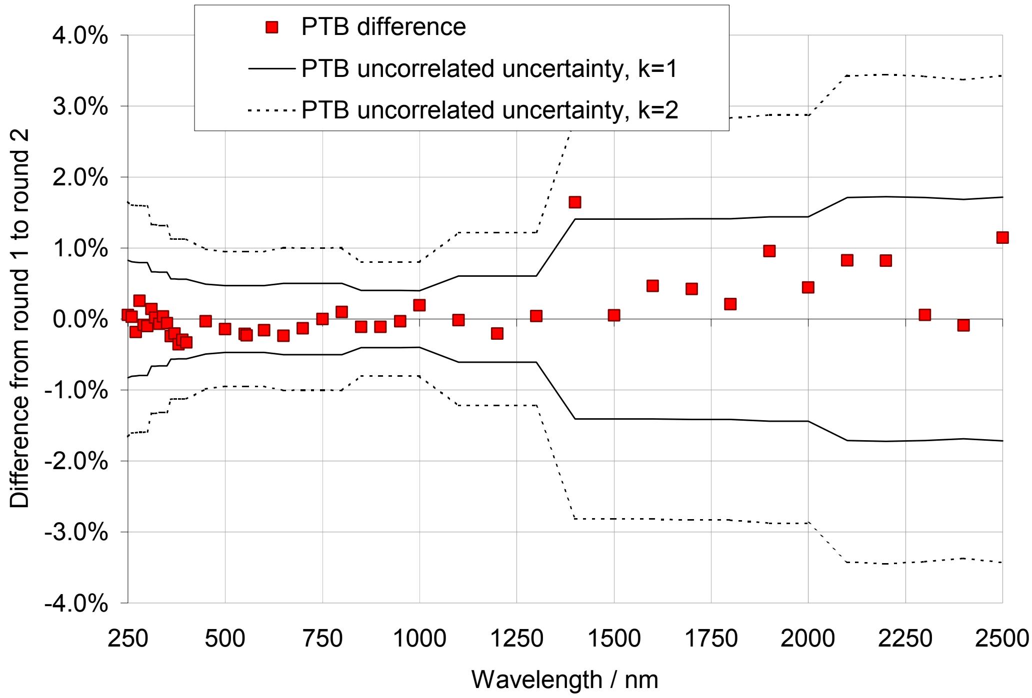


Figure 15-5 Difference between first and second round measurements of FEL BN 9101 240 by PTB. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the PTB measurements

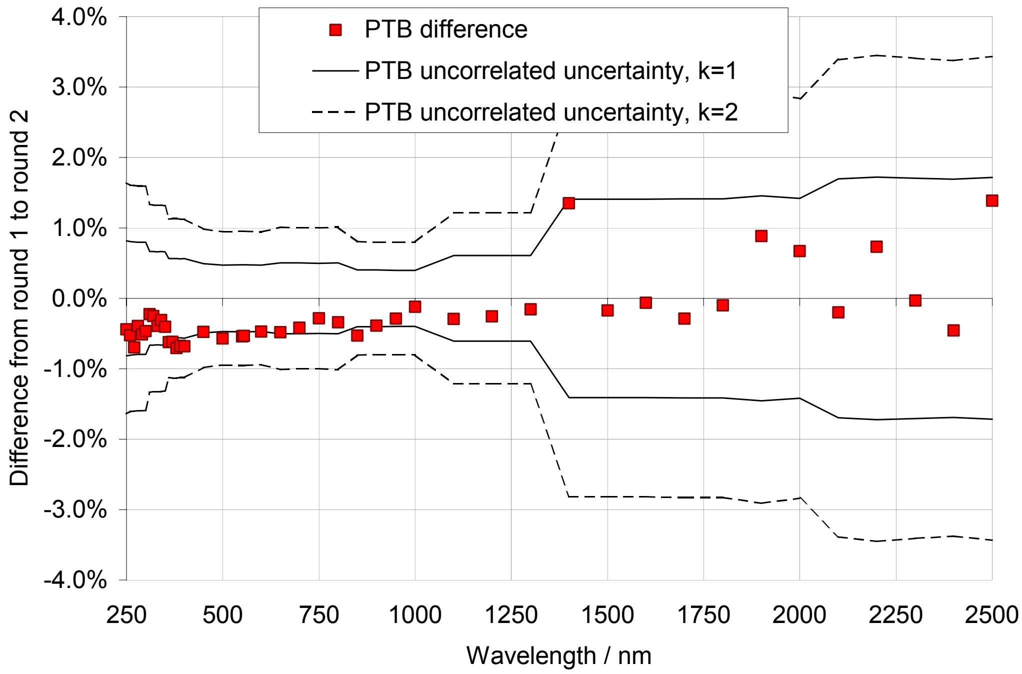


Figure 15-6 Difference between first and second round measurements of FEL BN 9101 227 by PTB. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the PTB measurements

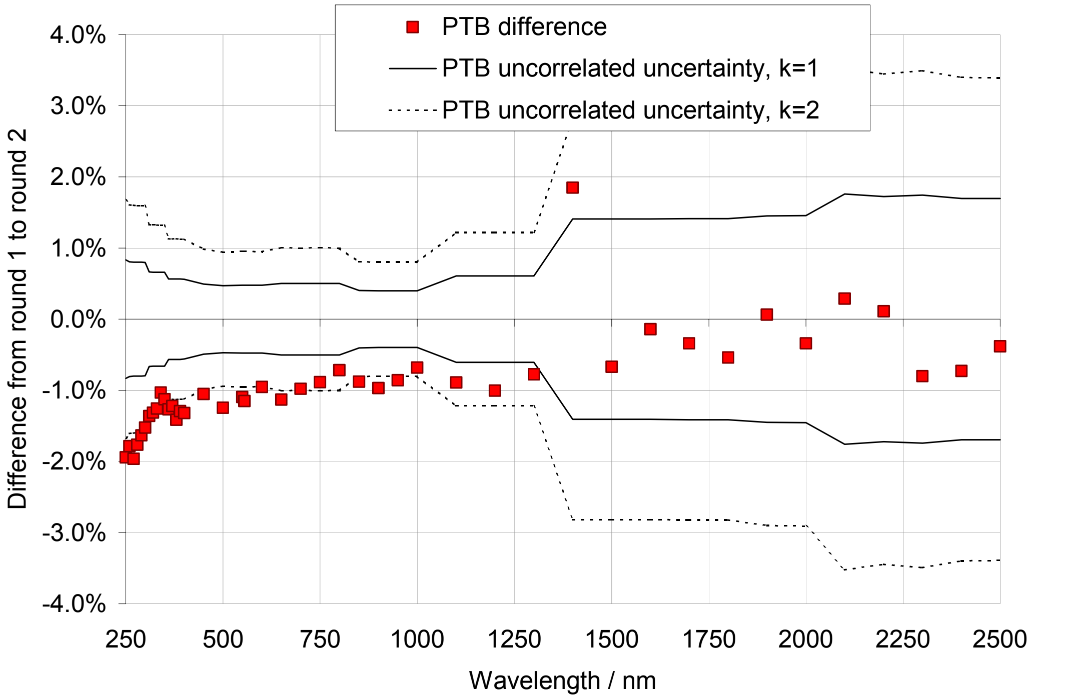


Figure 15-7 Difference between first and second round measurements of FEL BN 9101 198 by PTB. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the PTB measurements

15.10 Bilateral comparison between PTB and the comparison scale

This graph shows the difference between the PTB and NPL measurements of the PTB lamps. A version of this graph normalised to show the relative difference between the lamps, but not the absolute difference between the measurements was used to assist in choosing which lamp measurements to use.

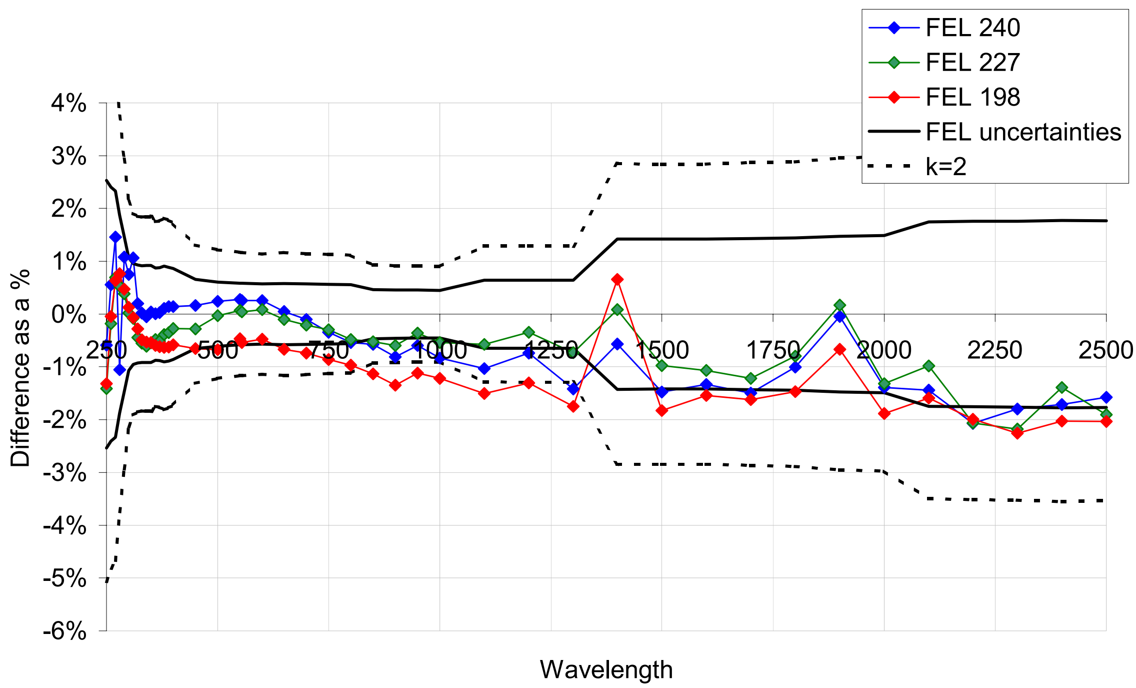


Figure 15-8 Bilateral comparisons of the PTB lamps to the comparison scale

15.11 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to PTB the information in the graphs Figure 15-2 to Figure 15-7. It was decided that both participant measurements and both pilot measurements would be used for both FEL BN 9101 240 and for FEL BN 9101 227, but that only the second PTB measurement would be used for FEL BN 9101 198. This lamp shows a difference between the rounds that is larger than PTB's uncertainties. Therefore, it is assumed that the lamp changed on the first journey from PTB to NPL.

15.12 References

[1] Metzdorf J., Metrologia, 1993, 30, 403-408.

[2] Sapritsky V. I., Khlevnoy B. B., Khromchenko V. B., Lisiansky B. E., Mekhontsev S. N., Melenevsky U. A., Morozova S. P., Prokhorov A. V., Samoilov L. N., Shapoval V. I., Sudarev K. A., Zelener M. F., *Appl. Opt.*, 1997, **36**, 5403-5408.

[3] Sperfeld P., Metzdorf J., Galal Yousef S., Stock K. D., Möller W., *Metrologia*, 1998, **35**, 267-271.

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[5] Sperfeld P., Entwicklung einer empfängergestützten spektralen Bestrahlungsstärkeskala, Braunschweig, 1999. http://www.biblio.tu-bs.de/ediss/data/19990628a/19990628a.html

[6] Khlevnoy B.B., Harrison N.J., Rogers L.J., Pollard D.F., Fox N.P., Sperfeld P., Fischer J., Friedrich R., Metzdorf J., Seidel J., Samoylov M.L., Stolyarevskaya R.I., Khromchenko V.B., Ogarev S.A., Sapritsky V.I., *Metrologia*, 2003, **40**, S39–S44

16 Measurements at VNIIOFI

16.1 Scale realisation

The Spectral Irradiance Scale was realised using a high-temperature blackbody (1 in Figure 16-1). The blackbody was a BB3200pg [1] type with a pyrolytic graphite radiator. The cylindrical cavity of the BB3200pg had a depth of 200 mm, a diameter of 38 mm and an opening diameter of 25 mm. The bottom of the cavity was a graphite v-grooved disc. The BB3200pg was a windowless blackbody: no glass plate covered the radiation output opening. The BB3200pg was continuously blown through with argon, which went out through the output opening. The effective emissivity was estimated to be approximately 0.999.

A feedback system was used to stabilise the blackbody temperature. The feedback optics (2 in the diagram) were placed just in front of the blackbody output. They consisted of a flat mirror, a lens, a glass filter and a Si photodiode. All elements were within a temperature-stabilised water jacket. Part of the radiation from the cavity bottom was reflected by the flat mirror and used for the feedback. The majority of the radiation from the cavity went through the large hole in the centre of that mirror without any changes in its spectrum.

In front of the feedback optics unit there was a precision aperture with diameter of approximately 8 mm. The temperature of the aperture holder was controlled by a water thermostat.

The temperature of the B3200pg was approximately 3050 K. The TSP-2 [2] pyrometer was used to accurately measure the BB3200pg temperature. The TSP-2 was based on a temperature-stabilised detector, which was a combination of a Si photodiode and an interference filter with a central wavelength of 650 nm and a bandpass of 20 nm. The relative responsivity of the TSP-2 was accurately measured. Originally, the TSP-2 was calibrated against a copper fixed-point blackbody and a set of temperature standard lamps. In October 2000, the TSP-2 took part in the international comparison of radiation temperature scales [3] and an experiment to determine the Re-C fixed-point temperature [4]. Just before the spectral irradiance comparison, the calibration of the TSP-2 was checked against a Re-C fixed-point blackbody.

16.2 Description of the measurement facility

The spectral irradiance measurement facility used for this comparison is shown schematically in Figure 16-1.

The facility consists of the following elements:

1) High-temperature blackbody of type BB3200pg
2) Feedback optics for blackbody temperature stabilisation system
3) Precision aperture
4) Lamp being measured
5) Rotating table for the lamps
6) Integrating sphere
7) System of flat mirrors
8) Focusing mirror
9) Double grating monochromator
10) Set of order-sorting filters for the monochromator
11) Chopper for the monochromator
12) Set of replaceable detectors (photomultiplier, Si or InGaAs);
13) PbS photoresistor
14) Pyrometer for blackbody temperature measurements
15) Set of alignment lasers
16) Translation stage
17) Shutter.

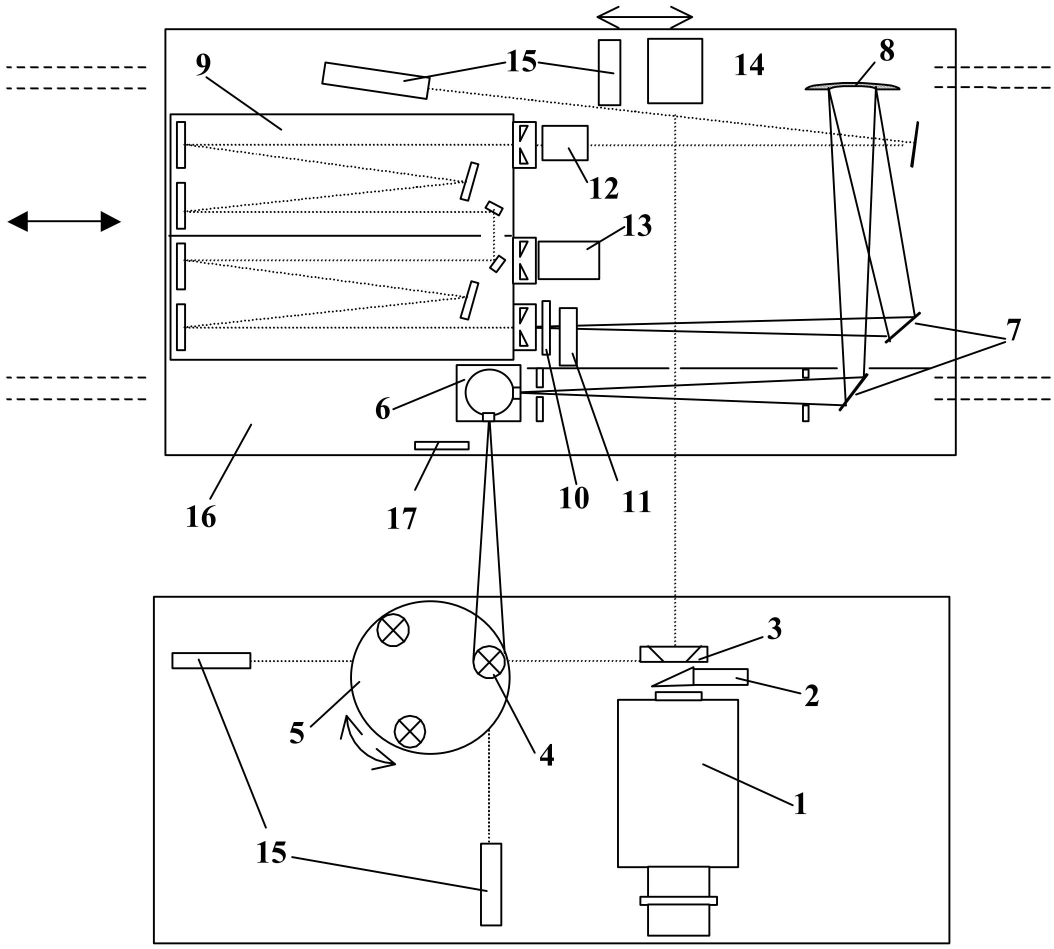

Figure 16-1 Spectral Irradiance Facility (Number labels on diagram correspond to numbers in the text above)

16.3 Laboratory conditions

Throughout the calibration of the comparison lamps the laboratory temperature was controlled and at 22 ± 1 ºC. The humidity was not controlled.

16.4 Laboratory standards

The lamps that took part in the comparison were measured by direct comparison with the BB3200pg. Therefore there were no transfer standards for the comparison lamp measurements.

16.5 Measurement procedure

The measurement lamp position was next to the blackbody, about 300 mm from it. Lamps were set up on the rotating table 5 (Figure 16-1). This allowed three lamps to be aligned in advance, but only one lamp was turned on and measured at any time.

All elements of the comparator were set up on the translation stage opposite the source table with the blackbody and lamps. Therefore, the comparator could be moved along the source table as a whole. The translation of the stage was 500 mm, thus only two sources could be measured (one lamp and the blackbody). There were two working positions of the stage: the first where the integrating sphere was opposite the BB3200pg and the second where it was opposite the lamp.

The integrating sphere had an internal diameter of 40 mm, a circular entrance hole of 10 mm diameter and an exit slit with the dimensions 4×15 mm. The exit slit of the sphere was refocused onto the entrance slit of the monochromator by the mirror pair (7 and 8 in Figure 16-1).

The monochromator was a JOBIN YVON HRD1 double grating type. Three pairs of gratings (1200, 600 and 300 grooves/mm) were used to cover the entire spectral range from 250 to 2500 nm. The gratings were changed manually.

Four detectors were used: a multialkali PMT, a Si photodiode, an InGaAs photodiode and a PbS photoresistor. The PMT, Si and InGaAs detectors were alternatively mounted in front of the main exit slit of the monochromator (position 12 in the diagram), and were changed manually. The PbS, which was used for the range from 1700 to 2500 nm, was mounted on the additional exit slit. For this detector, the monochromator was operated as a single monochromator.

The wavelength setting, stage positioning and detector signal readings were made automatically within several spectral ranges.

The measurement procedure was as follows:

- wavelength set
- stage moved to the lamp position
- detector signal read
- shutter closed, dark signal read
- stage moved to the BB
- dark signal read
- shutter opened, BB signal read
- ratio LAMP/BB calculated
- signals and ratio saved to the file

After this, the measurements were repeated so that four ratios were measured for each wavelength with necessary stage movements. Following that, the new wavelength was set and the measurement cycle repeated.

The temperature of the blackbody was measured twice for each individual cycle of measurements: just before and immediately after each cycle.

The spectral irradiance of the lamp was calculated as follows:

$$E_{\text{lamp}}(\lambda) = R(\lambda) \cdot E_{\text{BB}}(\lambda, T) \qquad (16\text{-}1)$$

where $R(\lambda)$ is the LAMP/BB signal ratio taking account of the dark readings.

16.6 Uncertainty determination

16.6.1 Primary scale uncertainties

The uncertainty of the TSP-2 during the spectral irradiance comparison was estimated to be 0.8 K (see Table 16-1).

Table 16-1. Uncertainty budget of the temperature measurement

Uncertainty sources for the temperature measurement of a blackbody at 3050 K (k = 1) / K	
Cu blackbody realisation	0.2
Relative Spectral responsivity	0.55
Size-of-source effect	0.3
Non-linearity and gain ratio	0.1
Stability	0.4
Alignment and focusing repeatability	0.15
Ambient temperature	0.1

The Spectral Irradiance realised by the blackbody was calculated as:

$$E_{\mathrm{BB}}(\lambda,T)=\frac{A}{d^2}\cdot\varepsilon_{\mathrm{eff}}\cdot\frac{c_1}{\pi\lambda^5 n^2}\cdot\frac{1}{\exp\left(\frac{c_2}{\lambda T n}\right)-1} \qquad (16\text{-}2)$$

where

$c_1 = 3.74177\cdot10^{-16}$ W m^2

$c_2 = 1.4388\cdot10^{-2}$ K m

λ - wavelength in vacuum

T – temperature of the blackbody

n = 1.000284 – air refractive index

$\varepsilon_{\mathrm{eff}}$ – effective emissivity of the blackbody

A – Area of the precision blackbody aperture

d = 500 mm – distance from the blackbody aperture to the sphere entrance aperture. The distance was set up equal to 500 mm using a standard 500 mm rod.

The uncertainty of the spectral irradiance realisation is shown in Table 16-2.

Table 16-2 Uncertainty budget of the primary scale spectral irradiance realisation

Wavelength / nm	Uncertainty (k = 1) / %									
	n	c_1	c_2	ε_{eff}	T 0.8 K	Blackbody Uniformity 0.03 K	Blackbody Stability 0.25 K	Aperture Area	Distance	Combined standard uncertainty
250	0.05	0.01	0.10	0.10	0.51	0.19	0.16	0.02	0.06	0.59
260	0.05	0.01	0.09	0.10	0.49	0.18	0.15	0.02	0.06	0.57
270	0.05	0.01	0.09	0.10	0.47	0.18	0.15	0.02	0.06	0.55
280	0.05	0.01	0.09	0.10	0.46	0.17	0.14	0.02	0.06	0.53
290	0.04	0.01	0.08	0.10	0.44	0.17	0.14	0.02	0.06	0.51
300	0.04	0.01	0.08	0.10	0.43	0.16	0.13	0.02	0.06	0.50
325	0.04	0.01	0.07	0.10	0.40	0.15	0.12	0.02	0.06	0.47
350	0.04	0.01	0.07	0.10	0.37	0.14	0.11	0.02	0.06	0.43
400	0.03	0.01	0.06	0.05	0.32	0.12	0.10	0.02	0.06	0.37
450	0.03	0.01	0.05	0.05	0.28	0.11	0.09	0.02	0.06	0.33
500	0.02	0.01	0.05	0.05	0.26	0.10	0.08	0.02	0.06	0.30
550	0.02	0.01	0.04	0.05	0.23	0.09	0.07	0.02	0.06	0.28
600	0.02	0.01	0.04	0.05	0.21	0.08	0.07	0.02	0.06	0.25
650	0.02	0.01	0.04	0.05	0.20	0.07	0.06	0.02	0.06	0.24
700	0.02	0.01	0.03	0.05	0.18	0.07	0.06	0.02	0.06	0.22
800	0.01	0.01	0.03	0.05	0.16	0.06	0.05	0.02	0.06	0.20
900	0.01	0.01	0.03	0.05	0.14	0.05	0.04	0.02	0.06	0.18
1000	0.01	0.01	0.02	0.05	0.13	0.05	0.04	0.02	0.06	0.17
1050	0.01	0.01	0.02	0.05	0.13	0.05	0.04	0.02	0.06	0.17
1200	0.01	0.01	0.02	0.05	0.11	0.04	0.03	0.02	0.06	0.15
1300	0.01	0.01	0.02	0.05	0.10	0.04	0.03	0.02	0.06	0.14
1400	0.01	0.01	0.02	0.05	0.09	0.04	0.03	0.02	0.06	0.13
1550	0.00	0.01	0.02	0.05	0.09	0.03	0.03	0.02	0.06	0.13
1700	0.00	0.01	0.02	0.05	0.08	0.03	0.02	0.02	0.06	0.12
1900	0.00	0.01	0.01	0.05	0.07	0.03	0.02	0.02	0.06	0.12
2100	0.00	0.01	0.01	0.05	0.07	0.03	0.02	0.02	0.06	0.11
2300	0.00	0.01	0.01	0.05	0.06	0.02	0.02	0.02	0.06	0.11
2500	0.00	0.01	0.01	0.05	0.06	0.02	0.02	0.02	0.06	0.11

16.6.2 Calibration uncertainties

The typical uncertainties of the lamp measurements are shown in Table 16-3. This combines the uncertainty of the primary scale as realised on the blackbody (Table 16-2) and the uncertainty due to the transfer to lamps. Table 16-3 lists the spectral points that were directly measured. Other points were interpolated. For interpolated points there was additional uncertainty (Type B) of 0.05 %.

The Type A uncertainty combines both the standard deviation of the measurements during one calibration cycle (without turning the lamp off – system repeatability) and a larger component due to the standard deviation of multiple measurements of the lamp (lamp repeatability).

Table 16-3. Uncertainty budget for spectral irradiance lamp measurement. "Scale" corresponds to the information in Table 16-2

Wavelength / nm	Uncertainty in Spectral Irradiance / %						
	Type A	Type B					Combined standard uncertainty
	Standard deviation of measurements	Scale	Distance	Lamp current	Wavelength	Alignment	
250	1.03	0.59	0.06	0.12	0.03	0.10	1.20
260	0.80	0.57	0.06	0.11	0.03	0.10	1.00
270	0.74	0.55	0.06	0.11	0.03	0.10	0.93
280	0.56	0.53	0.06	0.10	0.03	0.10	0.79
290	0.42	0.51	0.06	0.10	0.02	0.10	0.68
300	0.44	0.50	0.06	0.10	0.02	0.10	0.68
325	0.28	0.46	0.06	0.09	0.02	0.10	0.55
350	0.25	0.43	0.06	0.08	0.02	0.10	0.52
400	0.28	0.37	0.06	0.07	0.02	0.10	0.49
450	0.17	0.33	0.06	0.06	0.02	0.10	0.40
500	0.12	0.30	0.06	0.06	0.01	0.10	0.35
550	0.15	0.28	0.06	0.05	0.01	0.10	0.34
600	0.13	0.25	0.06	0.05	0.01	0.10	0.31
656.3	0.13	0.24	0.06	0.04	0.01	0.10	0.30
700	0.09	0.22	0.06	0.04	0.02	0.10	0.27
800	0.11	0.20	0.06	0.04	0.02	0.10	0.26
900	0.14	0.18	0.06	0.03	0.01	0.10	0.26
1000	0.21	0.17	0.06	0.03	0.01	0.10	0.29
1050	0.22	0.16	0.06	0.03	0.01	0.10	0.30
1200	0.27	0.15	0.06	0.02	0.01	0.10	0.33
1300	0.24	0.14	0.06	0.02	0.01	0.10	0.30
1400	0.23	0.13	0.06	0.02	0.01	0.10	0.29
1550	0.26	0.13	0.06	0.02	0.01	0.10	0.32
1700	0.42	0.12	0.06	0.02	0.01	0.10	0.45
1900	0.47	0.12	0.06	0.02	0.01	0.10	0.50
2100	0.50	0.11	0.06	0.01	0.01	0.10	0.53
2300	0.62	0.11	0.06	0.01	0.01	0.10	0.64
2500	0.96	0.11	0.06	0.01	0.01	0.10	0.97

16.6.3 Correlation

VNIIOFI only measured the lamps for the comparison in one round. Therefore the only types of correlation to be considered are effects that are entirely correlated for all lamps and effects that are entirely uncorrelated.

The scale realisation on the blackbody and the wavelength accuracy of the monochromator are entirely correlated for all lamps. The lamp distance, current and alignment and the measurement repeatability are uncorrelated.

16.7 VNIIOFI Results

VNIIOFI measured two lamps. The results for FEL BN 9101 217 are given in Table 16-4 and the results for FEL BN 9101 195 are given in Table 16-5.

Table 16-4 VNIIOFI Results for FEL BN 9101 217. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1

FEL 217	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.304E-04	1.05 %	0.59 %	0.00 %	1.21 %					
260	2.338E-04	0.53 %	0.57 %	0.00 %	0.78 %					
270	3.918E-04	0.36 %	0.55 %	0.00 %	0.66 %					
280	6.229E-04	0.36 %	0.55 %	0.00 %	0.66 %					
290	9.497E-04	0.32 %	0.51 %	0.00 %	0.60 %					
300	1.394E-03	0.24 %	0.50 %	0.00 %	0.55 %					
310	1.974E-03	0.24 %	0.50 %	0.00 %	0.56 %					
320	2.731E-03	0.24 %	0.50 %	0.00 %	0.56 %					
330	3.683E-03	0.20 %	0.46 %	0.00 %	0.51 %					
340	4.852E-03	0.20 %	0.46 %	0.00 %	0.51 %					
350	6.264E-03	0.19 %	0.43 %	0.00 %	0.47 %					
360	7.941E-03	0.19 %	0.43 %	0.00 %	0.47 %					
370	9.895E-03	0.19 %	0.43 %	0.00 %	0.47 %					
380	1.213E-02	0.19 %	0.43 %	0.00 %	0.47 %					
390	1.465E-02	0.19 %	0.43 %	0.00 %	0.47 %					
400	1.747E-02	0.17 %	0.37 %	0.00 %	0.41 %					
450	3.590E-02	0.20 %	0.33 %	0.00 %	0.39 %					
500	6.042E-02	0.28 %	0.30 %	0.00 %	0.41 %					
550	8.808E-02	0.28 %	0.28 %	0.00 %	0.40 %					
555	9.092E-02	0.28 %	0.28 %	0.00 %	0.40 %					
600	1.161E-01	0.26 %	0.25 %	0.00 %	0.36 %					
650	1.415E-01	0.26 %	0.26 %	0.00 %	0.37 %					
700	1.631E-01	0.28 %	0.22 %	0.00 %	0.36 %					
750	1.799E-01	0.28 %	0.23 %	0.00 %	0.36 %					
800	1.917E-01	0.27 %	0.20 %	0.00 %	0.34 %					
850	1.988E-01	0.27 %	0.21 %	0.00 %	0.34 %					
900	2.018E-01	0.28 %	0.18 %	0.00 %	0.33 %					
950	2.017E-01	0.32 %	0.18 %	0.00 %	0.37 %					
1000	1.990E-01	0.32 %	0.17 %	0.00 %	0.37 %					
1100	1.879E-01	0.35 %	0.16 %	0.00 %	0.38 %					
1200	1.727E-01	0.35 %	0.15 %	0.00 %	0.38 %					
1300	1.545E-01	0.32 %	0.14 %	0.00 %	0.35 %					
1400	1.370E-01	0.31 %	0.13 %	0.00 %	0.34 %					
1500	1.203E-01	0.33 %	0.14 %	0.00 %	0.36 %					
1600	1.052E-01	0.54 %	0.13 %	0.00 %	0.56 %					
1700	9.220E-02	0.54 %	0.12 %	0.00 %	0.56 %					
1800	8.050E-02	0.55 %	0.13 %	0.00 %	0.57 %					
1900	7.016E-02	0.55 %	0.12 %	0.00 %	0.57 %					
2000	6.132E-02	0.57 %	0.12 %	0.00 %	0.58 %					
2100	5.373E-02	0.57 %	0.11 %	0.00 %	0.58 %					
2200	4.708E-02	0.60 %	0.12 %	0.00 %	0.61 %					
2300	4.127E-02	0.60 %	0.11 %	0.00 %	0.61 %					
2400	3.628E-02	0.97 %	0.12 %	0.00 %	0.97 %					
2500	3.200E-02	0.97 %	0.11 %	0.00 %	0.97 %					

Table 16-5 VNIIOFI Results for FEL BN 9101 195. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1

FEL 195	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.444E-04	1.04 %	0.59 %	0.00 %	1.20 %					
260	2.637E-04	0.82 %	0.57 %	0.00 %	1.00 %					
270	4.403E-04	0.76 %	0.55 %	0.00 %	0.94 %					
280	6.917E-04	0.58 %	0.53 %	0.00 %	0.79 %					
290	1.046E-03	0.45 %	0.51 %	0.00 %	0.68 %					
300	1.521E-03	0.47 %	0.50 %	0.00 %	0.68 %					
310	2.146E-03	0.47 %	0.50 %	0.00 %	0.69 %					
320	2.950E-03	0.47 %	0.50 %	0.00 %	0.69 %					
330	3.961E-03	0.32 %	0.46 %	0.00 %	0.56 %					
340	5.201E-03	0.32 %	0.46 %	0.00 %	0.56 %					
350	6.690E-03	0.29 %	0.43 %	0.00 %	0.52 %					
360	8.445E-03	0.29 %	0.43 %	0.00 %	0.52 %					
370	1.048E-02	0.29 %	0.43 %	0.00 %	0.52 %					
380	1.279E-02	0.29 %	0.43 %	0.00 %	0.52 %					
390	1.539E-02	0.29 %	0.43 %	0.00 %	0.52 %					
400	1.829E-02	0.31 %	0.37 %	0.00 %	0.48 %					
450	3.709E-02	0.21 %	0.33 %	0.00 %	0.39 %					
500	6.167E-02	0.18 %	0.30 %	0.00 %	0.35 %					
550	8.914E-02	0.20 %	0.28 %	0.00 %	0.34 %					
555	9.193E-02	0.20 %	0.28 %	0.00 %	0.35 %					
600	1.166E-01	0.18 %	0.25 %	0.00 %	0.31 %					
650	1.415E-01	0.18 %	0.26 %	0.00 %	0.31 %					
700	1.624E-01	0.15 %	0.22 %	0.00 %	0.27 %					
750	1.785E-01	0.15 %	0.23 %	0.00 %	0.27 %					
800	1.897E-01	0.17 %	0.20 %	0.00 %	0.26 %					
850	1.963E-01	0.17 %	0.21 %	0.00 %	0.26 %					
900	1.988E-01	0.18 %	0.18 %	0.00 %	0.26 %					
950	1.981E-01	0.24 %	0.18 %	0.00 %	0.30 %					
1000	1.950E-01	0.24 %	0.17 %	0.00 %	0.30 %					
1100	1.835E-01	0.29 %	0.16 %	0.00 %	0.33 %					
1200	1.678E-01	0.29 %	0.15 %	0.00 %	0.33 %					
1300	1.504E-01	0.27 %	0.14 %	0.00 %	0.30 %					
1400	1.330E-01	0.26 %	0.13 %	0.00 %	0.29 %					
1500	1.166E-01	0.29 %	0.14 %	0.00 %	0.32 %					
1600	1.018E-01	0.44 %	0.13 %	0.00 %	0.46 %					
1700	8.892E-02	0.44 %	0.12 %	0.00 %	0.45 %					
1800	7.760E-02	0.48 %	0.13 %	0.00 %	0.50 %					
1900	6.772E-02	0.48 %	0.12 %	0.00 %	0.50 %					
2000	5.910E-02	0.51 %	0.12 %	0.00 %	0.53 %					
2100	5.160E-02	0.51 %	0.11 %	0.00 %	0.53 %					
2200	4.505E-02	0.63 %	0.12 %	0.00 %	0.64 %					
2300	3.943E-02	0.63 %	0.11 %	0.00 %	0.64 %					
2400	3.470E-02	0.97 %	0.12 %	0.00 %	0.97 %					
2500	3.084E-02	0.97 %	0.11 %	0.00 %	0.97 %					

16.8 Pilot Results

NPL's results for FEL BN 9101 217 are given in Table 16-6 and the results for FEL BN 9101 195 are given in Table 16-7.

Table 16-6 NPL Results for FEL BN 9101 217. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1

FEL 217	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.331E-04	0.81 %	0.32 %	2.06 %	2.23 %	1.306E-04	0.35 %	0.00 %	2.06 %	2.09 %
260	2.340E-04	0.55 %	0.32 %	2.05 %	2.15 %	2.297E-04	0.27 %	0.00 %	2.05 %	2.07 %
270	3.901E-04	0.40 %	0.31 %	2.05 %	2.11 %	3.831E-04	0.23 %	0.00 %	2.05 %	2.06 %
280	6.207E-04	0.32 %	0.29 %	1.56 %	1.62 %	6.099E-04	0.20 %	0.00 %	1.56 %	1.57 %
290	9.477E-04	0.27 %	0.27 %	1.08 %	1.15 %	9.318E-04	0.19 %	0.00 %	1.08 %	1.10 %
300	1.395E-03	0.24 %	0.33 %	0.45 %	0.61 %	1.373E-03	0.18 %	0.15 %	0.45 %	0.50 %
310	1.988E-03	0.22 %	0.38 %	0.43 %	0.62 %	1.957E-03	0.17 %	0.20 %	0.43 %	0.51 %
320	2.753E-03	0.20 %	0.43 %	0.37 %	0.60 %	2.712E-03	0.16 %	0.25 %	0.37 %	0.48 %
330	3.715E-03	0.18 %	0.47 %	0.36 %	0.62 %	3.661E-03	0.16 %	0.28 %	0.36 %	0.48 %
340	4.896E-03	0.11 %	0.53 %	0.35 %	0.65 %	4.827E-03	0.15 %	0.33 %	0.35 %	0.51 %
350	6.319E-03	0.17 %	0.58 %	0.34 %	0.69 %	6.233E-03	0.15 %	0.36 %	0.34 %	0.52 %
360	8.003E-03	0.16 %	0.67 %	0.33 %	0.77 %	7.897E-03	0.14 %	0.43 %	0.33 %	0.56 %
370	9.961E-03	0.16 %	0.72 %	0.32 %	0.80 %	9.833E-03	0.14 %	0.46 %	0.32 %	0.58 %
380	1.221E-02	0.15 %	0.81 %	0.31 %	0.88 %	1.205E-02	0.13 %	0.52 %	0.31 %	0.62 %
390	1.475E-02	0.15 %	0.78 %	0.31 %	0.85 %	1.456E-02	0.13 %	0.50 %	0.31 %	0.60 %
400	1.758E-02	0.15 %	0.72 %	0.30 %	0.80 %	1.737E-02	0.13 %	0.46 %	0.30 %	0.56 %
450	3.606E-02	0.14 %	0.31 %	0.27 %	0.43 %	3.566E-02	0.12 %	0.10 %	0.27 %	0.31 %
500	6.045E-02	0.13 %	0.31 %	0.24 %	0.42 %	5.982E-02	0.11 %	0.00 %	0.24 %	0.26 %
550	8.807E-02	0.12 %	0.33 %	0.22 %	0.42 %	8.721E-02	0.09 %	0.00 %	0.22 %	0.24 %
555	9.089E-02	0.12 %	0.33 %	0.22 %	0.42 %	9.001E-02	0.09 %	0.00 %	0.22 %	0.23 %
600	1.159E-01	0.12 %	0.33 %	0.20 %	0.40 %	1.149E-01	0.09 %	0.00 %	0.20 %	0.22 %
650	1.415E-01	0.04 %	0.32 %	0.18 %	0.37 %	1.404E-01	0.08 %	0.00 %	0.18 %	0.20 %
700	1.631E-01	0.13 %	0.31 %	0.17 %	0.38 %	1.620E-01	0.08 %	0.00 %	0.17 %	0.19 %
750	1.798E-01	0.12 %	0.30 %	0.16 %	0.36 %	1.788E-01	0.08 %	0.00 %	0.16 %	0.18 %
800	1.916E-01	0.10 %	0.29 %	0.15 %	0.34 %	1.905E-01	0.07 %	0.00 %	0.15 %	0.17 %
850	1.988E-01	0.10 %	0.28 %	0.14 %	0.32 %	1.976E-01	0.07 %	0.00 %	0.14 %	0.16 %
900	2.018E-01	0.09 %	0.26 %	0.13 %	0.31 %	2.007E-01	0.07 %	0.00 %	0.13 %	0.15 %
950	2.015E-01	0.09 %	0.25 %	0.13 %	0.30 %	2.004E-01	0.07 %	0.00 %	0.13 %	0.14 %
1000	1.985E-01	0.08 %	0.25 %	0.12 %	0.29 %	1.974E-01	0.07 %	0.00 %	0.12 %	0.14 %
1100	1.867E-01	0.08 %	0.25 %	0.11 %	0.29 %	1.860E-01	0.07 %	0.00 %	0.11 %	0.13 %
1200	1.706E-01	0.08 %	0.28 %	0.10 %	0.31 %	1.703E-01	0.08 %	0.00 %	0.10 %	0.13 %
1300	1.531E-01	0.08 %	0.32 %	0.09 %	0.35 %	1.528E-01	0.08 %	0.00 %	0.09 %	0.12 %
1400	1.358E-01	0.08 %	0.33 %	0.09 %	0.35 %	1.353E-01	0.08 %	0.00 %	0.09 %	0.12 %
1500	1.195E-01	0.08 %	0.30 %	0.08 %	0.32 %	1.191E-01	0.08 %	0.00 %	0.08 %	0.12 %
1600	1.047E-01	0.08 %	0.26 %	0.08 %	0.28 %	1.045E-01	0.08 %	0.00 %	0.08 %	0.11 %
1700	9.136E-02	0.09 %	0.23 %	0.08 %	0.26 %	9.160E-02	0.10 %	0.00 %	0.08 %	0.12 %
1800	7.971E-02	0.23 %	0.21 %	0.08 %	0.32 %	8.020E-02	0.12 %	0.00 %	0.08 %	0.14 %
1900	6.968E-02	0.40 %	0.23 %	0.07 %	0.47 %	7.001E-02	0.14 %	0.00 %	0.07 %	0.16 %
2000	6.105E-02	0.47 %	0.29 %	0.08 %	0.56 %	6.097E-02	0.17 %	0.00 %	0.08 %	0.19 %
2100	5.357E-02	0.57 %	0.38 %	0.07 %	0.69 %	5.320E-02	0.17 %	0.00 %	0.07 %	0.18 %
2200	4.710E-02	0.67 %	0.45 %	0.06 %	0.81 %	4.673E-02	0.17 %	0.00 %	0.06 %	0.18 %
2300	4.149E-02	0.95 %	0.45 %	0.06 %	1.05 %	4.131E-02	0.19 %	0.00 %	0.06 %	0.20 %
2400	3.623E-02	1.14 %	0.76 %	0.09 %	1.37 %	3.640E-02	0.28 %	0.00 %	0.09 %	0.29 %
2500	3.207E-02	1.14 %	1.46 %	0.08 %	1.86 %	3.213E-02	0.24 %	0.00 %	0.08 %	0.25 %

Table 16-7 NPL Results for FEL BN 9101 195. Uncertainties have been split according to correlation between lamps and between rounds and are at k = 1

FEL 195	First round data					Second round data				
Wavelength /nm	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty	Irradiance /W m^{-2} nm^{-1}	Uncorrelated	Correlated within the round	Entirely correlated	Combined standard uncertainty
250	1.508E-04	5.52 %	0.32 %	2.06 %	5.90 %	1.466E-04	2.92 %	0.00 %	2.06 %	3.58 %
260	2.623E-04	3.68 %	0.32 %	2.05 %	4.23 %	2.562E-04	1.88 %	0.00 %	2.05 %	2.79 %
270	4.331E-04	2.59 %	0.31 %	2.05 %	3.31 %	4.244E-04	1.39 %	0.00 %	2.05 %	2.47 %
280	6.833E-04	1.96 %	0.29 %	1.56 %	2.52 %	6.711E-04	1.18 %	0.00 %	1.56 %	1.95 %
290	1.036E-03	1.60 %	0.27 %	1.08 %	1.95 %	1.019E-03	1.06 %	0.00 %	1.08 %	1.52 %
300	1.514E-03	1.36 %	0.33 %	0.45 %	1.47 %	1.492E-03	0.96 %	0.15 %	0.45 %	1.07 %
310	2.146E-03	1.18 %	0.38 %	0.43 %	1.31 %	2.116E-03	0.84 %	0.20 %	0.43 %	0.97 %
320	2.955E-03	1.01 %	0.43 %	0.37 %	1.16 %	2.916E-03	0.72 %	0.25 %	0.37 %	0.85 %
330	3.967E-03	0.87 %	0.47 %	0.36 %	1.05 %	3.917E-03	0.61 %	0.28 %	0.36 %	0.76 %
340	5.206E-03	0.74 %	0.53 %	0.35 %	0.98 %	5.142E-03	0.52 %	0.33 %	0.35 %	0.71 %
350	6.691E-03	0.67 %	0.58 %	0.34 %	0.95 %	6.611E-03	0.46 %	0.36 %	0.34 %	0.68 %
360	8.442E-03	0.62 %	0.67 %	0.33 %	0.97 %	8.343E-03	0.43 %	0.43 %	0.33 %	0.69 %
370	1.047E-02	0.58 %	0.72 %	0.32 %	0.98 %	1.035E-02	0.42 %	0.46 %	0.32 %	0.70 %
380	1.279E-02	0.56 %	0.81 %	0.31 %	1.03 %	1.265E-02	0.43 %	0.52 %	0.31 %	0.74 %
390	1.540E-02	0.55 %	0.78 %	0.31 %	1.00 %	1.523E-02	0.44 %	0.50 %	0.31 %	0.73 %
400	1.831E-02	0.53 %	0.72 %	0.30 %	0.95 %	1.811E-02	0.46 %	0.46 %	0.30 %	0.71 %
450	3.713E-02	0.43 %	0.31 %	0.27 %	0.60 %	3.675E-02	0.47 %	0.10 %	0.27 %	0.55 %
500	6.167E-02	0.35 %	0.31 %	0.24 %	0.53 %	6.107E-02	0.43 %	0.00 %	0.24 %	0.49 %
550	8.918E-02	0.31 %	0.33 %	0.22 %	0.51 %	8.833E-02	0.35 %	0.00 %	0.22 %	0.41 %
555	9.197E-02	0.31 %	0.33 %	0.22 %	0.50 %	9.111E-02	0.34 %	0.00 %	0.22 %	0.40 %
600	1.167E-01	0.29 %	0.33 %	0.20 %	0.48 %	1.156E-01	0.30 %	0.00 %	0.20 %	0.36 %
650	1.417E-01	0.28 %	0.32 %	0.18 %	0.47 %	1.404E-01	0.33 %	0.00 %	0.18 %	0.38 %
700	1.626E-01	0.32 %	0.31 %	0.17 %	0.48 %	1.611E-01	0.34 %	0.00 %	0.17 %	0.38 %
750	1.786E-01	0.29 %	0.30 %	0.16 %	0.44 %	1.771E-01	0.32 %	0.00 %	0.16 %	0.35 %
800	1.897E-01	0.24 %	0.29 %	0.15 %	0.40 %	1.881E-01	0.28 %	0.00 %	0.15 %	0.32 %
850	1.962E-01	0.20 %	0.28 %	0.14 %	0.37 %	1.946E-01	0.26 %	0.00 %	0.14 %	0.29 %
900	1.988E-01	0.17 %	0.26 %	0.13 %	0.34 %	1.972E-01	0.23 %	0.00 %	0.13 %	0.27 %
950	1.980E-01	0.16 %	0.25 %	0.13 %	0.33 %	1.965E-01	0.22 %	0.00 %	0.13 %	0.26 %
1000	1.946E-01	0.17 %	0.25 %	0.12 %	0.32 %	1.932E-01	0.27 %	0.00 %	0.12 %	0.30 %
1100	1.825E-01	0.23 %	0.25 %	0.11 %	0.36 %	1.813E-01	0.40 %	0.00 %	0.11 %	0.42 %
1200	1.663E-01	0.29 %	0.28 %	0.10 %	0.42 %	1.653E-01	0.46 %	0.00 %	0.10 %	0.47 %
1300	1.490E-01	0.35 %	0.32 %	0.09 %	0.49 %	1.480E-01	0.52 %	0.00 %	0.09 %	0.53 %
1400	1.319E-01	0.37 %	0.33 %	0.09 %	0.50 %	1.310E-01	0.57 %	0.00 %	0.09 %	0.57 %
1500	1.159E-01	0.34 %	0.30 %	0.08 %	0.46 %	1.151E-01	0.55 %	0.00 %	0.08 %	0.56 %
1600	1.013E-01	0.30 %	0.26 %	0.08 %	0.40 %	1.008E-01	0.51 %	0.00 %	0.08 %	0.52 %
1700	8.821E-02	0.50 %	0.23 %	0.08 %	0.55 %	8.813E-02	0.74 %	0.00 %	0.08 %	0.74 %
1800	7.692E-02	1.37 %	0.21 %	0.08 %	1.39 %	7.699E-02	1.05 %	0.00 %	0.08 %	1.05 %
1900	6.731E-02	2.43 %	0.23 %	0.07 %	2.44 %	6.723E-02	1.37 %	0.00 %	0.07 %	1.37 %
2000	5.905E-02	2.71 %	0.29 %	0.08 %	2.72 %	5.872E-02	1.78 %	0.00 %	0.08 %	1.78 %
2100	5.176E-02	3.05 %	0.38 %	0.07 %	3.08 %	5.138E-02	1.86 %	0.00 %	0.07 %	1.86 %
2200	4.533E-02	3.71 %	0.45 %	0.06 %	3.74 %	4.510E-02	1.61 %	0.00 %	0.06 %	1.61 %
2300	3.979E-02	5.37 %	0.45 %	0.06 %	5.39 %	3.967E-02	1.85 %	0.00 %	0.06 %	1.85 %
2400	3.487E-02	6.29 %	0.76 %	0.09 %	6.34 %	3.486E-02	2.30 %	0.00 %	0.09 %	2.30 %
2500	3.072E-02	7.75 %	1.46 %	0.08 %	7.89 %	3.085E-02	1.84 %	0.00 %	0.08 %	1.84 %

16.9 Lamp Behaviour

16.9.1 VNIIOFI Lamps

The following lamps were supplied to VNIIOFI by NPL:

FEL BN 9101 217 FEL BN 9101 195 FEL BN 9101 219

Measurements were made in the sequence: NPL – VNIIOFI – NPL. VNIIOFI did not make a second set of measurements.

FEL BN 9101 219 had been damaged during transit to VNIIOFI on the first occasion, and therefore has been removed from the comparison.

VNIIOFI measured (or interpolated) all intercomparison wavelengths.

16.9.2 Lamp history

Table 16-8 Lamp history for FEL BN 9101 217

Date period	Activity	Burn hours:minutes
June – November 2001	First round measurement at NPL	10:17
November 2001	Air-freight shipment to VNIIOFI	
March – April 2002	First round measurement at VNIIOFI	20:11
June 2002	Air-freight shipment to NPL	
January – May 2003	Second round measurement at NPL	15:39
June 2003	Air-freight shipment to VNIIOFI	

Table 16-9 Lamp history for FEL BN 9101 195

Date period	Activity	Burn hours:minutes
June – November 2001	First round measurement at NPL	10:00
November 2001	Air-freight shipment to VNIIOFI	
March – April 2002	First round measurement at VNIIOFI	18:14
June 2002	Air-freight shipment to NPL	
January – May 2003	Second round measurement at NPL	15:40
June 2003	Air-freight shipment to VNIIOFI	

16.9.3 Lamp electrical stability

The lamp was operated at 8.100 A at both laboratories, the lamp voltage measured was:

Table 16-10 Electrical Potential across lamp as measured by both laboratories

Lamp	Potential first NPL measurement	Potential VNIIOFI measurement	Potential second NPL measurement
FEL BN 9101 217	105.9 V	106.0 V	106.1 V
FEL BN 9101 195	105.1 V	105.4 V	105.4 V

16.9.4 Lamp stability from pilot measurements

These graphs show the reproducibility of the pilot's measurements of the VNIIOFI lamps. The difference between the first and second pilot measurement is compared with the uncertainties relating to effects that were independent between the rounds – the "entirely uncorrelated" and "round correlated" effects.

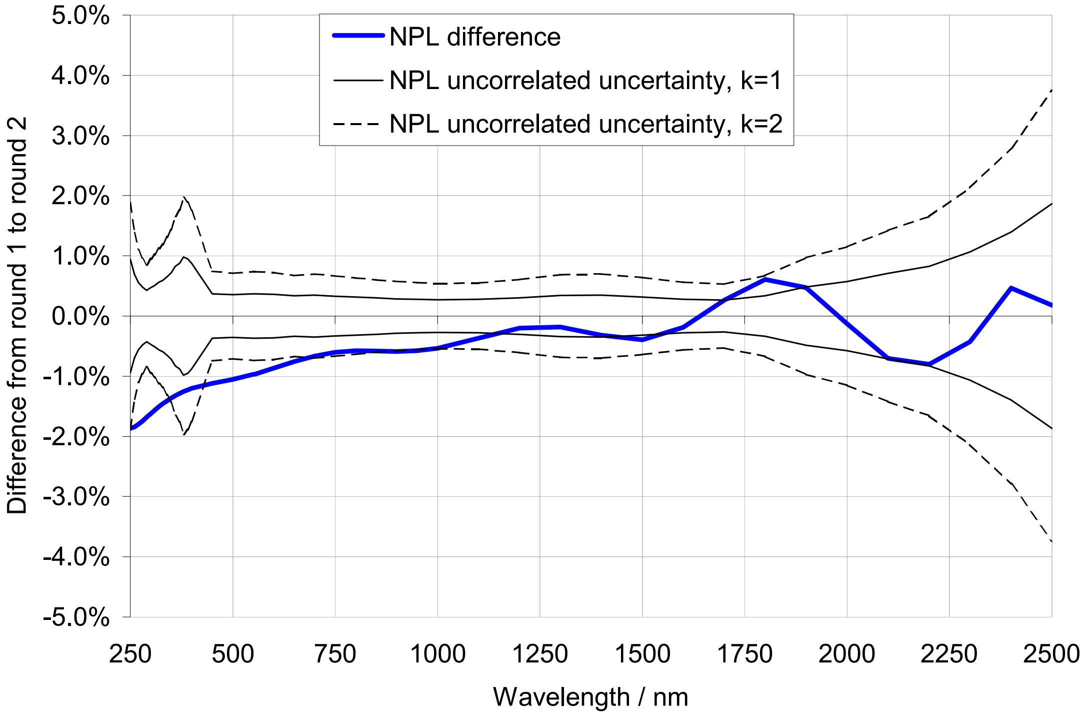

Figure 16-2 Difference between first and second round measurements of FEL BN 9101 217 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

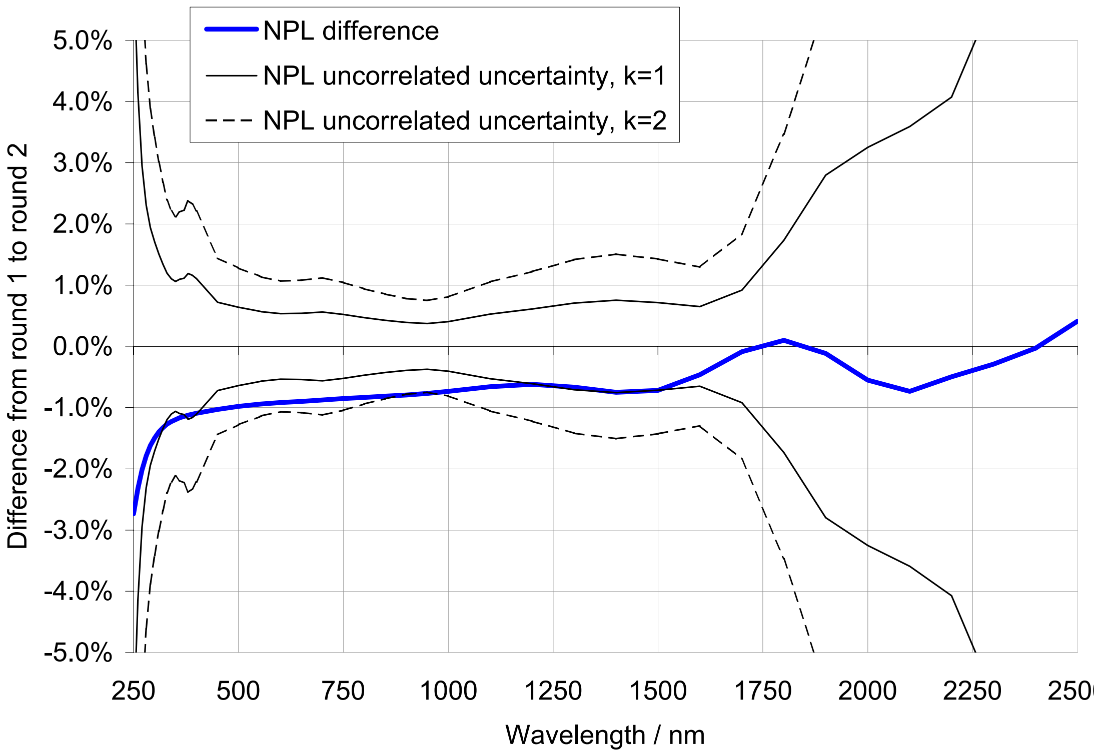

Figure 16-3 Difference between first and second round measurements of FEL BN 9101 195 by NPL. The graph also shows the combination of the uncertainties of the entirely uncorrelated and round-correlated effects of the NPL measurements

16.9.5 Lamp stability from VNIIOFI measurements

Because VNIIOFI only measured the lamps on one occasion it is not possible to get any lamp stability information from the VNIIOFI measurements.

16.10 Bilateral comparison between VNIIOFI and the comparison scale

This graph shows the difference between the VNIIOFI and NPL measurements of the VNIIOFI lamps. A version of this graph normalised to show the relative difference between the lamps, but not the absolute difference between the measurements was used to assist in choosing which lamp measurements to use.

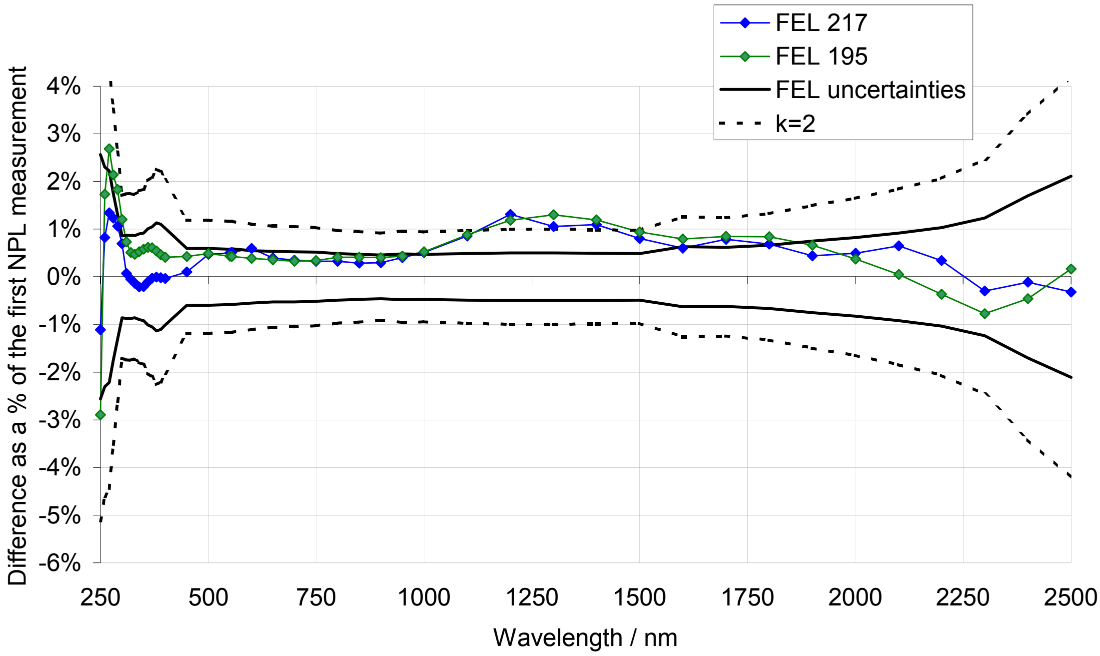

Figure 16-4 Bilateral comparisons of the VNIIOFI lamps

16.11 Decisions on which measurements to use

At the pre-draft A stage, the pilot submitted to VNIIOFI the information in the graphs Figure 16-2 to Figure 16-4. It was decided that both participant measurements and both pilot measurements would be used for both lamps.

16.12 References

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17 Analysis Methodology

17.1 Objective

In accordance with the MRA [1], the following results need to be reported for this key comparison:

1) The individual measurements provided by each participating National Metrology Institute (NMI), together with the declared associated uncertainties.
2) A key comparison reference value (KCRV) and an associated uncertainty.
3) For each participating NMI, the deviation from the KCRV and the uncertainty associated with that deviation (at a 95 % level of confidence), i.e., its (unilateral) degree of equivalence (DoE).
4) The (bilateral) DoEs between the measurements of each pair of participating NMIs.

In particular, the aim of this analysis can be expressed as:

The objective is to provide a KCRV and degrees of equivalence for this key comparison that correspond to a measurement by each participating NMI of a single typical lamp.

The uncertainty associated with each NMI measurement relates to a combination of uncorrelated and correlated effects and is that which an NMI would typically quote for a customer calibration. It is therefore such NMI measurements and associated uncertainties that are being compared.

The method of analysis for the comparison described here ensures that each participant, including the pilot, is treated equitably and in particular that the results are not dependent on the number of lamps measured by any particular participant.

The manner in which the KCRV for this comparison is assigned is consistent with the guidelines of the CCPR Key Comparison Working Group, being based on the use of a weighted mean with cut-off.

17.2 Nature of the key comparison

For a comparison consisting of a single, stable artefact that is transported between several participating NMIs, the KCRV can be obtained directly from measurements by the NMIs of the stipulated physical attribute of the artefact. If a second comparison were carried out by transporting another artefact between a subset of the participants in the first comparison and some additional NMIs, the second artefact would also have an associated reference value in the units of the measurement. To help calculate bilateral DoEs between measurements provided by NMIs that participated only in the first comparison and those that participated only in the second comparison, it is possible to determine an overall KCRV for the combined comparison by comparing the measurements provided by the linking NMIs (those that participated in both comparisons) with each individual reference value. It may be that the overall KCRV is considered to be equal to the reference value of one comparison or, alternatively, a KCRV may be calculated by combining, in some way, the two reference values. In the latter case the KCRV does not relate to the value of a physical artefact.

The nature of this comparison, designed to cope with the fragility of lamps, means that there were a large number of separate but linked bilateral comparisons, each comparison involving one NMI and the pilot. Following the philosophy described above, it is possible to use the linking provided by the pilot to assign an overall KCRV for this comparison. In this case also, the KCRV does not relate to an actual artefact.

17.2.1 Comparison design

For each stipulated wavelength, the current comparison constitutes a set of bilateral comparisons, each involving a single participating NMI and the pilot NMI. For any individual participating NMI, the bilateral comparison consists of comparisons involving two or three lamps.

The analysis of the key comparison considers the measurements for each wavelength as a separate comparison. For any one wavelength, a number of NMIs (between 10 and 13, depending on wavelength) each measured two or three separate lamps within one or two *measurement rounds* (or simply *rounds*). The pilot measured each lamp involved in the comparison within two (of three) rounds. No other NMI measured these lamps.

The measurement rounds for the pilot correspond approximately to the years 2001, 2002 and 2003. The pilot measured the lamps allocated to each participating NMI in rounds 1 and 2 or in rounds 2 and 3. Between rounds, the pilot's facility used for this comparison was overhauled and some components were replaced or recalibrated (see Section 3). Similarly participant NMIs made measurements several months apart as well. Some participants also recalibrated instruments on their facility and re-set-up the facility between their two rounds.

The rounds were interspersed, i.e., for any one NMI, in the sequence Pilot–NMI–Pilot–NMI or NMI–Pilot–NMI–Pilot or Pilot–NMI–Pilot. The measurements of each lamp in the three or four rounds were analysed to determine whether its irradiance characteristic had changed during transportation and, where it had shown significant change, some, or all, of the measurements of that lamp were excluded, as described in the final section of each NMI's chapter. This process considered any changes unexplained by an NMI's declared random and round-dependent systematic uncertainties to be caused by changes to the lamp on transportation. If the lamp had one successful sequence of NMI–Pilot–NMI or Pilot–NMI–Pilot, then the single measurement before or after this sequence was excluded. If the lamp had no consistent sequence then all measurements of that lamp were excluded. This initial screening process excluded data from the analysis that showed clear gross changes. It did not account for more subtle ageing effects, which may have occurred. The information available following this procedure is given in Table 17-1 on page 300 and shows that, in this case, each NMI was left with at least two lamps for which measurements were suitable for subsequent analysis.

17.2.1.1 Linked bilateral comparisons

The measurements made by the participating NMIs are interrelated in several ways:

1) Each measurement made by each NMI of each lamp is regarded nominally as an estimate of the value of the *lamp spectral irradiance**. Thus there are estimates of the lamp spectral irradiance from the pilot and from the participant that measured that lamp.
2) These measurements include an unknown constant *underlying systematic factor* (hopefully close to unity), specific to each NMI, for all lamps it measures.
3) A change made to an NMI's measurement system between two rounds introduces a further unknown constant systematic factor to each of its measurements in each of these rounds.

17.2.2 Uncertainty information

As is common practice in this technical discipline, spectral irradiance measurements are accompanied by associated standard uncertainties expressed in fractional (or relative or percentage) terms. Let e denote a spectral irradiance measurement. A fractional standard uncertainty $\tilde{u}(e)$ associated with e implies that the (absolute) standard uncertainty $u(e)$ associated with e is related to $\tilde{u}(e)$ by

* Sometimes described as 'true' spectral irradiance, although such terminology is discouraged by the GUM [4]

$$\tilde{u}(e) = u(e)/e. \qquad (17\text{-}1)$$

If a percentage standard uncertainty $\breve{u}(e)$ were quoted, then

$$\breve{u}(e) = 100\,\tilde{u}(e) = 100\,u(e)/e. \qquad (17\text{-}2)$$

The relationships between these uncertainty representations are relevant to the analysis used here.

In this key comparison, each NMI provided a spectral irradiance measurement, and the associated fractional (or percentage) standard uncertainty, for each lamp it measured at each wavelength within each round it measured the lamp. The components of these fractional uncertainties corresponding to those effects that were (a) common to all measurements by that NMI, (b) common to all measurements made by that NMI within a round and (c) uncorrelated were reported individually.

The pilot supplied an irradiance measurement and the associated fractional standard uncertainty for each lamp at each wavelength within each round it measured the lamp. The components of these fractional uncertainties corresponding to those effects that were (a) common to all measurements made by the pilot, (b) common to all measurements made by the pilot within a round, (c) common to all measurements made by the pilot within the first and second rounds, (d) common to all measurements made by the pilot within the second and third rounds and (e) uncorrelated were reported individually.

Since the systematic effects relating to the measurements taken in each of the two (three for the pilot) measurement rounds for each NMI are identical (section 17.2.1.1) they are perfectly correlated. The uncertainties and covariances associated with these and other effects are inferred from the uncertainty budgets submitted by each NMI (see section 17.2.3.1 and individual NMI chapters).

17.2.2.1 Implementation of the CCPR KCWG uncertainty cut-off strategy

The CCPR KCWG specifies that a cut-off uncertainty should be applied for the calculation of the KCRV to ensure that no single NMI has a dominating effect. The cut-off uncertainty is determined as the arithmetic mean of those combined standard uncertainties reported by the set of participating NMIs that are less than or equal to the median of those uncertainties. This calculation is made more complicated for the current key comparison because some NMIs declared different uncertainties for different rounds, or even for different lamps. The pilot dealt with this aspect by taking *for this purpose* the combined standard uncertainty for each NMI's measurement as the arithmetic mean of the combined standard uncertainty for each lamp measured by that NMI.

The cut-off is applied only for purposes of assigning the KCRV. Elsewhere in the analysis the declared uncertainty of each NMI for each measurement of each lamp is used.

17.2.3 Correlation effects

This section considers the manner in which correlation effects associated with the NMIs' measurements are quantified.

17.2.3.1 Between individual NMIs' measurements

The measurements made by any one participating NMI are mutually correlated as a consequence of the common underlying systematic factor and the round-dependent systematic factor(s). The terms in the uncertainty budget associated with that NMI's measurements can be grouped into

(a) The uncertainty associated with random effects, which are uncorrelated between measurements and lamps.

(b) The uncertainty associated with systematic effects common to all its measurements.

(c) The uncertainty associated with systematic effects common to all its measurements within a round.

The effects of the common underlying systematic factors are taken into account by including, in the model, quantities corresponding to those factors. The effects of each round-dependent systematic factor are taken into account by incorporating terms in the covariance matrix* associated with the measurements made by all participating NMIs. These covariance terms are associated with each pair of measurements made in that round by that NMI and are equal to the squared standard uncertainty associated with that effect, obtained from the NMI's uncertainty budget.

17.2.3.2 Between different NMIs' measurements

Each measurement made by one of the participating NMIs is correlated with that made by another participating NMI if either

(a) One of these NMIs obtains traceability from the other, or

(b) Both these NMIs obtain traceability from a further NMI, whether or not that further NMI participated in the comparison.

Two instances of circumstance (a) arose in this comparison. MSL-IRL obtains traceability from NIST, and CENAM obtains traceability from PTB. Since CENAM will be excluded from consideration in the expression for the KCRV†, the only correlation to be considered is that associated with the measurements provided by MSL-IRL and NIST. No instance of circumstance (b) applied in this case. NRC obtained traceability from "NBS", the previous name for NIST. The traceability relates to calibrations performed in 1985 and 1987. Since NIST has re-established its spectral irradiance scale since then, and the new spectral irradiance scale, while consistent with the old, was independently realised, there is no correlation between the NIST and NBS scales, and hence no correlation between the NRC and NIST scales. In addition, NRC takes traceability from the "World mean" of the 1975 comparison. Almost all NMIs that participated in that comparison have performed independent new realisations of their spectral irradiance scales since that date, therefore again the correlation is considered negligible.

The manner in which the consequences of traceability were manifested in terms of covariances was as follows. Generically, consider NMIs A and B, where B obtains traceability from A. The terms in the uncertainty budget associated with A's measurements can be grouped into

(a) The uncertainty associated with random effects.

(b) The uncertainty associated with systematic effects.

The terms in B's uncertainty budget can be grouped similarly. However, the uncertainty in B's budget associated with systematic effects can be considered to constitute two components: that 'transferred' from A as part of obtaining traceability, and that independent of A. Thus, the covariance associated with the measurements made by A and B is the square of the uncertainty in (b) above for NMI A.

The use of this correlation for the solution of the model is discussed in Section 17.4.2. The use in the KCRV is described in Section 17.4.1.

17.3 Model of the measurements

17.3.1 Construction of the model

The measurement of lamp ℓ's spectral irradiance at the given wavelength made by NMI i in its round r is denoted here by $e_\ell^{i,r}$. This measurement differs from the spectral irradiance‡, E^ℓ, of the lamp

* The covariance matrix associated with the measurements has as its (i, j)th element the covariance between the ith and jth measurements. It follows that the diagonal elements of the covariance matrix are the variances (squared standard uncertainties) associated with the measurements. The off-diagonal elements express the correlation between measurements.

† Unfortunately, CENAM did not receive the second protocol and measured the lamps at 8.3 A rather than 8.1 A. Because of a misunderstanding in the supplied information, this fact only became apparent at the end of the measurement stage of the comparison, when it was too late to perform additional measurements. In response, CENAM recalculated its results with a correction factor to deal with the change in current. As has been agreed by the CCPR KCWG, CENAM's corrected results will be analysed to determine unilateral and bilateral DoEs, but will not influence the KCRV.

‡ See footnote, page 281.

by a systematic factor, S_i, common to all NMI i's measurements and by random and round-dependent effects. The measurement $e_\ell^{i,r}$ is therefore an estimate (within random and round uncertainties) of the value of

$$E_i^\ell = E^\ell S_i, \tag{17-3}$$

where E_i^ℓ is NMI i's measurement scale realisation of the spectral irradiance of lamp ℓ.

Mathematically, Equation (17-3) is a *functional model* and NMI i's measurements of this lamp are estimates of the *model value*, the right-hand side of the expression. The measurement can be expressed as a measurement equation,

$$e_\ell^{i,r} = E_i^\ell \, \varepsilon_\ell^{i,r} = E^\ell S_i \, \varepsilon_\ell^{i,r}, \tag{17-4}$$

where $\varepsilon_\ell^{i,r}$ is the random factor of the specific measurement. This factor includes the random effects described in the uncertainty analysis, and also any round-specific common effects. $\varepsilon_\ell^{i,r}$ has an expected value of unity (if a large number of measurements were taken, its value would average out to unity.)

Knowledge of these relevant random repeatability effects, of effects due to any change made between rounds to that NMI's measurement scale and of common factors due to measurement traceability is encapsulated within the covariance matrix associated with the complete set of measurements $e_\ell^{i,r}$. The functional model accommodates the underlying systematic effect (bias) for the NMI's measurements through the systematic factor S_i.

This functional model is based on the knowledge of the interrelationships between measurements expressed in section 17.2.1.1. It relates the lamp spectral irradiance realised by an NMI's measurement scale to the model parameters, viz., the lamp spectral irradiance and the underlying NMI systematic factor. The interrelationships in section 17.2.1.1 are expressed in terms of

(a) The lamp spectral irradiance, denoted by E^ℓ, for lamp ℓ, which applies to all measurements of lamp ℓ by the participant NMI and the pilot.

(b) The overall systematic factor, denoted by S_i, for NMI i, which applies to all lamps measured by NMI i.

As a means of providing the KCRV and the unilateral and bilateral DoEs, the analysis determines:

1) An estimate of the value E^ℓ for each lamp ℓ measured.
2) An estimate of the value S_i for each participating NMI i.
3) The standard uncertainties and covariances, in the form of a covariance matrix, associated with these estimates.

The uncertainties associated with the NMI measurements are summarised by a covariance matrix, with elements as discussed in Section 17.2.2. This covariance matrix is based on (a) the NMI random effects and (b) the different systematic factors in different rounds.

Estimates of the values of these model parameters are obtained by least-squares adjustment (LSA), i.e., by determining them such that the estimates of the model values most closely match the NMI measurements, whilst respecting the covariance matrix associated with these measurements. LSA is used because there are more measurements than model parameters. Typically for each lamp, there are two NMI measurements and two pilot measurements, corresponding to four equations, of the form of Equation (17-4), containing E^ℓ. There are similarly up to 6 measurement equations containing S_i for a particular NMI and approximately 60 such equations for the pilot. At a typical wavelength there are over 100 such equations, and approximately 45 unknowns.

Despite this, the least squares solution is not unique. This lack of uniqueness arises because, given a particular solution, another solution can be formed by scaling the estimates of the values of the lamp spectral irradiances by a constant multiplicative factor and dividing the estimates of the underlying NMI systematic factors by that factor. In terms of the model (Equation (17-3)), the E^{ℓ} can be multiplied by an arbitrary constant K and S_i divided by K without changing it:

$$E^{\ell} S_i = E^{\ell} K \times S_i / K . \quad (17\text{-}5)$$

To obtain a unique solution from the family of possible solutions, an equality *resolving constraint* equation is introduced that interrelates the unknown quantities in these linked equations. See Section 17.3.3.1. Mathematically, the choice of constraint is arbitrary, providing a means for obtaining a particular solution from the family. Metrologically, a practical interpretation is required. A member of the family is chosen, based on the NMIs' underlying systematic factors, such that the assignment of the KCRV follows the guidelines of the CCPR KCWG.

The model (Equation (17-3)) is a multiplicative counterpart of the additive models considered by White [2] and Cox and Harris [3]. White also considers a set of comparisons using different artefacts that are linked through common 'linking laboratories'.

17.3.2 Definition of the DoEs

LSA provides best estimates of the spectral irradiances for the measured lamps and the systematic factors for the NMIs, including the pilot. In the case of a straightforward comparison consisting of one artefact transported amongst participating NMIs, the unilateral DoE would be the difference between an NMI's measurement of that artefact and the KCRV for that artefact.

In this comparison the analogous concept is the ratio of the NMI measurement to the lamp spectral irradiance. From Equation (17-4)

$$e_{\ell}^{i,r} / E^{\ell} = S_i \, \varepsilon_{\ell}^{i,r} . \quad (17\text{-}6)$$

There will be a value of this ratio for each measurement made by the NMI; however, the aim is to obtain a single 'best value' of the ratio. The expected value of the random factor is unity. Therefore the 'best value' of the ratio is the value of S_i for that NMI. The associated uncertainty is, however, the uncertainty associated with S_i combined with that associated with the random factor. The value of S_i is also expected to be unity and therefore we consider the unilateral DoE to have a value equal to the difference (expressed as a percentage) between S_i and unity, and the unilateral DoE's uncertainty to be the quadrature combination of the relative uncertainties associated with the systematic and random factors. Because there is a variation in uncertainties associated with random effects stated by some NMIs from one lamp to the next, the random uncertainty used in this calculation is the root mean square of the stated relative uncertainties associated with these random effects.

The bilateral DoEs are calculated from the unilateral DoEs.

17.3.3 Use of the model: outline data analysis procedure

The results obtained by fitting the model to the NMIs' spectral irradiance measurements are used to infer the KCRV and the unilateral and bilateral DoEs.

The measurement data analysis procedure adopted is summarised by the following steps and given in more detail, together with motivation and rationale, in the indicated sections. It is applied separately for each wavelength. Since the solution so obtained should only be considered valid if the model is consistent with the measurements, the procedure incorporates a strategy for treating discrepant measurements.

1) Determine estimates of the values of the lamp spectral irradiances and the NMIs' relative systematic factors, by using LSA to fit the model (Equation (17-3)) to the measurements provided by the NMIs, subject to the resolving constraint. The input covariance matrix used for this purpose is based on (a) the NMI random effects and (b) covariance effects that account for the different systematic factors in different rounds. See Section 17.4.2 for details.

2) Test the consistency of the model solution and the measurements. Introduce a random lamp instability factor to account for any variation, and repeat Step 1 as necessary. See Section 17.5.

3) Obtain the (output) covariance matrix associated with the estimates of the values of the lamp spectral irradiances and the NMI systematic factors, by propagating the covariance matrix associated with the NMIs' random and systematic effects (with no cut-off uncertainty applied) and with the lamp instability factor through the least-squares solution. See Section 17.4.2.

4) Take the differences between the estimated NMI systematic factors and unity as the values of the unilateral DoEs. Take twice the associated standard uncertainty of these factors, obtained from the output covariance matrix, combined with the NMI measurement uncertainties associated with random effects, as the uncertainty associated with the unilateral DoEs. See Section 17.6. The KCRV is defined such that a weighted geometric mean (with cut-off) of the systematic factors is unity. See section 17.3.3.1 for details of the assignment of the weights.

5) Take the difference between the unilateral degrees of equivalence for each pair of NMIs, together with twice the standard uncertainties associated with this difference, accounting for any correlations, as the bilateral degree of equivalence. See Section 17.6.4.

This method is represented graphically in Figure 17-1 and Figure 17-2.

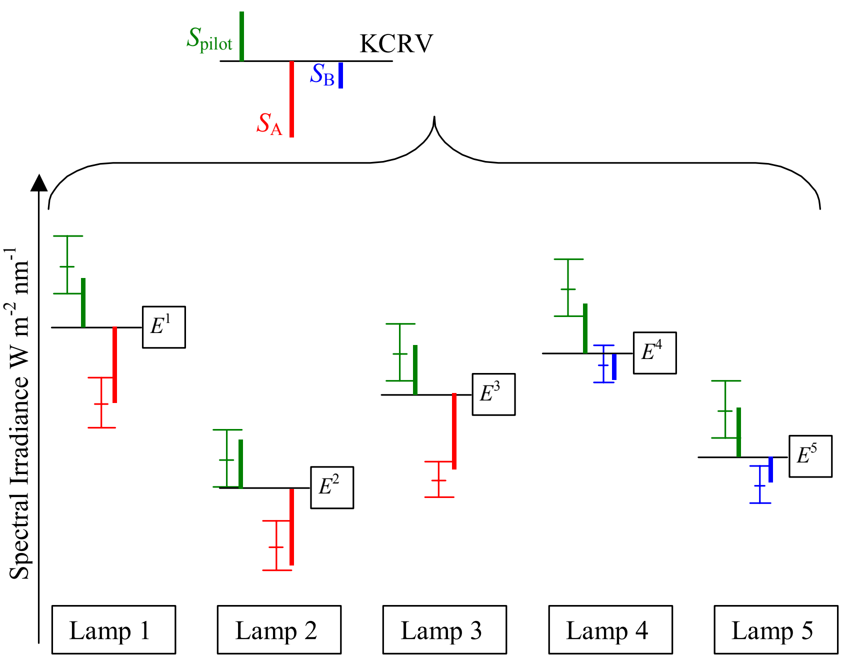

Figure 17-1 Graphical representation of the philosophy behind the analysis. The thick bars represent the systematic factors common to all measurements made by an NMI. The thin bars represent the random variation of individual measurements. The analysis aims to determine the systematic factors (and their associated uncertainties – not shown here). Note – this diagram implies an absolute systematic offset, when in fact the model assumes a relative systematic factor.

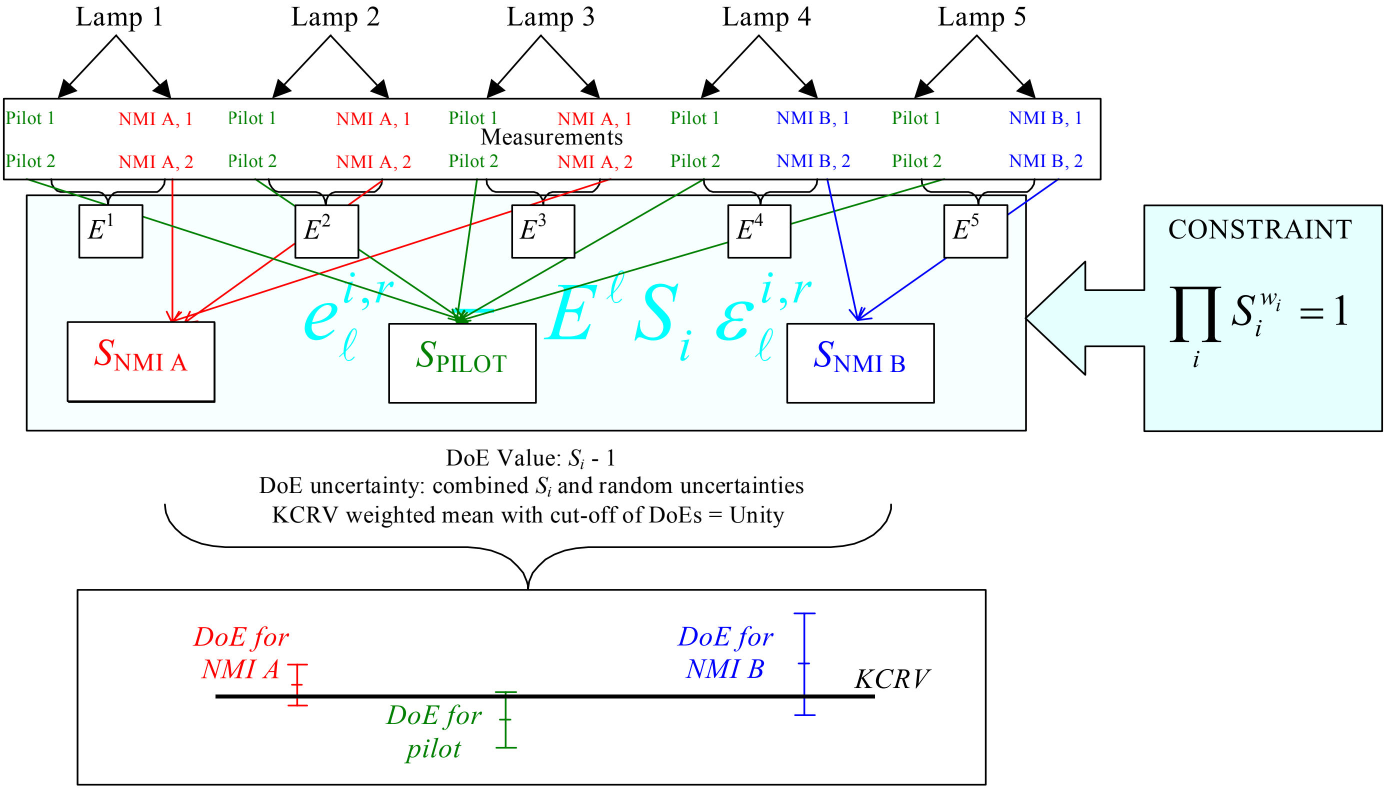

Figure 17-2. Pictorial representation of the analysis method. The relative positions of the pilot and participants are entirely arbitrary and for illustration purposes only.

17.3.3.1 Resolving constraint

A member of the family of possible solutions is selected by appending to the model equations a *resolving constraint*. This constraint can take the form of an equation involving one or more of the E^ℓ, or one or more of the S_i, or both.

The solution estimates of the values of the lamp spectral irradiances and the NMI systematic factors depend on the choice of constraint. The estimates of the values of the unilateral DoEs, calculated from the values of the NMI systematic effects, also depend on the choice (and, by the very definition of unilateral DoEs, on the choice of KCRV). The estimates of the values of the bilateral DoEs are invariant to the choice of constraint, as are the uncertainties associated with these estimates. See section 17.7.3.2.

Mathematically, the choice of constraint is arbitrary. It provides a means for obtaining a particular solution from the family of possible solutions. Metrologically, a practical interpretation is required. The resolving constraint applied is that the generalised weighted geometric mean* of the NMI systematic factors is unity, i.e.,

$$\prod_i S_i^{w_i} = 1, \tag{17-7}$$

where the w_i denote the weights. The choice corresponds, for an additive as opposed to a multiplicative model, to a weighted sum of zero (cf. White [2]). If the measurements made by different NMIs were uncorrelated, w_i would be taken as proportional to the reciprocal of the squared combined standard uncertainty associated with NMI i's measurements, i.e., accounting for both random and

* The geometric mean of multiplicative quantities is analogous to the arithmetic mean of additive quantities. See also Section 17.4.1.

systematic effects, but limited according to the CCPR KCWG cut-off strategy guidelines concerning KCRVs. The proportionality constant is set such that the sum of the weights is unity. Because there is a correlation between NIST and MSL-IRL, a generalised weighted mean is required and the weights depend on this correlation. This is described in Section 17.4.1.

The rationale for the choice (Equation (17-7)) of resolving constraint is that in the absence of further information each factor can be expected to be equally likely to be greater or less than unity, and hence the product to be unity. The 'actual' values of the S_i are unknown; otherwise correction should be made for them [4].

Because the KCRV is defined as the weighted geometric mean (with cut-off) of the systematic factors, this constraint prescribes the value unity to the KCRV.

17.3.3.2 Interpretation

Each NMI's underlying systematic factor (bias) is an unknown to be determined, with a value depending on the resolving constraint, and therefore on the underlying systematic factors of other NMIs. However, if the weight of any NMI is set to zero in the resolving constraint, this NMI has a very minor effect on the unilateral DoEs for the measurements of other NMIs (see Section 17.7.3.2). Consequently the model is made robust to any systematic effects that have not been properly accounted for by any individual NMI by setting the corresponding weight to zero in that formula. The unilateral DoE for the excluded NMI can still be estimated by the least squares analysis and will depend on the systematic factors estimated for those NMIs that have been assigned non-zero weights.

This property of the model also simplifies the inclusion of the Type II lamps, used by two participating NMIs, and which were not intended to be used for the calculation of the KCRV*, to determine DoEs. Since it was necessary to calculate a correction factor to convert from its measurements at 8.3 A to ones at 8.1 A†, CENAM has requested that its measurements are not included in the determination of the KCRV. The model permits this exclusion whilst allowing DoEs to be calculated; however, see Section 17.6.5 for a further discussion of this point.

The weight for any other NMI can also be set to zero if this is considered appropriate, an aspect discussed further in Section 17.7.5.

17.4 Solution of the model equations

The model (Equation (17-3)) is non-linear in the unknown quantities as it involves the products of lamp spectral irradiances E^ℓ and NMI underlying systematic factors S_i. If used as it stands, its solution would require the application of an algorithm for solving a non-linear least-squares problem subject to an equality constraint. However, the equations can be transformed into an equivalent linear system, which makes the solution process more manageable. The solution process therefore involves such a transformation, accounting for the effect on the relevant uncertainties, solved accordingly, including an evaluation of the associated uncertainties, and the results and uncertainties obtained, which are transformed back into the required form.

The following sections describe the various stages in the solution process.

17.4.1 Transformation of multiplicative-effects model to absolute-effects model

The NMIs' spectral irradiance measurements $e_\ell^{i,r}$ are transformed into logged irradiance measurements $f_\ell^{i,r} = \ln e_\ell^{i,r}$. Correspondingly, the fractional covariance matrix associated with these measurements based on (a) the NMI random effects and (b) covariance effects that account for the

* NIM originally measured lamps at the wrong current, as they had not received the second protocol. As a consequence NIM made additional measurements of the Type I lamps, which they were unable to measure in the region 750–1150 nm. Therefore, for NIM only, Type II lamps are used in determining the KCRV in that spectral region, as agreed previously by all participants.

† See footnote, page 283.

different systematic factors in different rounds is transformed into the covariance matrix associated with the logged irradiance measurements.

Specifically, the model is transformed into one that is linear in the logarithms of the unknown quantities, viz., the logarithms of the lamp spectral irradiances E^ℓ and the logarithms of the NMI systematic factors S_i. For this purpose, let

$$F^\ell = \ln E^\ell, \tag{17-8}$$

$$T_i = \ln S_i. \tag{17-9}$$

By taking logarithms, the model (Equation (17-3)) then takes the additive or absolute form

$$F_i^\ell = F^\ell + T_i, \tag{17-10}$$

where

$$F_i^\ell = \ln E_i^\ell \tag{17-11}$$

denotes the logarithm of the spectral irradiance E_i^ℓ of lamp ℓ realised by NMI i's measurement scale. The logarithms are also taken of the measured spectral irradiances:

$$f_\ell^{i,r} = \ln e_\ell^{i,r}. \tag{17-12}$$

Then, rather than fitting the model (Equation (17-3)) to the NMIs' spectral irradiance measurements $e_\ell^{i,r}$, the model (Equation (17-10)) is fitted to the logarithms $f_\ell^{i,r}$ of these measurements. This problem is linear in the (transformed) model parameters F^ℓ and T_i.

The complete set of $f_\ell^{i,r}$ are regarded as realisations of a multivariate normal distribution with vector expectation containing in appropriate positions the least-squares estimates of the values of the $F_i^\ell + T_i$, and represented by $\hat{\mathbf{y}}$ in section 4.2, and covariance matrix equal to the fractional covariance matrix associated with the vector of the original NMI irradiance measurements $e_\ell^{i,r}$ (see below). This assumption permits the application of tests based on a chi-squared distribution (Section 17.5). Because the treatment here is in terms of the logarithms of quantities, the standard uncertainty $u(f)$ associated with $f = \ln e$, say, is needed. From the relationship $F = \ln E$ between the corresponding quantities, $\partial F / \partial E = 1/E$, and hence applying the law of propagation of uncertainty,

$$u(f) = u(e)/e = \tilde{u}(e) \tag{17-13}$$

(cf. Section 17.2.2). In words, given the fractional standard uncertainty $\tilde{u}(e)$ associated with e, the standard uncertainty $u(f)$ associated with $f = \ln e$ is equal to $\tilde{u}(e)$.

An analogous statement applies to a set of correlated spectral irradiance measurements. Given the fractional covariance matrix associated with a vector of such measurements (a matrix containing a squared fractional uncertainty in each diagonal position and the product of a correlation coefficient and two fractional standard uncertainties in each off-diagonal position), the covariance matrix associated with the vector of the logarithms of these measurements is equal to that matrix (cf. Section 17.2.2).

Thus the covariance matrix associated with the vector of the logged NMI spectral irradiance measurements $f_\ell^{i,r}$, needed in the analysis here, is identical to the fractional covariance matrix associated with the vector of the original NMI irradiance measurements $e_\ell^{i,r}$.

The constraint equation (Equation (17-7)) is also transformed accordingly by taking the logarithm of both sides:

$$\sum_i w_i T_i = 0. \qquad (17\text{-}14)$$

By analogy with the identical form for the KCRV x_{ref} for a key comparison constituting the circulation among the participating NMIs of a single stable measurement standard, it is appropriate to assign weights w_i (with $\sum_i w_i = 1$) such that the standard uncertainty associated with x_{ref} is minimal. This choice is

$$w_i = u^{-2}(x_i)/W, \qquad (17\text{-}15)$$

where

$$W = \sum_j u^{-2}(x_j), \qquad (17\text{-}16)$$

when the NMIs' measurements x_i are mutually independent [5].

In a mutually independent version of this comparison, the weights in the constraint equation would be the inverse squares of the declared measurement uncertainty for a single lamp by each NMI or the inverse square of the cut-off uncertainty — whichever were the smaller. The weight for Type II lamps (apart from that for NIM in the region 750 – 1100 nm) has been set to zero, as has the weight for CENAM.

In this case this weighted mean is extended to a *generalised weighted mean*, to account for the correlation between NIST and MSL-IRL. It should be noted that there is still some debate at the CCPR about the inclusion of correlation within the KCRV. The method proposed here has been accepted by the participants of this comparison, for this comparison, but should not be considered a recommendation of the CCPR or set any precedent for future comparisons. The generalised weighted mean is used to provide different weights w_i that depend on the entire covariance matrix. The values of the w_i so assigned for NIST and MSL-IRL would be smaller than those on the assumption of mutual independence, and the remaining w_i larger.

However, it is not possible to use the same covariance matrix as for the solution of the least squares problem. This is because it is necessary to reduce the 20 matrix elements (the 5 measurements from NIST and the 4 measurements by MSL-IRL) to a single element and because the application of the cut-off has altered the "effective" uncertainty associated with the NMIs' measurements.

This aspect is addressed by calculating the correlation coefficients $\rho_{i,j}$ for the 20 measurement pairs, using a simple (arithmetic) mean to average them, and then calculating a new covariance term for the two participants

$$\operatorname{cov}(x_k, x_l) = \rho_{k,l}\, u(x_k)\, u(x_l), \qquad (17\text{-}17)$$

where the uncertainties $u(x_k)$ and $u(x_l)$ are the declared uncertainties limited by the cut-off and $\rho_{k,l}$ is the simple mean of the 20 correlation coefficients.

17.4.2 Solution of the absolute-effects model

Estimates of the values of the logged lamp spectral irradiances F^{ℓ} and the NMIs' absolute systematic offsets T_i, are obtained by using LSA to fit the transformed (linear) model (Equation (17-10)) to the transformed measurements $f_{\ell}^{i,r}$ provided by the NMIs (less any excluded measurements), subject to the transformed (linear) equality constraint (Equation (17-14)). In this process, measurements are excluded as necessary (Section 17.5), and the input covariance matrix used is based on the random and round-dependent effects associated with the retained measurements.

The formulation can be treated using conventional least-squares theory. Generically, denote the logged measurements $f_{\ell}^{i,r}$ collectively by the vector $\mathbf{y}$ and the unknowns F^{ℓ} and T_i collectively by the vector $\mathbf{x}$. Further, denote the covariance matrix associated with the random components and round-dependent effects of $\mathbf{y}$ by $\mathbf{V}_{\mathrm{rr}}$. Then, if $\mathbf{A}$ denotes the *design matrix**, viz., the matrix relating the model values $\hat{\mathbf{y}}$ (corresponding to $\mathbf{y}$) to $\mathbf{x}$, by $\hat{\mathbf{y}} = \mathbf{A}\mathbf{x}$, the least-squares estimate of the value of $\mathbf{x}$ satisfies

$$\mathbf{A}^{\mathrm{T}}(\mathbf{V}_{\mathrm{rr}})^{-1}\mathbf{A}\mathbf{x} = \mathbf{A}^{\mathrm{T}}(\mathbf{V}_{\mathrm{rr}})^{-1}\mathbf{y}. \quad (17\text{-}18)$$

These model values are given by the estimates of the values of F_i^{ℓ} obtained from model (Equation (17-10)) by using the solution estimates of the values of F^{ℓ} and T_i.

Of all possible solutions to Equation (17-18) there is only one satisfying the constraint equation (Equation (17-14)). Recognised numerical procedures [6] can be used to solve this formulation.

The covariance matrix associated with the solution $\mathbf{x}$ could be taken as

$$\mathbf{V}_{\mathrm{x}} = \left(\left(\mathbf{A}^*\right)^{\mathrm{T}}\left(\mathbf{V}_{\mathrm{rr}}\right)^{-1}\mathbf{A}^*\right)^{-1}, \quad (17\text{-}19)$$

where $\mathbf{A}^*$ is a variant of $\mathbf{A}$ that accounted for the constraint. It contains the squared standard uncertainties associated with the estimates of the values of the logged lamp spectral irradiances F^{ℓ} and the NMIs' absolute systematic offsets T_i.

However, because the input covariance matrix $\mathbf{V}_{\mathrm{rr}}$ accounts only for those components that are random or round-dependent, the output covariance matrix that would be calculated by conventional least-squares, viz., (17-19), would be inappropriate in this situation.

To obtain the appropriate output covariance matrix, the solution calculated using LSA as described above is regarded as a GUM input-output model [7]. Formally, $\mathbf{x} = \mathbf{H}\mathbf{y}$, where

$$\mathbf{H} = \left(\left(\mathbf{A}^*\right)^{\mathrm{T}}\left(\mathbf{V}_{\mathrm{rr}}\right)^{-1}\mathbf{A}^*\right)^{-1}\left(\mathbf{A}^*\right)^{\mathrm{T}}\left(\mathbf{V}_{\mathrm{rr}}\right)^{-1}. \quad (17\text{-}20)$$

Therefore the full covariance matrix, $\mathbf{V}_{\mathrm{y}}$, considering appropriately the random, round-dependent and systematic effects in forming it, is propagated through this input-output model to determine the full covariance matrix $\mathbf{V}_{\mathrm{x}}$ associated with the least-squares estimates of the values of the output quantities – and thus provides the uncertainties associated with the estimates of the (logged) reference irradiance of the lamps and the (logged) NMI systematic factors. $\mathbf{V}_{\mathrm{y}}$ contains some non-zero off-diagonal terms relating to the indicated common effects in the measurements. In particular, the measurements of any one NMI are correlated with each other, and the measurements of MSL-IRL and NIST are also correlated. The form of this matrix is as shown in Figure 17-3. $\mathbf{V}_{\mathrm{x}}$ is formed as $\mathbf{V}_{\mathrm{x}} = \mathbf{H}\mathbf{V}_{\mathrm{y}}\mathbf{H}^{\mathrm{T}}$, a formula representing a generalisation of the law of propagation of uncertainty to a multivariate output quantity [8].

* The design matrix **A** is constructed as follows. Each row of **A** corresponds to an NMI measurement and hence the corresponding model equation (17-10). The particular row of **A** corresponding to measurement $f_{\ell}^{i,r}$ contains zeros except in the column positions corresponding to model parameters F_i^{ℓ} and T_i, where the elements are equal to unity.

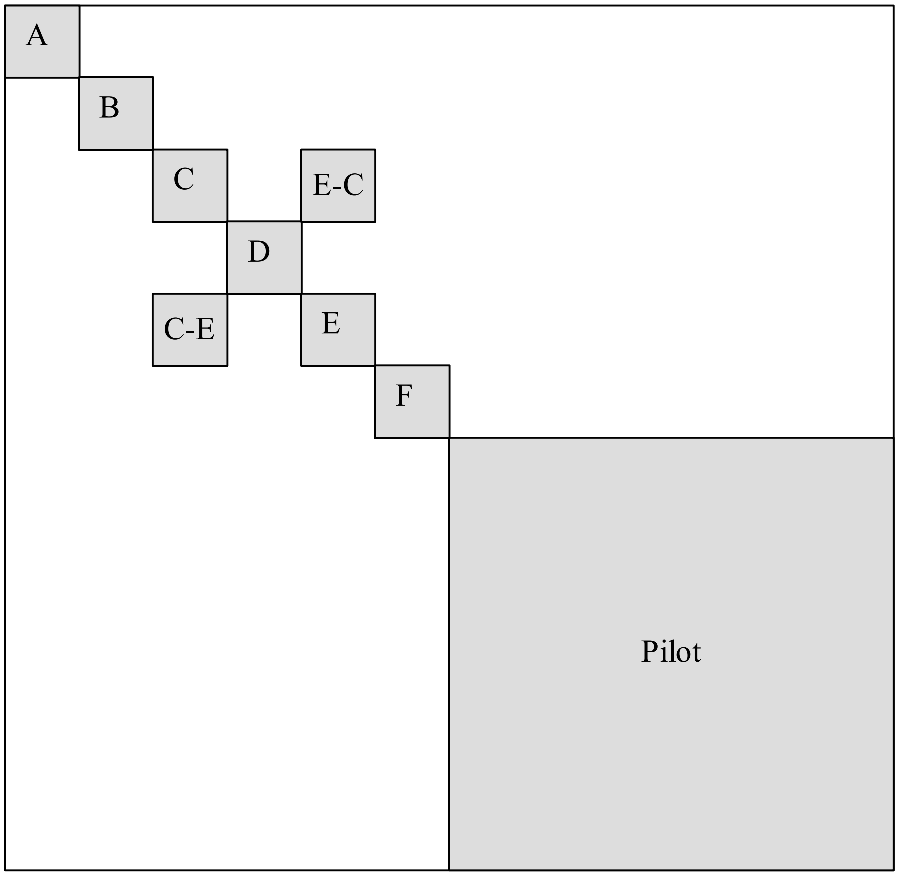

Figure 17-3 Input covariance matrix for the measurements. In this case the only non-zero values are those in the greyed areas corresponding to correlations between measurements by one NMI and correlations between measurements made by NMI C and NMI E. There are no correlations between the measurements made by any other pair of NMIs.

17.4.3 Transformation of solution to absolute-effects model to that of multiplicative-effects model

The solution to the transformed problem, viz., the estimates f^{ℓ}, say, of the values of the logged lamp spectral irradiances F^{ℓ} and the estimates t_i, say, of the values of the NMI absolute systematic offsets T_i, is then transformed back to give the required corresponding estimates $e^{\ell} = \exp\left(f^{\ell}\right)$ of the values of the lamp spectral irradiances and estimates $s_i = \exp\left(t_i\right)$ of the values of the NMI systematic factors.

The unilateral DoEs are calculated from

$$D_i = \exp(t_i) - 1 = s_i - 1. \quad (17\text{-}21)$$

The fractional covariance matrix associated with the e^{ℓ} and s_i is equal to the covariance matrix indicated at the end of section 17.4.2.

17.5 Consistency of model and the NMIs' spectral irradiance measurements

In order to draw valid conclusions from the results of modelling measurement data generally, it is necessary (a) that the data is consistent with itself and (b) that the model is consistent with the data. Aspect (a) can often be considered as falling within (b), but here the distinction is useful. For (a), the manner in which certain measurements of each lamp were excluded as necessary from further consideration before the detailed analysis was undertaken is indicated in Section 17.2.1. Aspect (b) is now considered.

A chi-squared test on the results of LSA is used to check the consistency of a model and the NMIs' measurement data. If the test fails, it indicates that one or more of the NMI measurements are discrepant; a subsidiary test can be used to help identify such measurements. The chi-squared test describes how well the model actually fits the data compared with how well it can be expected to fit the data. A ratio of a chi-squared value for the model fit and a critical value is taken. If the ratio exceeds unity the model and data are regarded as inconsistent. Because the underlying NMI systematic factors have been modelled, the subsidiary tests can be regarded as identifying those measurements for which the uncertainties associated with random effects or with round-dependent systematic effects are inconsistent with the model. Inconsistencies in the systematic effects compared with the NMI declared uncertainties might lead to an NMI's measurements being excluded from the calculation of the KCRV. This aspect is discussed separately in Section 17.7.5.

Inconsistency with the model may be because the uncertainty associated with random effects is too small, or because the round-dependent uncertainties overestimate the correlation within a round, or underestimate the variation between rounds. Alternatively, and in this case quite probably, the model is not a complete representation of the physical situation. In particular, the model does not account for any drift or ageing of the lamps caused by use or transportation. Whilst the most obvious cases of lamp drift have been removed before any of this analysis, this was carried out in a relatively conservative manner. For example, some lamps were not excluded if only a few wavelengths showed 'poor repeatability' compared with the declared uncertainty, particularly if the NMI only had a few measurements available. The chi-squared test generally fails on these instances.

The importance of consistency of model and data must be emphasised. If consistency is not achieved, the results obtained from the use of a model (for example output uncertainties) are at worst invalid and at best must be treated with caution. Therefore it is important to develop methods to deal with any inconsistency.

17.5.1 Exclusions

One common method is to exclude individual measurements in order to achieve the largest possible consistent set from the remaining measurements. If a large number of measurements have to be excluded, it would be necessary to develop a better model, i.e., explaining further effects not so far considered.

When measurements are mutually independent, one way to exclude a measurement is to identify that giving greatest contribution to the value of chi-squared. That value would be excluded, a new solution obtained using LSA, a further measurement excluded as necessary, and so on. In the presence of correlation effects, as here, there is no one-to-one correspondence, as for mutually independent measurements, between such a measurement and a contribution to chi-squared. If two measurements are highly correlated, the exclusion of one of them can change the chi-squared value appreciably, but it is difficult *a priori* to decide which one, if either, should be excluded.

A simple, computer-intensive strategy can be used to exclude individual measurements successively, which does ensure that, at each stage, the measurement excluded is that giving greatest contribution to the value of chi-squared. At any one stage every one of the measurements retained is considered as a candidate for exclusion. Consequently, a solution is obtained using LSA for each such possibility. As many solutions as there are retained measurements are thus formed, and for each of which a chi-squared ratio calculated. The measurement excluded is that yielding the smallest chi-squared ratio.

Mathematically, the manner in which generally the consistency of a model and measurements is judged is as follows. Let $\mathbf{y}$ denote a vector of m measurements, regarded as an estimate of the value of a vector quantity $\mathbf{Y}$. Let the model be $\mathbf{Y} = \mathbf{AX}$, where $\mathbf{A}$ is the design matrix and $\mathbf{X}$ is a vector of n model parameters. Let $\mathbf{V}$ be the covariance matrix associated with $\mathbf{y}$. Let $\mathbf{x}$ denote the estimate of the value of **X**, obtained, e.g., by least squares. The deviations of the measurements from the model are $\mathbf{e} = \mathbf{y} - \mathbf{Ax}$.

For the key comparison here, **y** is the vector of logged irradiance measurements $f_\ell^{i,r}$ provided by the participating NMIs (after any of these measurements have been excluded from consideration in contributing to the estimate **x**), **x** the (combined) vector of logged lamp irradiances F^ℓ and the vector of NMI absolute systematic offsets T_i.

Consistent with the statement in Section 17.4.1, **Y** is regarded as being distributed normally with expectation **y** and covariance matrix **V**. Then, the chi-squared value

$$\chi^2_{\text{obs}} = \mathbf{e}^{\text{T}}\mathbf{V}^{-1}\mathbf{e} = \left(\mathbf{y} - \mathbf{Ax}\right)^{\text{T}} \mathbf{V}^{-1} \left(\mathbf{y} - \mathbf{Ax}\right) \quad (17\text{-}22)$$

is distributed as $\chi^2(\nu)$, i.e., as χ^2 with $\nu = m - n$ degrees of freedom. If χ^2_{obs} is significantly larger than the expectation $\nu = m - n$ of χ^2, it is unlikely that the normality assumption holds, i.e., that one or more of the measurements are discrepant. Specifically, if the probability of a chi-squared value χ^2 larger than the observed value χ^2_{obs} is smaller than, say, $\alpha = 0.05$, i.e.,

$$P\left\{\chi^2(\nu) > \chi^2_{\text{obs}}\right\} < \alpha, \quad (17\text{-}23)$$

the normality assumption is rejected at a 100α % level of significance.

The choice $\alpha = 0.05$ is not absolute, but is often used in practice. Consideration can be given to other choices, e.g., $\alpha = 0.01$, if it proved to be difficult to obtain consistency of model and measurements except by excluding an unduly large number of the NMIs' measurements, however in practice the results were not sensitive to the choice of α.

The interpretation of the degree of consistency is made simpler by working with a chi-squared ratio. Let $\chi^2_{1-a}(\nu)$ denote the $100\left(1-a\right)$ percentile of $\chi^2(\nu)$. Then the model and data are regarded as inconsistent if the chi-squared ratio

$$\chi^2_{\text{obs}} \big/ \chi^2_{1-a}(\nu) > 1. \quad (17\text{-}24)$$

The numerator χ^2_{obs} is given by expression (17-22) and the denominator $\chi^2_{1-a}(\nu)$ obtained from the chi-squared distribution.

In the measurement exclusion strategy, in which measurements are excluded one by one, the value of this ratio is examined at each stage before a possible exclusion. If it does not exceed one, the model is consistent with the retained measurements.

17.5.2 Model change

The approach described in section 17.5.1 was applied to the comparison data. However, this led to 10 or 11 measurements, out of approximately 120 being excluded at certain wavelengths. Several participants had concerns with using a process that led to the exclusion of this number of measurements and therefore the pilot proposed a variation of the model. This was acceptable to the participants and has been used for the analysis of this comparison.

We can postulate on physical grounds that the chi-squared test failed because for specific measurements the lamps changed or drifted on transportation or in use in a way that was too subtle to be detected by the initial analysis. This is reasonable given the large number of results indicating significant drift during the initial filtering process. On this basis we introduce an artefact factor to account for random lamp changes. The word "random" is important here, because we are assuming that the lamps are not changing in any systematic way, but by amounts that can be regarded as realisations of a random variable having some standard deviation that is unknown *a priori*. This again is reasonable since, in addition to an effective temperature change of the filament of the lamp, small movements of the coil can result in an increase or decrease in output. It is important to note that since this is an unknown factor, we must incorporate it in all lamp measurements even if they had not previously been excluded.

This lamp-instability is modelled by an uncertainty component in the covariance matrix used in the least-squares solution of the model equations and in the covariance matrices used to evaluate the uncertainty associated with the systematic factors and the uncertainties associated with the degrees of equivalence. It is, however, not included in the formation of the constraint equation (in the definition of the KCRV.) That continues to use the declared uncertainties limited by the cut-off to determine the weights.

It is important to stress that the uncertainty so introduced is associated with lamp instability. It is unrelated to the uncertainties associated with the participating NMIs' measurement capabilities.

The augmented model is

$$e_\ell^{i,r} = E_i^\ell \, \varepsilon_\ell^{i,r} = E^\ell S_i \, \varepsilon_\ell^{i,r} \delta_\ell^{i,r}, \qquad (17\text{-}25)$$

where $\delta_\ell^{i,r}$ is the effect of artefact instability and has an *expected* value of unity. The variance (squared standard uncertainty) associated with the $\delta_\ell^{i,r}$ enters the relevant covariance matrices as an additive term for each diagonal element.

The uncertainty associated with the $\delta_\ell^{i,r}$ is to be determined such that the model matches the data, i.e., the chi-squared ratio is equal to unity.

It is meaningless to determine this uncertainty to many significant digits. We choose to provide a value that yields a chi-squared value that rounds to 1.0, i.e., to a value between 0.95 and 1.05.

17.6 Interpretation of model solution

The unilateral and bilateral DoEs can be calculated, whether or not an NMI concerned has a corresponding non-zero weight in the formula for the KCRV. The expanded uncertainty component of each unilateral DoE can then be contrasted with the expanded uncertainty (at a 95 % level of confidence) associated with an NMI's measurement of a 'typical representative lamp', and which is used, as indicated above, as the basis for the corresponding weight in the KCRV formula. See section 17.6.1. AND ???

17.6.1 KCRV

The KCRV is defined such that a generalised weighted geometric mean of the systematic factors is unity. Doing so fixes the value of the multiplier K in expression (17-5) and causes the arbitrary base-line reference of the deviations to be a value that in some sense is central to the measurements.

Each weight is taken to be the reciprocal of the squared standard uncertainty associated with the measurement of a single lamp by the corresponding NMI, controlled by a cut-off value. This approach follows the CCPR KCWG draft guidelines for the determination of the KCRV. For this comparison, additionally, the covariance matrix for the generalised weighted mean considers the correlation between participants, as described in Section 17.4.1.

The KCRV is stipulated to be unity by applying a constraint such that the weighted geometric mean of the NMI systematic factors S_i takes this value:

$$\prod_i S_i^{w_i} = 1, \qquad (17\text{-}26)$$

which is re-parameterised in terms of the absolute offsets, T_i (Section 17.4.1), as

$$\sum_i w_i T_i = 0. \qquad (17\text{-}27)$$

17.6.2 Unilateral DoEs

The unilateral DoEs are defined as the difference between (a) the ratio of a typical lamp measurement by that NMI and the lamp spectral irradiance and (b) its expected value of unity. Such a ratio is

$$e_\ell^{i,r} / E^\ell = S_i \, \varepsilon_\ell^{i,r} \tag{17-28}$$

or, in terms of absolute offsets,

$$f_\ell^{i,r} - F^\ell = T_i + \eta_\ell^{i,r}, \tag{17-29}$$

where $\eta_\ell^{i,r} = \ln \varepsilon_\ell^{i,r}$. Since the expected value of $\varepsilon_\ell^{i,r}$ is unity (and that of $\eta_\ell^{i,r}$ is zero), the expected value of the ratio is the value of the systematic factor S_i (or systematic offset T_i). The expected value of the unilateral DoE is therefore the systematic factor minus unity. The uncertainty component of the DoE is the combined uncertainty associated with the systematic and random factors. This uncertainty is always quoted at the 95% level of confidence.

17.6.3 Data consistency

If there is a significant discrepancy between the uncertainty components of the unilateral DoEs and the corresponding NMI expanded uncertainties, then individual NMIs can successively be excluded from the formula for the KCRV until the agreement for the remaining NMIs is satisfactory.

The reciprocals of the squares of the NMIs' combined standard uncertainties would nominally be taken as the weights in the constraint equation, which defines the KCRV (Equations (17-7) and (17-14)), as done when forming a weighted mean of mutually independent measurements.

A weight of zero could instead be assigned if it were believed that an NMI's results should not contribute to the KCRV for that wavelength. The decision concerning which NMIs' measurements should be excluded from the calculation of the KCRV was agreed by consensus of all participants based on blind data prior to the publication of results. See Section 17.7.5 for a discussion on this point.

17.6.3.1 Treatment of the pilot

The analysis considers correlations between measurements made by the same NMI, whilst treating the pilot and the other participants equitably. In the formula for the KCRV, the pilot's systematic factor can be given the appropriate weight according to the pilot's declared uncertainty associated with the measurement of a single typical lamp. Doing so does not result in the very large number of measurements made by the pilot having a dominant effect. Even in the event that the measurements of the pilot were regarded as discrepant, the weight attached to the pilot's systematic factor can be taken as zero, whilst still permitting the estimation of the values of the systematic factors of the other participants.

The model separates the systematic effects from the random effects, the systematic effects being directly modelled. If an offset factor existed for all pilot results this would mean that the pilot's systematic factor would have a value inconsistent with the uncertainties the pilot declares. However, the model would still provide a solution, which would pass the chi-squared test based on the uncertainties due to random and round-dependent effects if *these* uncertainties were consistent with the pilot's measurements. Including systematic factors in the model is valuable, since it is the uncertainties associated with these effects that are often the most difficult to evaluate.

The value of the pilot's unilateral DoE is taken to be that of the systematic factor S_{Pilot} minus unity (as the random factor has an expected value of unity). The uncertainty component of the DoE is taken as twice the combined uncertainty associated with the systematic factor and a typical random factor.

The uncertainty associated with S_{Pilot} is dominated by the uncertainties due to systematic and round-dependent effects. This uncertainty is, by definition, associated with all the pilot's measurements and therefore cannot be affected by the number of measurements made by the pilot. The uncertainty in the unilateral DoE is a combination of the uncertainty due to the systematic factor and that due to a "typical" random factor – in this case it is taken as the arithmetic mean of the uncertainties associated with random effects that the pilot declared. Thus the large number of measurements the pilot made does not affect the uncertainty component of the DoE for the pilot.

The constraint equation (which defines the KCRV as unity) is the geometric weighted mean of the systematic factors. Each participant (including the pilot) has a weight* proportional to the inverse square of the declared standard uncertainty associated with the measurement of a single lamp or the inverse square of the defined cut-off uncertainty. In this way the weight for the pilot relates to the measurement of only a single lamp and the pilot does not over-weight the KCRV – there are 12 equitable participants in the KCRV (it is CENAM that is excluded, not the pilot).

As a consequence of these considerations, the pilot's measurements had to be made against a stable comparison scale to ensure that the pilot's systematic factors were consistent throughout the measurements. The magnitude of this factor would not influence the results of the analysis for any other NMI.

It may be that the pilot chooses to perform the comparison against a stable *comparison scale* that is different from the *dissemination scale* the pilot disseminates to its customers. In this case the pilot must perform an additional comparison between the comparison scale and the dissemination scale. However, in this comparison the pilot made all measurements in reference to its own dissemination scale and hence this distinction is not necessary.

17.6.4 Bilateral DoEs

Each relative bilateral DoE, as a measure of the difference between the measurements made by two NMIs of a single typical lamp, is determined as the difference between the unilateral DoEs for the two NMIs, together with twice the standard uncertainty associated with this difference.

Thus given the unilateral DoE for NMI i, D_i, and the unilateral DoE for NMI j, D_j, the bilateral DoE, D_{ij}, is calculated as

$$D_{ij} = D_i - D_j, \tag{17-30}$$

together with the associated uncertainty at the 95 % level of confidence. This definition follows the convention for the analysis of Key Comparisons and provides bilateral DoEs that are consistent with the unilateral DoEs†.

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* This is in practice changed slightly because of the correlation between NIST and MSL-IRL (See Section 17.4.1)

† This approach is however a departure from the multiplicative model. If the multiplicative model were fully adopted, the unilateral degrees of equivalence D_i and bilateral degrees of equivalence $D_{i,j}$ would be defined, respectively, as the deviation of the systematic factor from unity and the deviation of the ratio of the systematic factors from unity:

$$D_i = S_i - 1 = \exp\left[T_i\right] - 1$$

$$D_{ij} = S_i / S_j - 1 = \exp\left[T_i - T_j\right] - 1$$

together with their associated uncertainties at a 95 % level of confidence.

This definition of the bilateral DoEs is approximated by the conventional definition, given as Equation (17-30). The use of bilateral DoEs that are consistent with the multiplicative model gives rise to asymmetries in the numerical values obtained: $D_{ij} \neq D_{ji}$. Such asymmetries would barely be noticed in metrology disciplines where the relative uncertainties are much smaller than here. However, in spectral measurements, where uncertainties can be of the order of several percent, quoting asymmetric DoEs that are discernibly different in magnitude might be a source of confusion to users of those DoEs. Therefore the conventional, additive approach is more appropriate for this comparison.

17.6.5 Treatment of CENAM

Due to the small differences (always less than 0.05 %) between the unilateral DoEs calculated for each participant if CENAM's lamps are included in the analysis, as discussed in Section 17.7.3.2, the software has been run twice. The first software run, which did not involve CENAM's lamps, determined the unilateral and bilateral DoEs for all participants except CENAM. The second run, which included CENAM with a weight of zero in the constraint equation, determined the unilateral and bilateral DoEs for CENAM only.

CENAM's measurements were treated in the manner indicated in order to provide the results of the evaluation in a timely manner. The approach is not perfect, but the DoEs so obtained can nevertheless be expected to be close to those that would have been obtained by a more rigorous approach, which would be as follows.

Results for all participating NMIs apart from CENAM would be obtained using a first analysis. Thus all lamps measured would be used in this analysis, apart from those measured by CENAM. The measurements of the lamps measured by CENAM would be regarded as constituting an additional bilateral comparison. A second analysis would then be carried out, in which these measurements would be processed using a model of the type considered, except that instead of using a constraint equation relating to the KCRV, that equation would be replaced by a "linking constraint". That constraint would be chosen to ensure that the pilot's systematic factor was identical to that obtained in the first, main, analysis. The unilateral DoEs for CENAM would be formed from the results of the second analysis. The bilateral DoEs involving CENAM and all other participating laboratories would be formed from the results of both analyses.

Such an approach could not be implemented in the time available, but may be used as the basis for linking the results of bilateral and regional comparisons to the CCPR K1-a. Further considerations that would need to be taken into account in that case would be (i) whether the pilot laboratory was different, (ii) whether there was more than one laboratory involved in both comparisons, (iii) laboratory systematic factors that are common to both comparisons. Such considerations would have a significant effect on the analysis used.

17.7 Analysis decisions

The analysis technique is described in the previous part of this chapter. This section describes the specific decisions that were made regarding the analysis process.

17.7.1 Analysis input data

Prior to the analysis stage, each participant NMI, in discussion with the pilot, agreed which subset of its measurements was to be used in the analysis. These decisions were based on the repeatability information of the measurements at the participant and at the pilot. The information available for analysis is summarised in Table 17-1.

Table 17-1. Summary of available information for analysis. Blank cells indicate that either a measurement was not performed, or that the measurement has been rejected because of lamp instability. For details, see individual NMI chapters in the Draft A report.

Lamp	Wavelength region	1st Pilot measurement	2nd Pilot measurement	First participant measurement	Second participant measurement	Notes
197	300–2500	Round 2	Round 3	BNM-INM 1 (no 1100 nm)	BNM-INM 2	
246	300–2500	Round 2	Round 3	BNM-INM 1 (no 1100 nm)	BNM-INM 2	
211	250–2500					Not used in KCRV
255	250–2500	Round 1	Round 2	CENAM 1		
259	250–2500	Round 1	Round 2	CENAM 1		
196	250–2500	Round 1	Round 2	CSIRO 1	CSIRO 2	
206	250–2500	Round 1	Round 2	CSIRO 1	CSIRO 2	
247	250–2500	Round 1		CSIRO 1 (no 2500 nm)	CSIRO 2	
238	290–900	Round 2	Round 3		HUT 2	
245	290–900	Round 2	Round 3	HUT 1	HUT 2	
257	290 –900	Round 2	Round 3	HUT 1	HUT 2	
207	300–2200	Round 1	Round 2	IFA-CSIC 1	IFA-CSIC 2	
209	300–2200	Round 1	Round 2	IFA-CSIC 1	IFA-CSIC 2	
249	300–2200					
214	250–850	Round 1	Round 2	MSL-IRL 1	MSL-IRL 2	
215	250–850					
258	250–850	Round 1	Round 2	MSL-IRL 1	MSL-IRL 2	
208	250–700 & 1150–2500	Round 2	Round 3	NIM 3		
216	250–700	Round 2	Round 3	NIM 3		
235	250–700 & 1150–2500	Round 2	Round 3	NIM 3		
PA848	300–2500	Round 1	Round 2	NIM 1	NIM 2	KCRV only 750–1100
P249c	300–2500					
PA847	300–2500	Round 1	Round 2	NIM 1	NIM 2	
244	250–2500	Round 2	Round 3		NIST 2	
251	250–2500	Round 2	Round 3	NIST 1	NIST 2	
260	250–2500	Round 2	Round 3	NIST 1	NIST 2	
213	250–2500, not 555		Round 3	NMIJ 1	NMIJ 2	
220	250–2500, not 555	Round 2	Round 3	NMIJ 1	NMIJ 2	
252	250–2500, not 555	Round 2	Round 3	NMIJ 1	NMIJ 2	
210	250–2500, not 555	Round 1	Round 2	NRC 1		
218	250–2500, not 555					
248	250–2500, not 555	Round 1	Round 2	NRC 1		
P257c	300–2500, not 555	Round 1	Round 2	NRC 1		Not used in KCRV
P252c	300–2500, not 555					
P250c	300–2500, not 555	Round 1	Round 2	NRC 1		
198	250–2500	Round 2	Round 3		PTB 2	
227	250–2500	Round 2	Round 3	PTB 1	PTB 2	
240	250–2500	Round 2	Round 3	PTB 1	PTB 2	
195	250–2500	Round 1	Round 2	VNIIOFI 1		
217	250–2500	Round 1	Round 2	VNIIOFI 1		

17.7.2 Uncertainties and Cut-off

For each NMI the combined standard uncertainty associated with its measurement of a 'typical' lamp has been calculated by taking a simple average of the declared combined standard uncertainties associated with all measurements of all lamps made by that NMI. It is this 'typical' uncertainty that is used in the calculation of the KCRV through the constraint equation. Because Type II lamps are not used in the determination of the KCRV, a 'typical' uncertainty has been calculated for Type I lamps only – apart from for NIM in the spectral region where no Type I lamp measurements can be included.

The cut-off has been calculated by determining the median uncertainty value and then taking the simple mean of all uncertainties less than or equal to this value. The 'typical' lamp standard uncertainties are shown graphically, along with the cut-off in Figure 17-4.

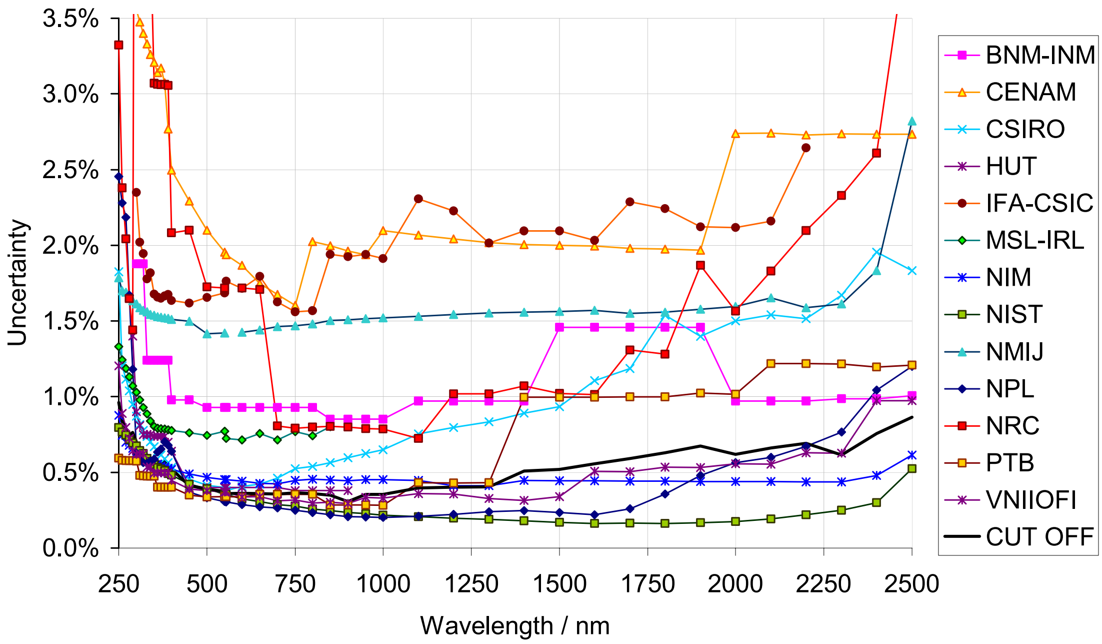

Figure 17-4 Combined standard uncertainty associated with measurements made by of a 'typical' lamp by each participant and cut-off. Points at adjacent wavelengths are joined by straight-line segments to facilitate visualisation.

For the constraint equation, the uncertainties used to determine the weights are these 'typical' uncertainties, limited by the cut-off. These are given in Table 17-2. The uncertainties for the constraint equation are either the values in this table, or the cut-off value given in the final column, if this is greater. These values were supplied to the software separately from the analysis. The analysis solution used the full uncertainties that were potentially different for each lamp and considered correlations between measurements made by an individual participant.

Table 17-2 Combined standard uncertainty associated with the measurement of a 'typical' lamp by each participant. Those uncertainties in bold red are lower than the calculated cut-off given in the final column. For the calculation of the constraint, these uncertainties have been replaced by the cut-off uncertainty. For NMIs that measured both types of lamp, this table lists the uncertainties for Type I lamps only, apart from for NIM in the region 750 – 1100 nm.

Wavelength	BNM-INM	CENAM	CSIRO	HUT	IFA-CSIC	MSL-IRL	NIM	NIST	NMIJ	NPL	NRC	PTB	VNIIOFI	CUT-OFF
250		6.87 %	1.82 %			1.33 %	**0.88 %**	**0.80 %**	1.78 %	2.45 %	3.32 %	**0.60 %**	1.20 %	0.96 %
260		4.80 %	1.20 %			1.24 %	**0.74 %**	**0.77 %**	1.70 %	2.28 %	2.38 %	**0.58 %**	0.89 %	0.84 %
270		3.84 %	1.12 %			1.18 %	**0.70 %**	**0.75 %**	1.69 %	2.18 %	2.04 %	**0.58 %**	0.80 %	0.79 %
280		3.72 %	1.04 %			1.13 %	**0.68 %**	**0.72 %**	1.66 %	1.67 %	1.65 %	**0.58 %**	**0.72 %**	0.75 %
290		3.63 %	0.95 %	1.40 %		1.07 %	**0.66 %**	**0.69 %**	1.63 %	1.18 %	1.44 %	**0.58 %**	**0.64 %**	0.76 %
300	1.88 %	3.55 %	0.87 %	0.90 %	2.35 %	1.03 %	**0.63 %**	**0.67 %**	1.61 %	**0.63 %**	10.06 %	**0.57 %**	**0.62 %**	0.70 %
310	1.88 %	3.47 %	0.82 %	0.81 %	2.02 %	0.98 %	**0.61 %**	**0.64 %**	1.59 %	**0.60 %**	7.09 %	**0.48 %**	**0.62 %**	0.65 %
320	1.88 %	3.40 %	0.78 %	0.75 %	1.94 %	0.93 %	**0.60 %**	**0.62 %**	1.57 %	**0.56 %**	6.10 %	**0.48 %**	**0.62 %**	0.63 %
330	1.24 %	3.33 %	0.74 %	0.75 %	1.78 %	0.89 %	**0.59 %**	**0.59 %**	1.56 %	**0.56 %**	5.05 %	**0.47 %**	**0.53 %**	0.61 %
340	1.24 %	3.26 %	0.70 %	0.75 %	1.82 %	0.84 %	**0.57 %**	**0.57 %**	1.54 %	**0.57 %**	4.06 %	**0.47 %**	**0.53 %**	0.60 %
350	1.24 %	3.21 %	0.67 %	0.74 %	1.68 %	0.80 %	**0.56 %**	**0.55 %**	1.54 %	0.59 %	3.07 %	**0.47 %**	**0.49 %**	0.58 %
360	1.24 %	3.14 %	0.64 %	0.74 %	1.66 %	0.79 %	**0.55 %**	**0.53 %**	1.53 %	0.63 %	3.06 %	**0.40 %**	**0.50 %**	0.57 %
370	1.24 %	3.17 %	0.61 %	0.74 %	1.65 %	0.79 %	**0.54 %**	**0.52 %**	1.52 %	0.65 %	3.06 %	**0.40 %**	**0.50 %**	0.57 %
380	1.24 %	3.07 %	0.59 %	0.74 %	1.67 %	0.79 %	**0.54 %**	**0.51 %**	1.52 %	0.70 %	3.06 %	**0.40 %**	**0.50 %**	0.57 %
390	1.24 %	2.77 %	0.57 %	0.70 %	1.68 %	0.78 %	**0.53 %**	**0.49 %**	1.52 %	0.68 %	3.06 %	**0.40 %**	**0.50 %**	0.55 %
400	0.98 %	2.50 %	0.53 %	0.64 %	1.64 %	0.78 %	**0.52 %**	**0.48 %**	1.51 %	0.64 %	2.08 %	**0.40 %**	**0.45 %**	0.52 %
450	0.98 %	2.29 %	0.45 %	**0.41 %**	1.62 %	0.76 %	0.49 %	0.42 %	1.50 %	**0.37 %**	2.10 %	**0.35 %**	**0.39 %**	0.41 %
500	0.93 %	2.10 %	0.41 %	0.40 %	1.66 %	0.74 %	0.47 %	0.39 %	1.41 %	**0.33 %**	1.72 %	**0.34 %**	**0.38 %**	0.39 %
550	0.93 %	1.95 %	0.40 %	0.40 %	1.69 %	0.77 %	0.45 %	**0.35 %**	1.42 %	**0.31 %**	1.72 %	**0.34 %**	**0.37 %**	0.37 %
555	0.93 %	1.94 %	0.38 %	0.40 %	1.76 %	0.72 %	0.45 %	**0.35 %**		**0.31 %**		**0.34 %**	0.37 %	0.36 %
600	0.93 %	1.87 %	0.41 %	0.40 %	1.72 %	0.71 %	0.44 %	**0.33 %**	1.43 %	**0.29 %**	1.72 %	**0.34 %**	**0.34 %**	0.36 %

Wavelength	BNM-INM	CENAM	CSIRO	HUT	IFA-CSIC	MSL-IRL	NIM	NIST	NMIJ	NPL	NRC	PTB	VNIIOFI	CUT-OFF
650	0.93 %	1.75 %	0.42 %	0.40 %	1.79 %	0.76 %	0.43 %	**0.31 %**	1.44 %	**0.27 %**	1.71 %	**0.36 %**	**0.34 %**	0.36 %
700	0.93 %	1.68 %	0.46 %	0.40 %	1.62 %	0.71 %	0.42 %	**0.29 %**	1.46 %	**0.26 %**	0.81 %	**0.35 %**	**0.31 %**	0.36 %
750	0.93 %	1.60 %	0.52 %	0.38 %	1.56 %	0.77 %	0.45 %	**0.28 %**	1.47 %	**0.25 %**	0.79 %	**0.35 %**	**0.32 %**	0.36 %
800	0.93 %	2.02 %	0.54 %	0.38 %	1.57 %	0.74 %	0.45 %	**0.26 %**	1.48 %	**0.23 %**	0.80 %	**0.36 %**	**0.30 %**	0.36 %
850	0.85 %	2.00 %	0.57 %	0.38 %	1.94 %	0.80 %	0.45 %	**0.25 %**	1.50 %	**0.22 %**	0.80 %	**0.28 %**	**0.30 %**	0.35 %
900	0.85 %	1.96 %	0.60 %	0.38 %	1.93 %		0.45 %	**0.24 %**	1.51 %	**0.21 %**	0.80 %	**0.28 %**	**0.29 %**	0.31 %
950	0.85 %	1.94 %	0.62 %		1.94 %		0.45 %	**0.23 %**	1.51 %	**0.20 %**	0.79 %	**0.28 %**	**0.33 %**	0.35 %
1000	0.85 %	2.10 %	0.65 %		1.91 %		0.45 %	**0.22 %**	1.52 %	**0.20 %**	0.79 %	**0.28 %**	**0.33 %**	0.36 %
1100	0.97 %	2.07 %	0.75 %		2.31 %		0.45 %	**0.21 %**	1.53 %	**0.21 %**	0.72 %	0.43 %	**0.36 %**	0.40 %
1200	0.97 %	2.04 %	0.80 %		2.23 %		0.41 %	**0.20 %**	1.54 %	**0.22 %**	1.02 %	0.43 %	**0.36 %**	0.40 %
1300	0.97 %	2.02 %	0.83 %		2.01 %		0.41 %	**0.19 %**	1.55 %	**0.24 %**	1.02 %	0.43 %	**0.33 %**	0.41 %
1400	0.97 %	2.01 %	0.89 %		2.09 %		**0.45 %**	**0.18 %**	1.56 %	**0.25 %**	1.07 %	1.00 %	**0.31 %**	0.51 %
1500	1.46 %	2.00 %	0.93 %		2.09 %		**0.44 %**	**0.17 %**	1.56 %	**0.23 %**	1.02 %	1.00 %	**0.34 %**	0.52 %
1600	1.46 %	1.99 %	1.11 %		2.03 %		**0.44 %**	**0.16 %**	1.57 %	**0.22 %**	1.01 %	1.00 %	**0.51 %**	0.56 %
1700	1.46 %	1.98 %	1.19 %		2.29 %		**0.44 %**	**0.17 %**	1.55 %	**0.26 %**	1.31 %	1.00 %	**0.50 %**	0.59 %
1800	1.46 %	1.97 %	1.54 %		2.24 %		**0.44 %**	**0.16 %**	1.56 %	**0.36 %**	1.28 %	1.00 %	**0.53 %**	0.63 %
1900	1.46 %	1.97 %	1.40 %		2.12 %		**0.44 %**	**0.17 %**	1.58 %	**0.48 %**	1.87 %	1.02 %	**0.53 %**	0.67 %
2000	0.97 %	2.74 %	1.50 %		2.12 %		**0.44 %**	**0.17 %**	1.59 %	**0.56 %**	1.56 %	1.02 %	**0.56 %**	0.62 %
2100	0.97 %	2.74 %	1.54 %		2.16 %		**0.44 %**	**0.19 %**	1.65 %	**0.60 %**	1.83 %	1.22 %	**0.55 %**	0.66 %
2200	0.97 %	2.73 %	1.51 %		2.64 %		**0.44 %**	**0.22 %**	1.59 %	**0.67 %**	2.10 %	1.22 %	**0.63 %**	0.69 %
2300	0.99 %	2.74 %	1.67 %				**0.44 %**	**0.25 %**	1.61 %	0.77 %	2.33 %	1.22 %	0.63 %	0.61 %
2400	0.99 %	2.73 %	1.95 %				**0.48 %**	**0.30 %**	1.83 %	1.04 %	2.61 %	1.20 %	0.97 %	0.76 %
2500	1.01 %	2.73 %	1.83 %				**0.61 %**	**0.52 %**	2.82 %	1.20 %	4.22 %	1.21 %	0.97 %	0.86 %

17.7.3 Software testing

The analysis procedure described here was performed using software developed by the pilot. The software was tested both to ensure that it performed the analysis described in this report and to ensure that the results were consistent with the expected behaviour of the model used.

17.7.3.1 Software functional testing

The software was developed to accept measurements provided in worksheets of Excel workbooks, to allow for missing and excluded data, and was written as a Visual Basic front end to Fortran code. The linear algebra operations required for the solution process were undertaken using routines from the NAG Fortran library, a proprietary library of high quality numerical software. Prototype software, used to investigate the appropriateness of the model for simple cases (no missing lamps), was initially developed using the Matlab programming package. The Visual Basic/Fortran software was confirmed to give the same results as the Matlab software under the simpler conditions.

17.7.3.2 Model conceptual tests

A series of tests were performed to test the concepts of the model and the performance of the software.

The model is able to calculate DoEs for measurements that are not to be included in the constraint equation. For example, CENAM and the Type II lamps are not to be used to determine the KCRV (and therefore must be given a weight of zero in the constraint equation). The question arises as to how these measurements can influence the unilateral DoEs of the other participants.

The software was run twice. On the first occasion CENAM and the Type II lamps were included in the analysis, but with a weight of zero in the constraint equation. On the second occasion these lamps were not included in the analysis at all. The unilateral DoEs calculated for the other participants differed slightly in these two cases, but never by more than 0.05 % for any participant at any wavelength. This difference is not significant in the analysis of this comparison (there is no change in the number of NMIs with the value of the unilateral DoE greater than its uncertainty at any wavelength). We believe that the cause of this small discrepancy is that the round-dependent correlation between all the pilot's measurements, which is considered in the LSA solution, means that with additional pilot measurements included (the pilot measurements of the CENAM and Type II lamps), the results are slightly affected.

This test was performed with no measurement exclusions and no additional uncertainty due to artefact instability. With the artefact instability factor included, its value had a small dependence on whether the CENAM and Type II lamps were included. Therefore, for the purposes of the comparison analysis, the full software was run twice. In the first instance these CENAM and Type II lamps were excluded. In the second instance these lamps were included. For most participants, the results of the first model were used; the second model gave values for CENAM and the Type II lamps.

A similar test was performed using an entirely different constraint. The constraint chosen was to set the weight for one NMI that measured at all the wavelengths to unity in the constraint equation and the weight of all other NMIs (including the pilot) to zero. Naturally the unilateral DoEs for all participants shifted, but the shift was almost a constant for all NMIs: all NMIs shifted by a certain amount plus or minus a small variation of up to 0.03 %. Again this small variation is probably due to the round-dependent correlations. In a test of an earlier version of the software, which did not consider the round dependent correlations, the shift was constant for all NMIs.

The bilateral DoEs calculated for the model with the normal constraint equation were compared to the bilateral DoEs calculated for the model with the constraint equation including only one NMI. The bilateral DoEs (both values and uncertainties) were identical in the two cases as expected.

17.7.4 Uncertainty in artefact factor

The uncertainty associated with the $\eta_{\ell}^{i,r}$, the artefact factor (see Section 17.5.2), has been determined such that the model matches the data, i.e., the chi-squared ratio is equal to unity. It is meaningless to determine this uncertainty to many significant digits. We choose to provide a value that yields a chi-squared value that rounds to 1.0, i.e., to a value between 0.95 and 1.05. The uncertainty due to the artefact factor is listed for each wavelength in Table 17-3.

Table 17-3 Chi-squared ratio before and after the uncertainty in the artefact instability factor is introduced and the value of that artefact instability factor at each wavelength.

Wavelength	Chi-squared Ratio before artefact instability uncertainty introduced	Artefact instability uncertainty introduced / %	Chi-squared ratio after
250	1.60	0.40	1.00
260	1.51	0.24	1.02
270	1.33	0.16	1.00
280	1.74	0.27	1.00
290	2.01	0.25	0.99
300	2.28	0.26	1.01
310	2.69	0.30	1.00
320	2.59	0.27	1.01
330	2.40	0.24	1.02
340	2.54	0.23	1.02
350	2.36	0.22	1.02
360	2.28	0.20	1.02
370	2.20	0.19	1.01
380	2.16	0.18	1.01
390	2.16	0.17	1.01
400	2.18	0.18	0.99
450	2.56	0.22	1.00
500	2.63	0.20	0.97
550	2.98	0.20	0.99
555	2.49	0.18	1.00
600	2.89	0.18	1.00
650	3.09	0.16	0.99
700	2.33	0.14	1.03
750	2.35	0.13	1.02
800	2.46	0.13	1.02
850	3.20	0.18	1.00
900	2.91	0.14	1.01
950	2.99	0.15	0.98
1000	2.85	0.14	1.00
1100	2.07	0.11	0.99
1200	1.57	0.09	1.00
1300	1.53	0.09	1.01
1400	1.69	0.11	1.00
1500	1.63	0.10	0.98
1600	1.45	0.08	0.98
1700	1.19	0.05	1.01
1800	1.38	0.09	1.02
1900	1.62	0.15	1.01
2000	1.37	0.16	0.99
2100	1.31	0.14	0.99

2200	1.08	0.07	0.99
2300	**0.94**	**0.00**	**0.94**
2400	**0.96**	**0.00**	**0.96**
2500	1.61	0.30	0.99

The standard uncertainty associated with the artefact factor has been plotted graphically by wavelength in Figure 17-5. Although we do not wish to read too much information into this graph, it is suggestive of an offset of approximately 0.1 % (due perhaps to movement of the filament, which can affect all wavelengths), combined with an exponential decay (due perhaps to changes in filament resistance). This figure supports the hypothesis that this factor is required to account for random changes in the lamps.

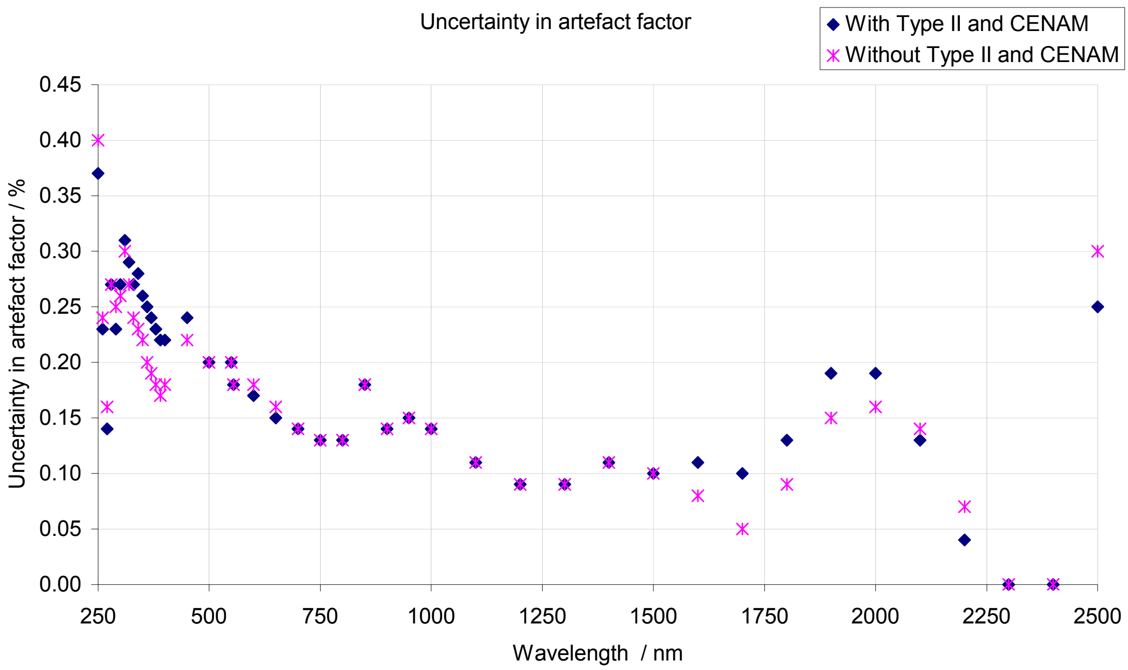

Figure 17-5 Graphical representation of the uncertainty in the artefact stability factor required at each wavelength in order to achieve a chi-squared ratio of unity.

The magnitude of this effect is “small” in some sense, but significant compared with the uncertainties declared by some participants.

The number of participants with unilateral DoEs inconsistent with the KCRV at different levels is given in Table 17-4. The count is cumulative – the number of NMIs having an absolute value for the unilateral DoEs greater than twice the standard uncertainty includes those NMIs with unilateral DoEs having an absolute value greater than three and four times the standard uncertainty.

Table 17-4 Number of NMIs having an absolute value for the unilateral DoE greater than 2, 3 or 4 times its associated standard uncertainty. Note, the pilot, NPL, is included within this data, but the Type II lamps are not, apart from for NIM in the region for which there are no Type I measurements. Also CENAM is not included in these results

Wavelength	Number of NMIs measuring this wavelength	Number of NMIs with absolute unilateral DoE values greater than		
		2 × standard uncertainty	3 × standard uncertainty	4 × standard uncertainty
250	9	0	0	0
260	9	0	0	0
270	9	0	0	0
280	9	0	0	0
290	10	0	0	0
300	12	**1**	0	0
310	12	0	0	0
320	12	0	0	0
330	12	0	0	0
340	12	0	0	0
350	12	0	0	0
360	12	0	0	0
370	12	0	0	0
380	12	0	0	0
390	12	0	0	0
400	12	0	0	0
450	12	0	0	0
500	12	0	0	0
550	12	0	0	0
555	10	0	0	0
600	12	0	0	0
650	12	0	0	0
700	12	0	0	0
750	12	0	0	0
800	12	0	0	0
850	12	**1**	0	0
900	11	**3**	**1**	0
950	10	**2**	0	0
1000	10	**3**	0	0
1100	10	**3**	**1**	0
1200	10	**2**	**1**	0
1300	10	**2**	**1**	0
1400	10	**3**	**2**	**1**
1500	10	**2**	**1**	0
1600	10	**3**	**1**	0
1700	10	**3**	0	0
1800	10	**3**	**1**	0
1900	10	**1**	0	0
2000	10	**1**	0	0
2100	10	**1**	0	0
2200	10	0	0	0
2300	9	**1**	0	0
2400	9	**1**	0	0
2500	9	**1**	0	0

17.7.5 KCRV and DoEs excluding one NMI from the KCRV

At wavelengths where two or more NMIs have discrepant unilateral DoEs, it is possible that the NMI with the larger discrepancy influences the KCRV in such a way as to bias it away from the other NMI. Therefore, if the NMI with the largest discrepancy is excluded from the calculation of the KCRV (by having a weight of zero set in the constraint equation), it is possible that other discrepant NMIs are no longer discrepant. If only one NMI is discrepant, no other NMI can benefit from that discrepant NMI being excluded.

At wavelengths where at least two NMIs had the absolute value of the unilateral DoE greater than twice the associated standard uncertainty, the NMI with the DoE whose absolute value was the greatest multiple of the standard uncertainty was excluded from the KCRV (not necessarily the same NMI at each wavelength), and the calculations were repeated. After this process, the number of NMIs with the absolute value of the unilateral DoEs greater that 2, 3 and 4 times the associated standard uncertainty are shown in Table 17-9.

Table 17-5 Number of NMIs with unilateral DoEs further from the KCRV than 2, 3 or 4 times the standard uncertainty of that unilateral DoE after one NMI is removed at some wavelengths (not necessarily the same NMI at each wavelength). The only wavelengths affected are those in this table.

Wavelength	Number of NMIs measuring this wavelength	Number of NMIs with the value of the unilateral DoEs greater than					
		2 × standard uncertainty		3 × standard uncertainty		4 × standard uncertainty	
		Now	Change	Now	Change	Now	Change
850	12	1	-2	1	0		
900	11	1	-1				
950	10	2	-1				
1000	10	2	-1	2	+1		
1100	10	2	0	1	0		
1200	10	2	0	2	+1	1	+1
1300	10	3	0	2	0	1	0
1400	10	2	0	2	+1		
1500	10	2	-1	1	0		
1600	10	2	-1	1	+1		
1700	10	1	-2	1	0		
1800	10	1	-2	1	0		

It can be seen from this table that while there is some minor improvement at the 2 times uncertainty level, at the 3 times and 4 times uncertainty level there is an increase in the number of NMIs whose unilateral DoE has a value greater than the uncertainty. This is because the two most discrepant NMIs supplied measurements that are either both greater or both less than the KCRV.

17.8 Analysis decisions

Following discussion with the participants that occurred prior to the participants seeing the comparison results, the method described above was agreed by common consent of all participants. The analysis has been performed using the model described above. For wavelengths where the model and data were inconsistent, as shown by the chi-squared test, an additional random factor was introduced to account for artefact drift. The uncertainty of this random factor was chosen to be as small as possible to achieve consistency between the model and the data.

All participants are included equitably in the KCRV, which is defined by the constraint equation as unity, being the generalised weighted geometric mean of the systematic factors for each NMI. The weights were calculated as the inverse of the square of the declared participant uncertainty for a single lamp, or the inverse of the square of the cut-off uncertainty, whichever was the smaller. For this comparison, the correlation between NIST and MSL-IRL was accounted for within the KCRV calculation. CENAM was excluded from the KCRV as requested, as were the Type II lamps, apart from for NIM in the region where no Type I measurements were taken. No other participant was excluded from the KCRV.

The results of this process are given in Chapter 18 and in the Appendix.

17.9 References

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[8] M G Cox and P M Harris. SS*f*M Best Practice Guide No. 6. Uncertainty evaluation. Technical report, National Physical Laboratory, Teddington, UK, 2004

18 Results

This chapter of the report gives the unilateral DoEs for each participant. The results are presented in three graphical forms – an overall graph showing all the results but no uncertainties for all participants which contribute to the definition of the KCRV (note CENAM are not included in this graph as discussed in chapter 5), graphs for each participant showing the unilateral DoEs, including their associated uncertainties (at $k = 2$) at all wavelengths and graphs for each wavelength showing all the participants' unilateral DoEs. It should be noted that in addition to the participants' individual graphs of their unilateral DoEs we also present, for completeness, the results for the Type II lamps in separate graphs. The results are also provided in tabulated form. In the graphs showing the overall results we have linked the individual data points with lines to aid clarity. It should however be noted that for the purposes of this comparison these lines have no meaning. For the individual participant graphs, it should further be noted that the axis scales are not uniform between participants to allow for the differences in declared uncertainties. These individual graphs include the standard uncertainty associated with the DoE value, as well as twice and three times that uncertainty. Twice the standard uncertainty is at the 95 % level of confidence and corresponds to the associated uncertainty as mandated by the Mutual Recognition Arrangement. In the single wavelength graphs and the table, the uncertainties are at the 95 % level of confidence.

The analysis was performed as described in Chapter 17. The software was run twice. On the first occasion CENAM, the Type II lamps for NRC and the Type II lamps for NIM outside the region 750 – 1100 nm were entirely excluded from the data, since they are not used to define the KCRV. The results of this process are used to establish the KCRV and the unilateral DoEs of all contributing participants. The software was then run a second time, including all the lamps, but, in the constraint equation, setting the weight for CENAM and the Type II lamps as zero. This allowed unilateral DoE for CENAM to be determined, and for information purposes, the unilateral DoEs of the Type II lamps. The second run gave slightly different answers because the application of the "artefact factor uncertainty" was different in the two cases (additional lamps), although the effect is negligible.

The bilateral DoEs were calculated from the unilateral DoEs and are given in the Appendix. Again the results were obtained by running the software twice, on the first occasion CENAM was not included and the results of that run are used to determine the bilateral DoEs for all pairs not including CENAM. To determine the bilateral DoEs between CENAM and the other participants, the results of the second run of the software, where CENAM was included, are used.

18.1 Results of all participants affecting the KCRV

The results of all participants contributing to the definition of the KCRV are presented below, in Figure 18-1and Figure 18-2.

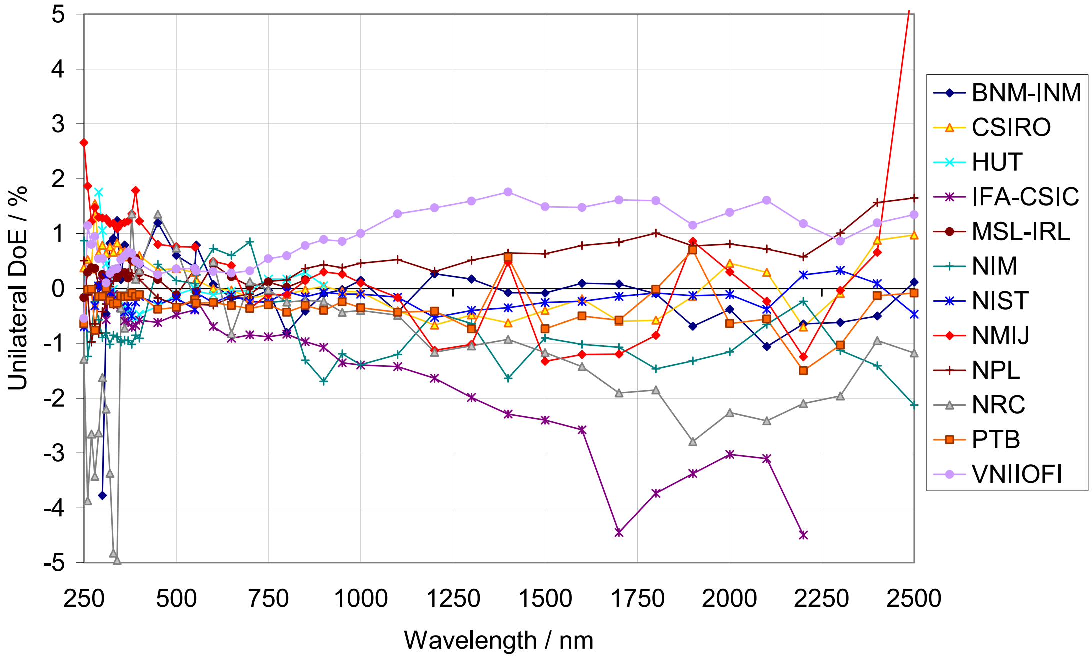


Figure 18-1Unilateral DoEs for all participants that are included in the constraint equation over the full comparison wavelength range.

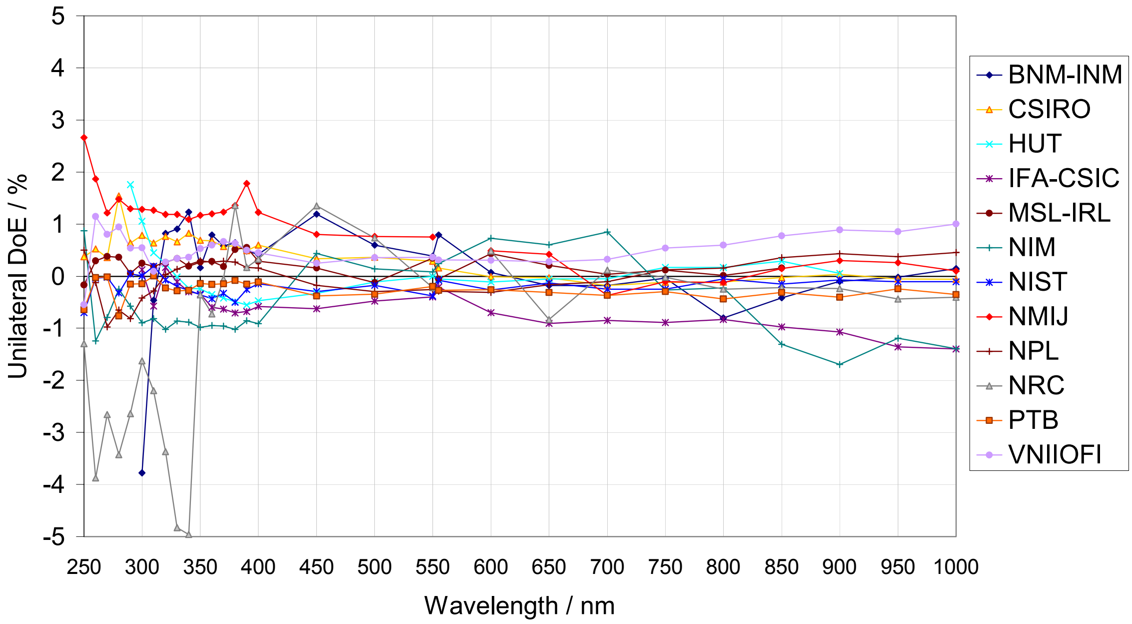
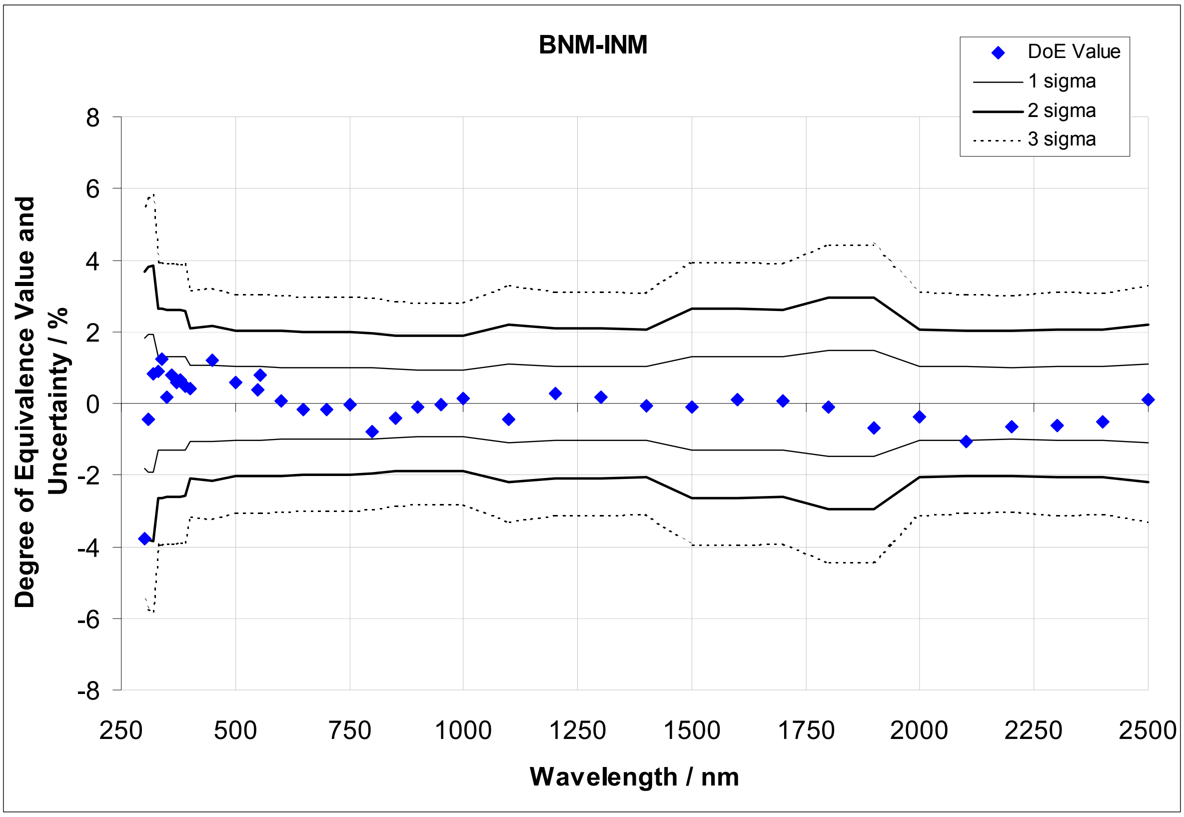


Figure 18-2Unilateral DoEs for all participants that are in the constraint equation over the wavelength interval from 250 to 1000 nm.

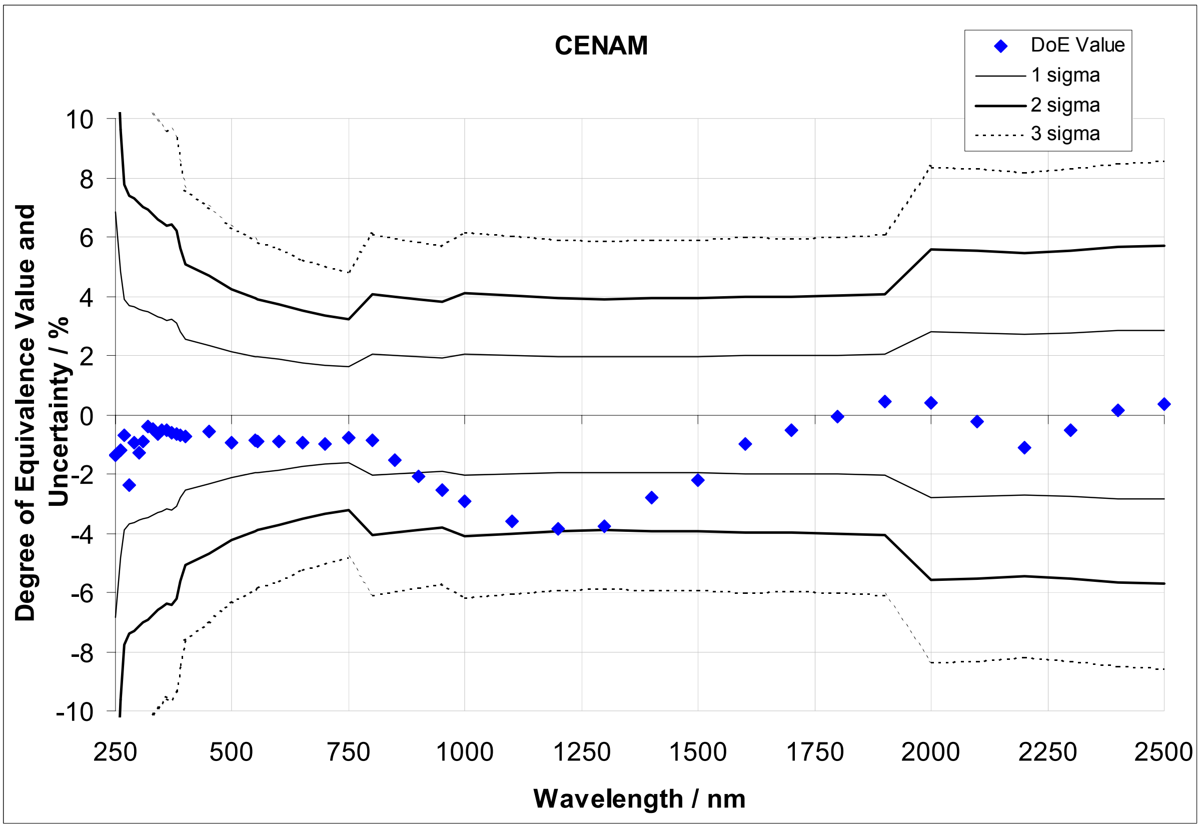
18.2 Results for each participant — all wavelengths

In these graphs, the terms “1 sigma”, “2 sigma”, “3 sigma” correspond to the standard uncertainty associated with the unilateral DoE value. Under the assumption of normality made in Chapter 17, “2 sigma” corresponds to the 95 % level of confidence associated with the DoE value as required by the Mutual Recognition Arrangement.

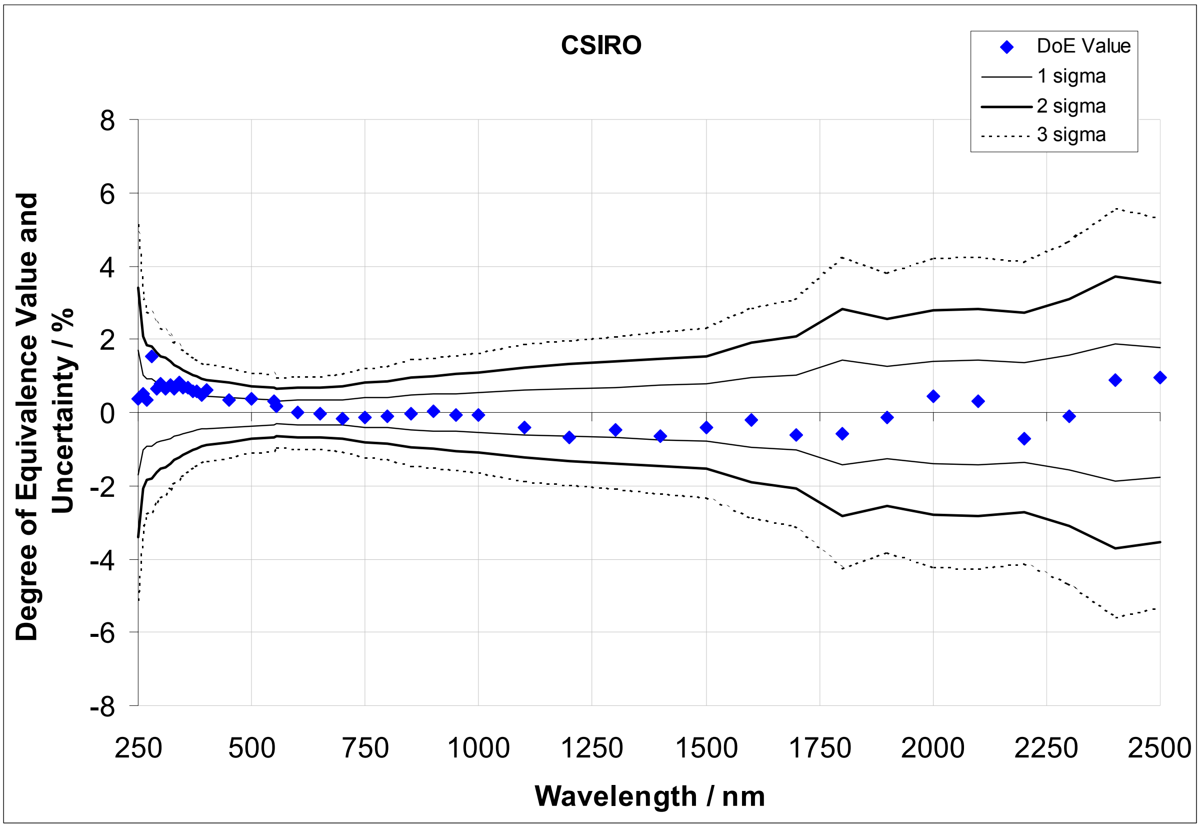
18.2.1 Results for BNM-INM



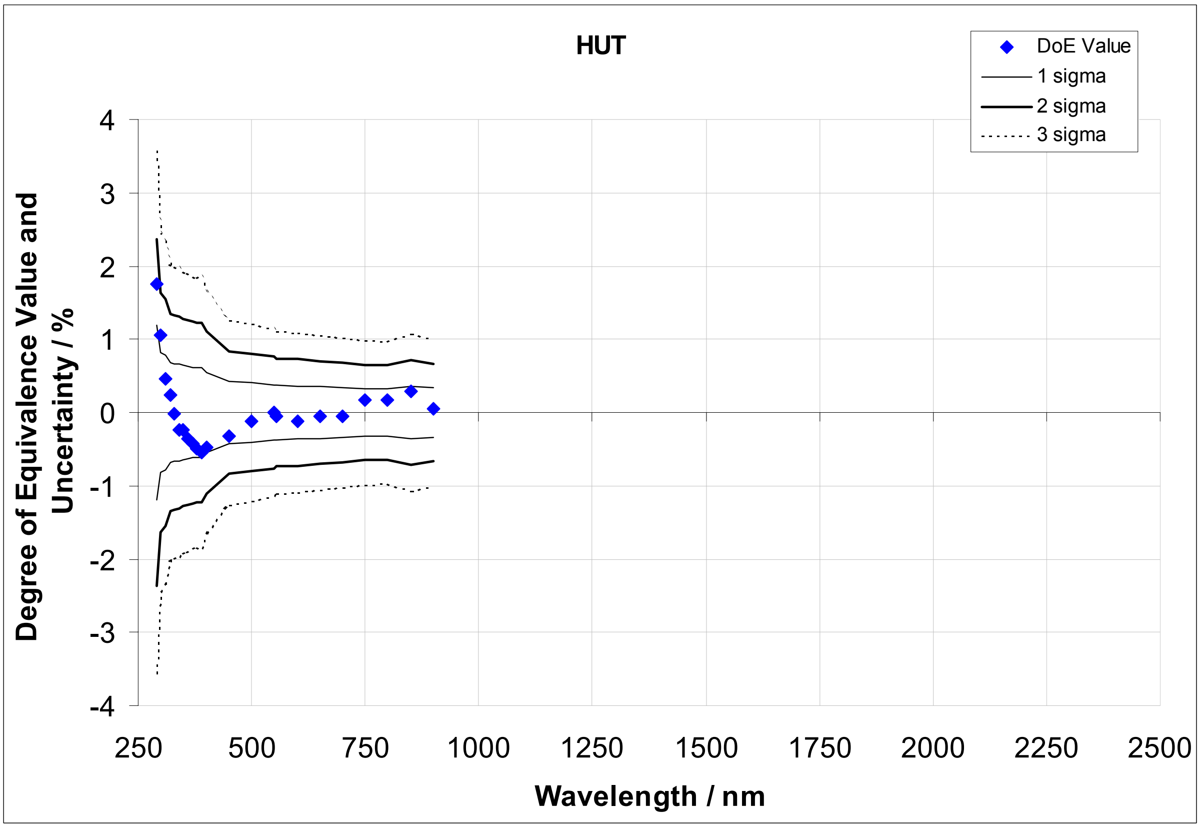
18.2.2 Results for CENAM



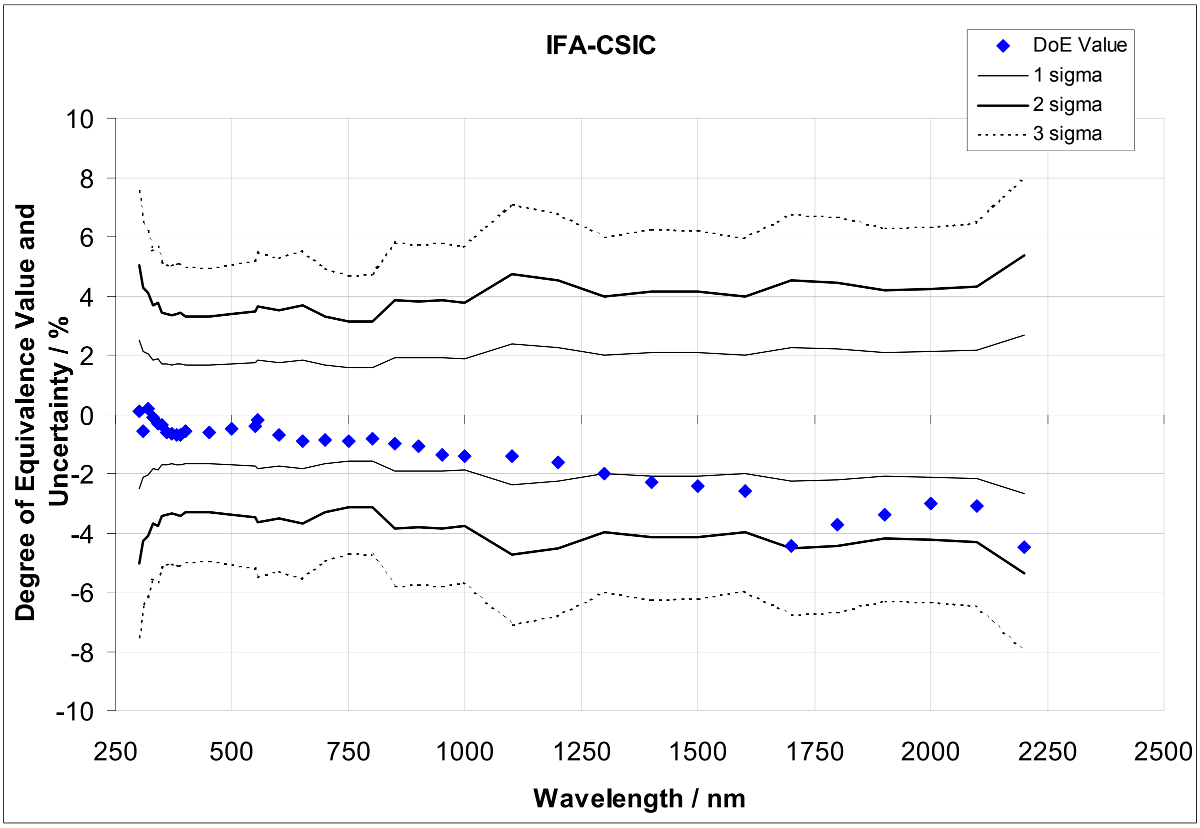
18.2.3 Results for CSIRO



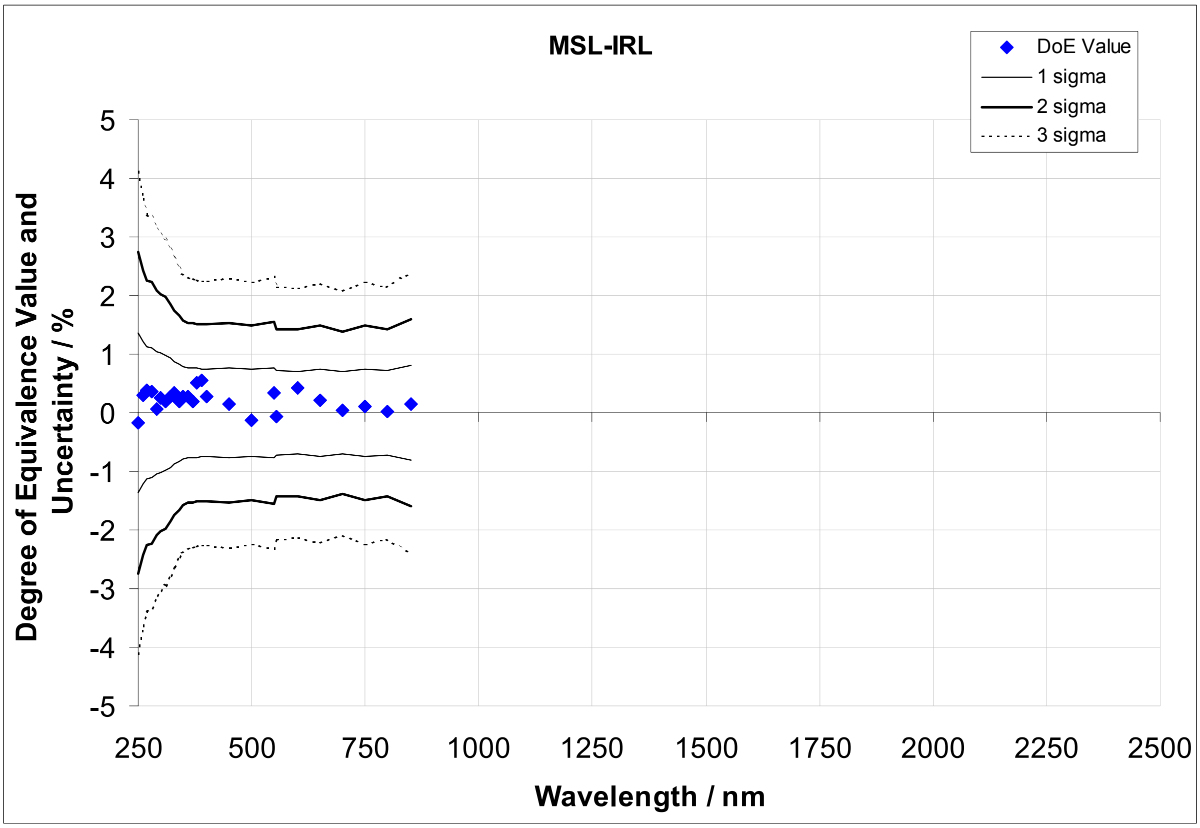
18.2.4 Results for HUT



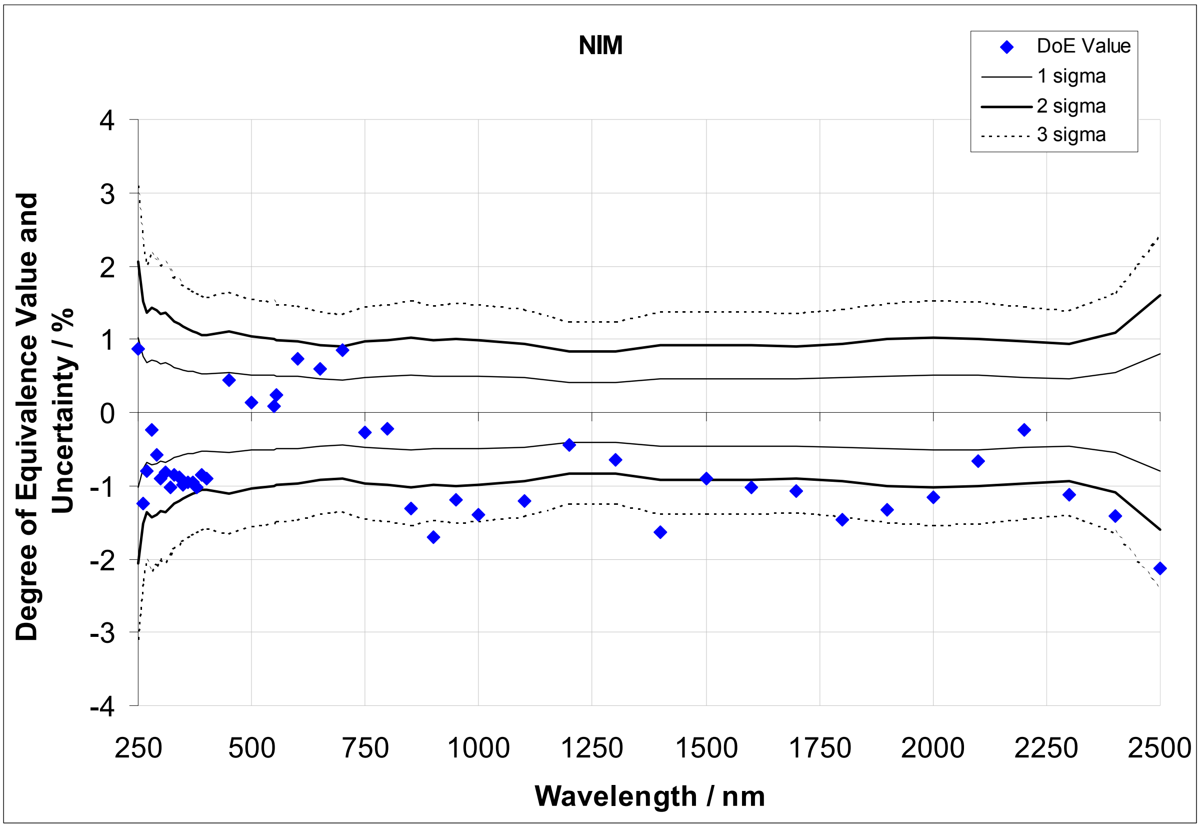
18.2.5 Results for IFA-CSIC

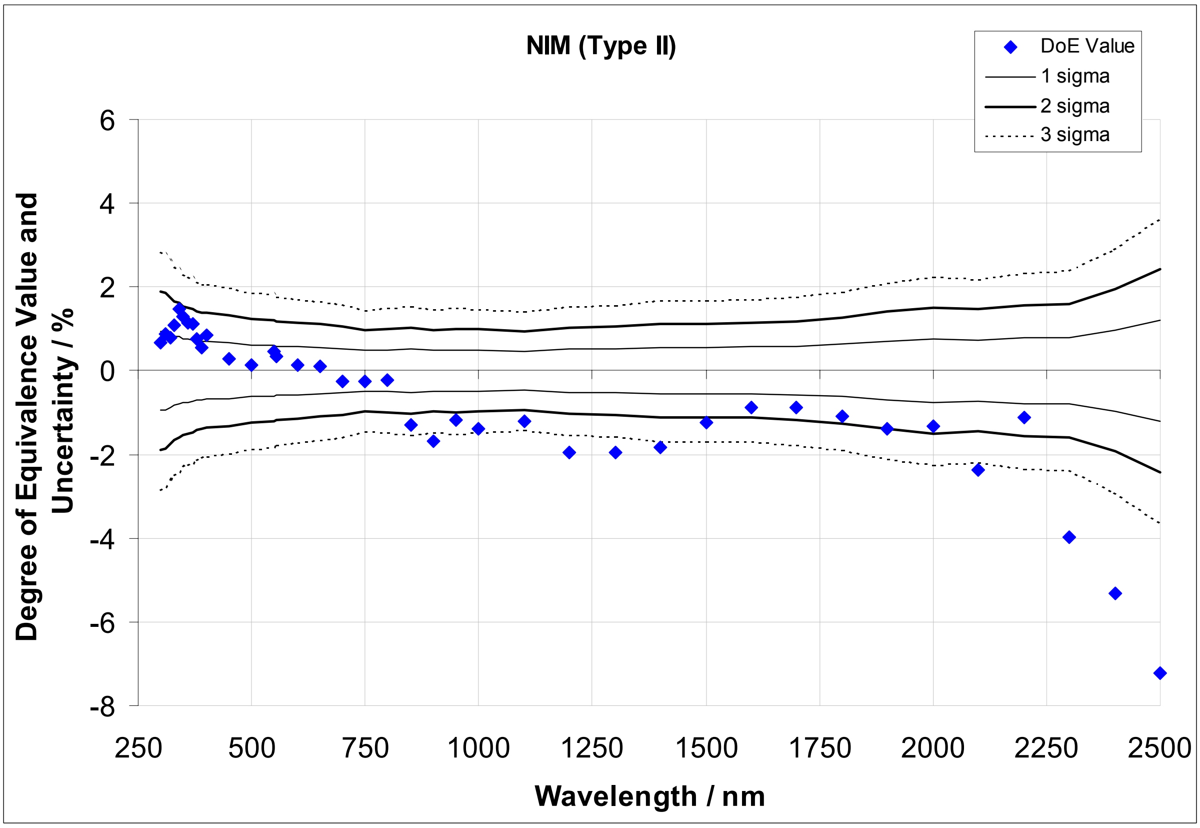


18.2.6 Results for MSL-IRL

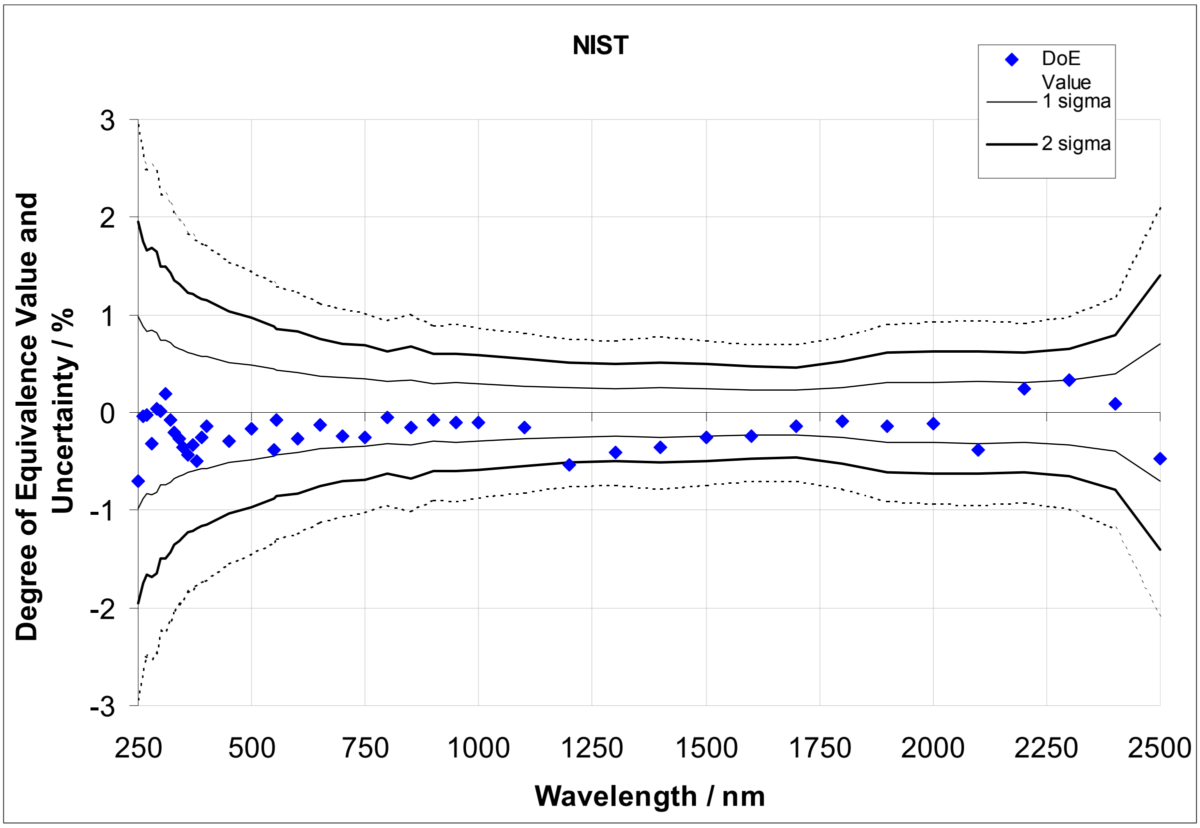


18.2.7 Results for NIM

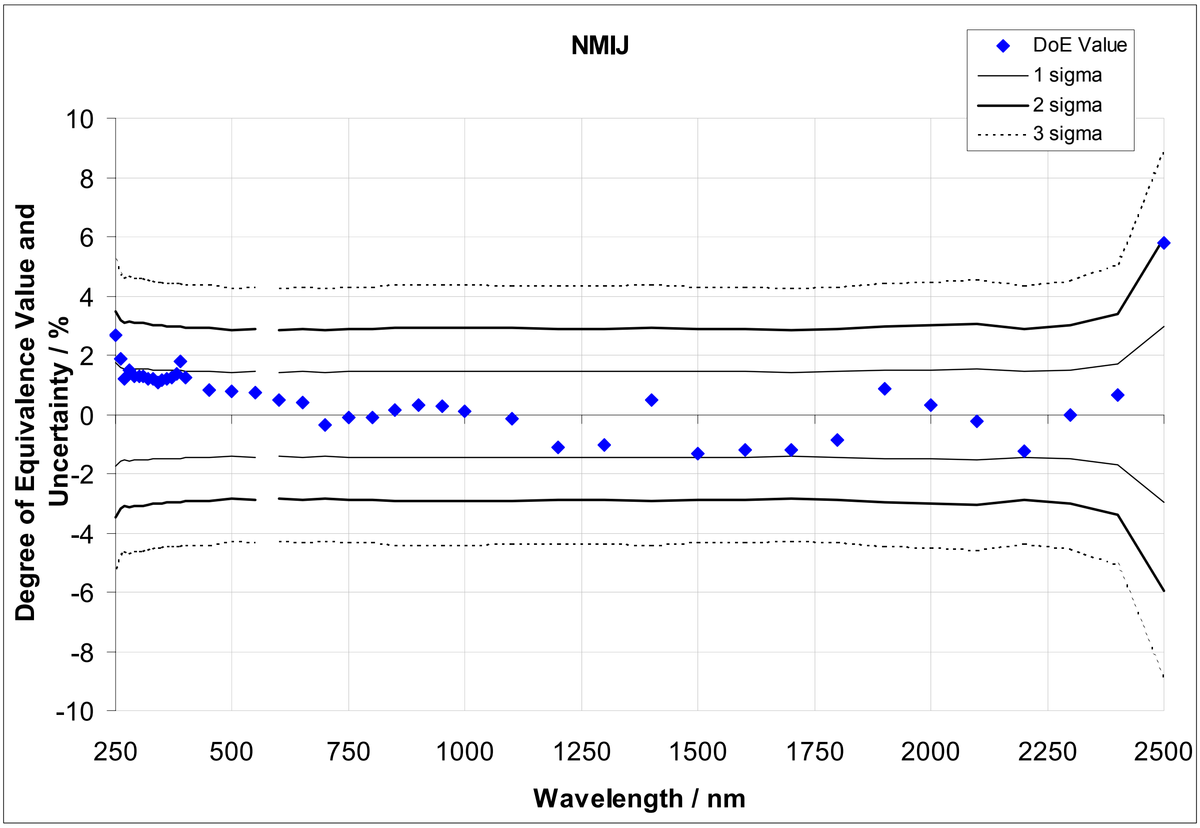




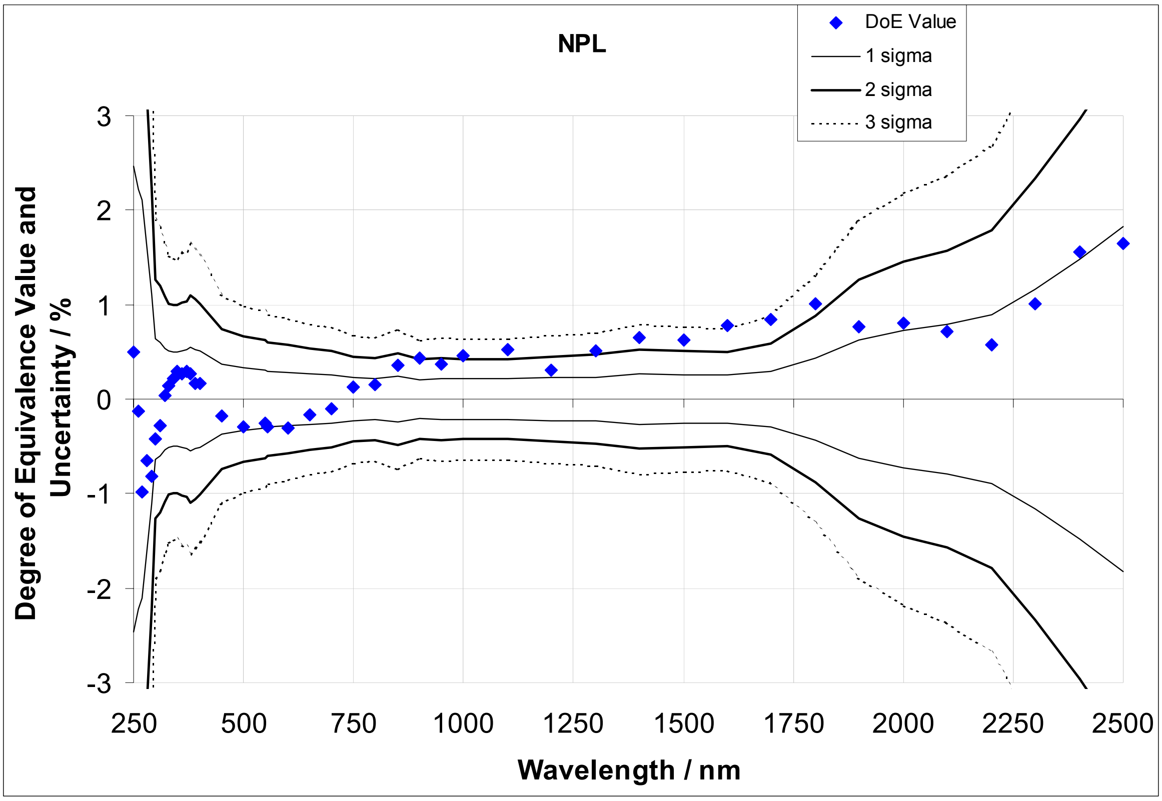
18.2.8 Results for NIST



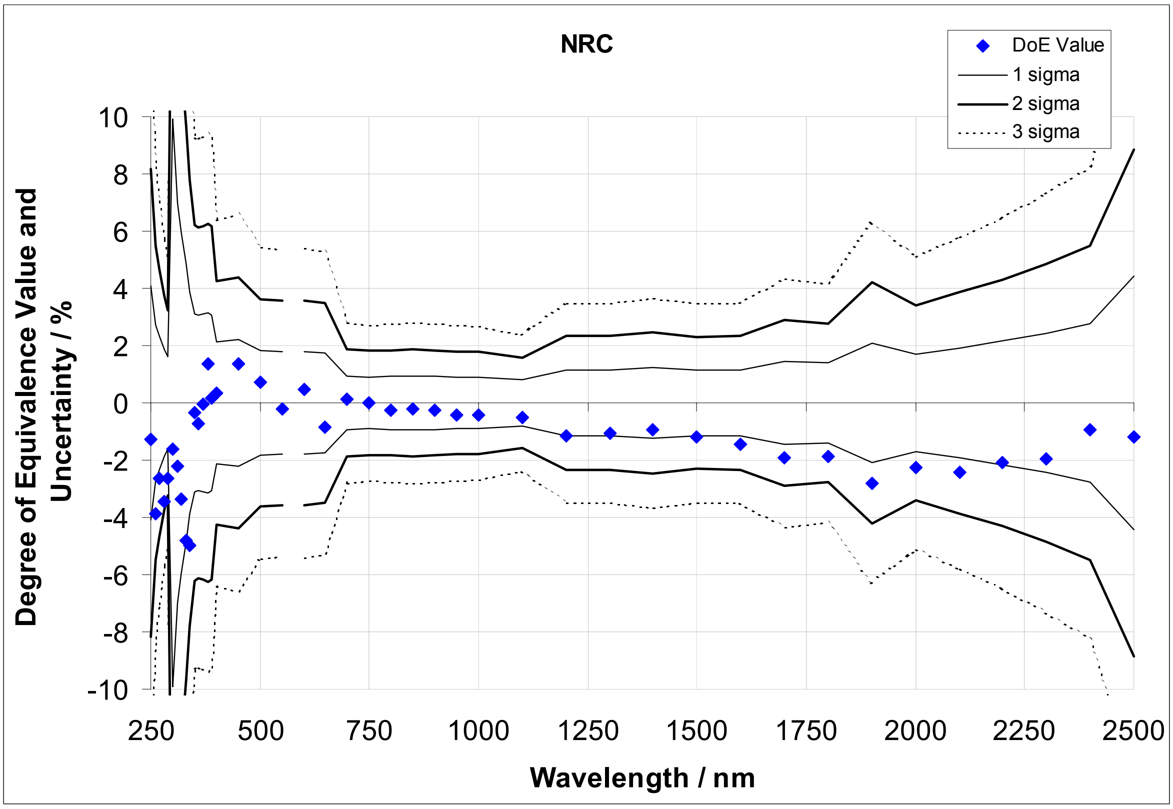
18.2.9 Results for NMIJ

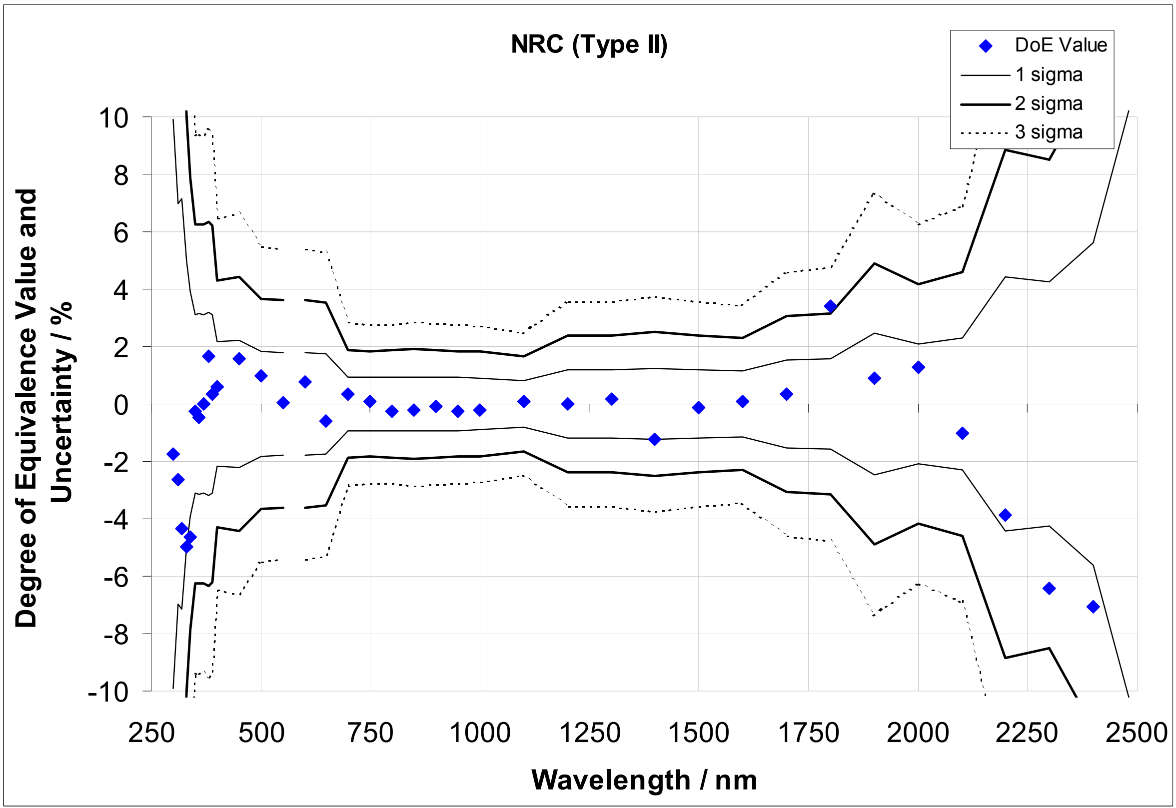


18.2.10 Results for NPL

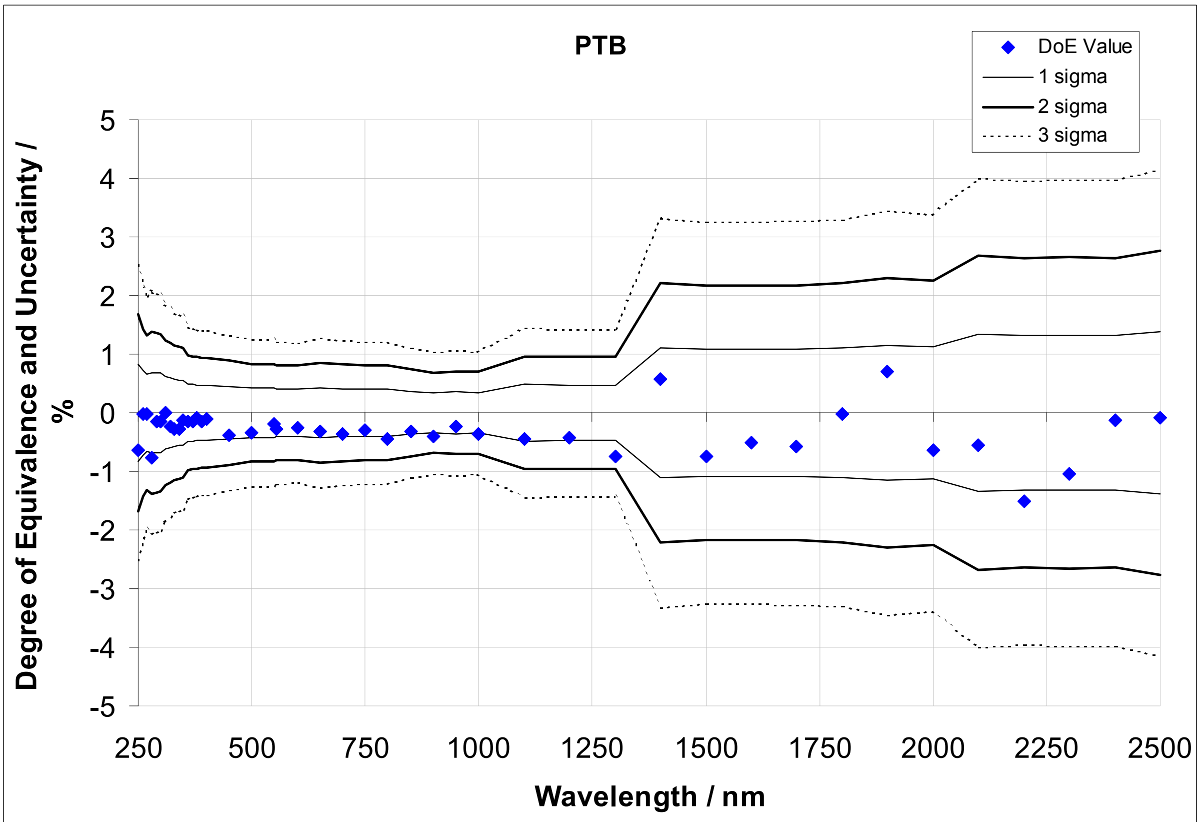


18.2.11 Results for NRC

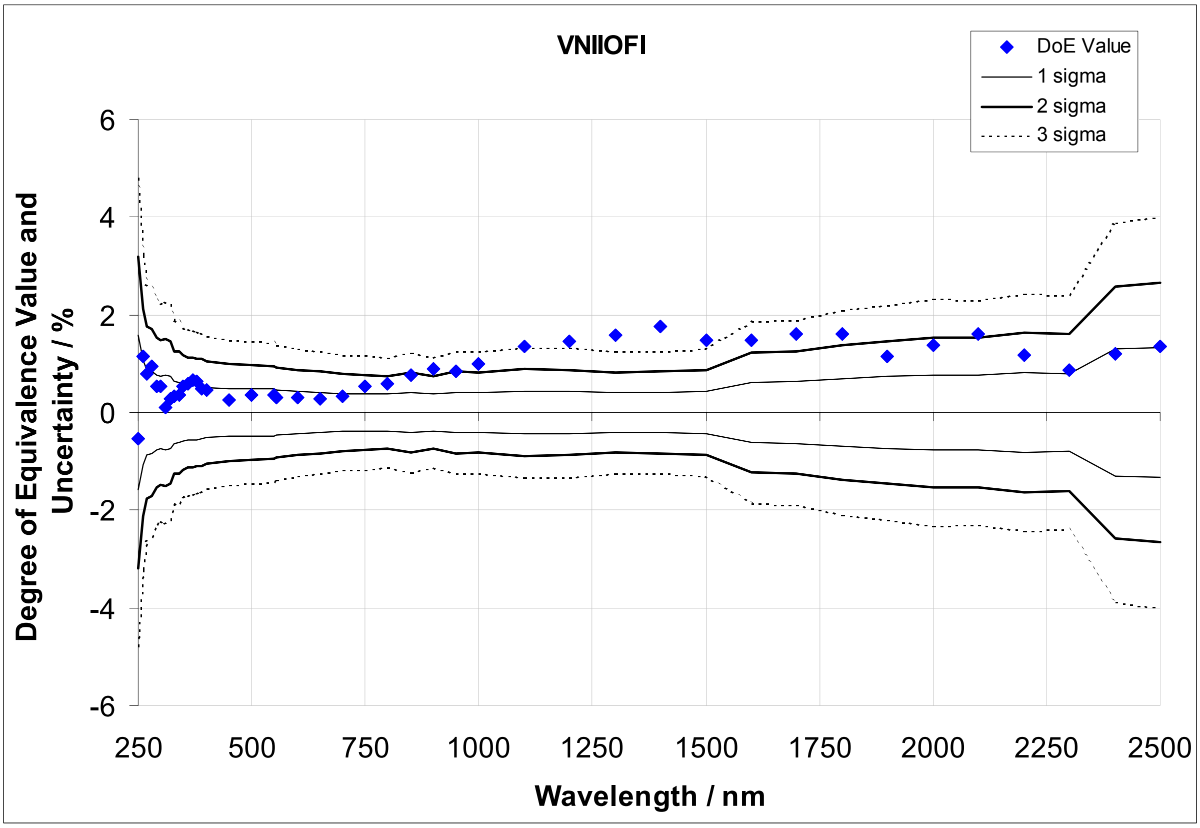




18.2.12 Results for PTB



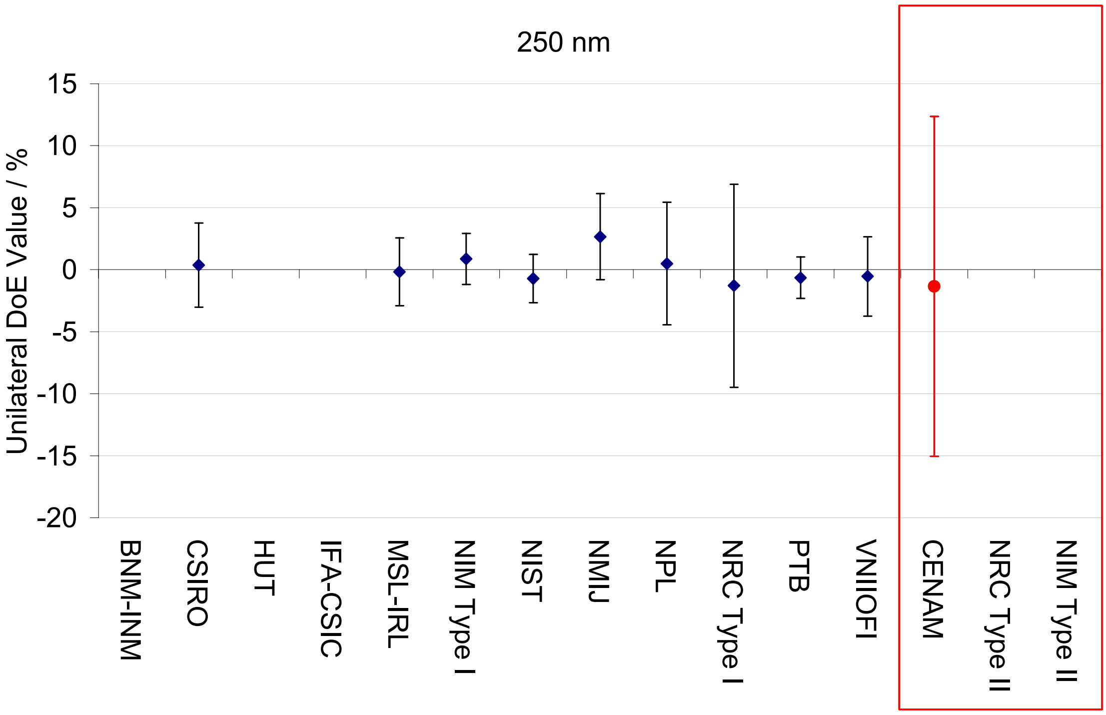
18.2.13 Results for VNIIOFI



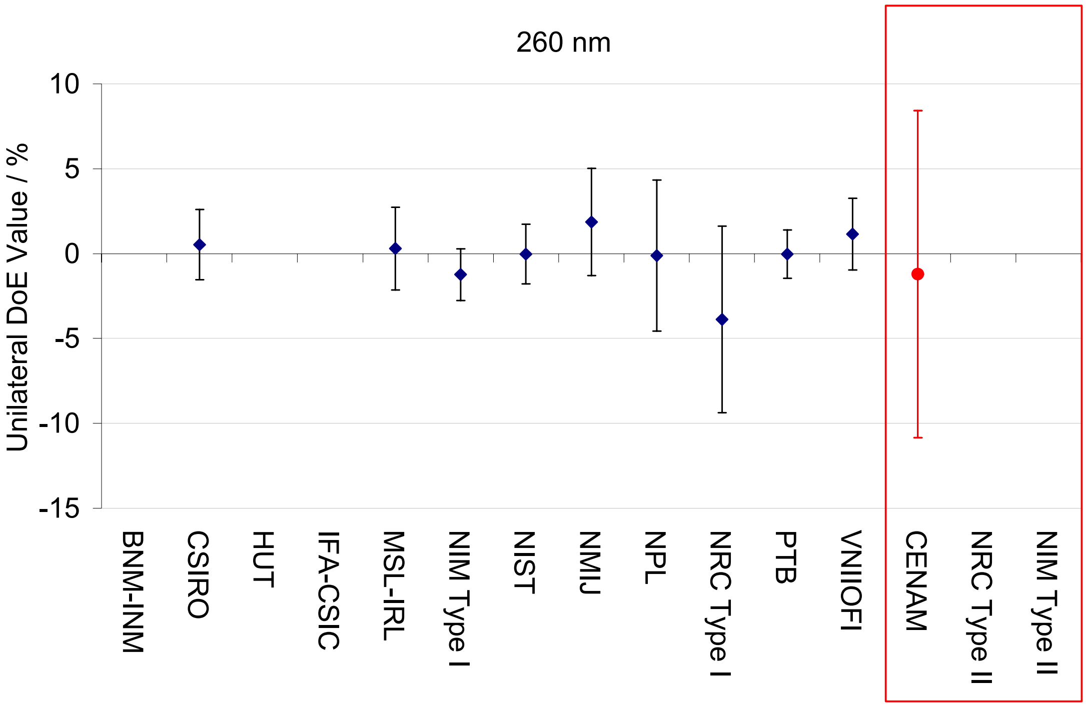
18.3 Results by wavelength

Uncertainty 'bars' on these graphs are at the 95 % level of confidence.

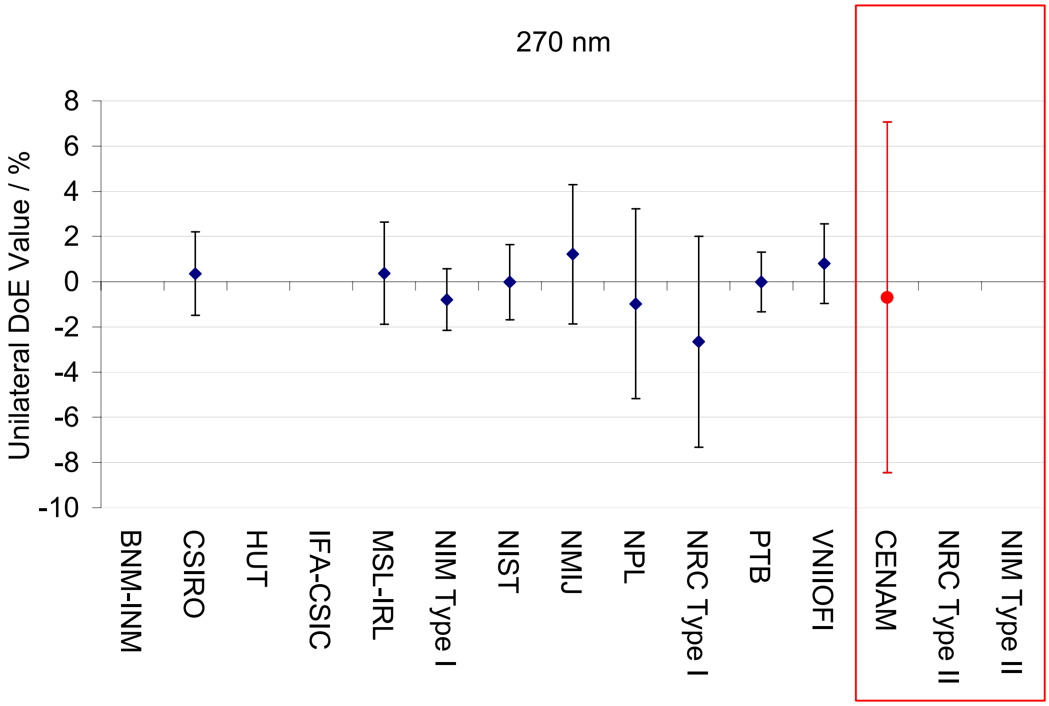
18.3.1 Results at 250 nm



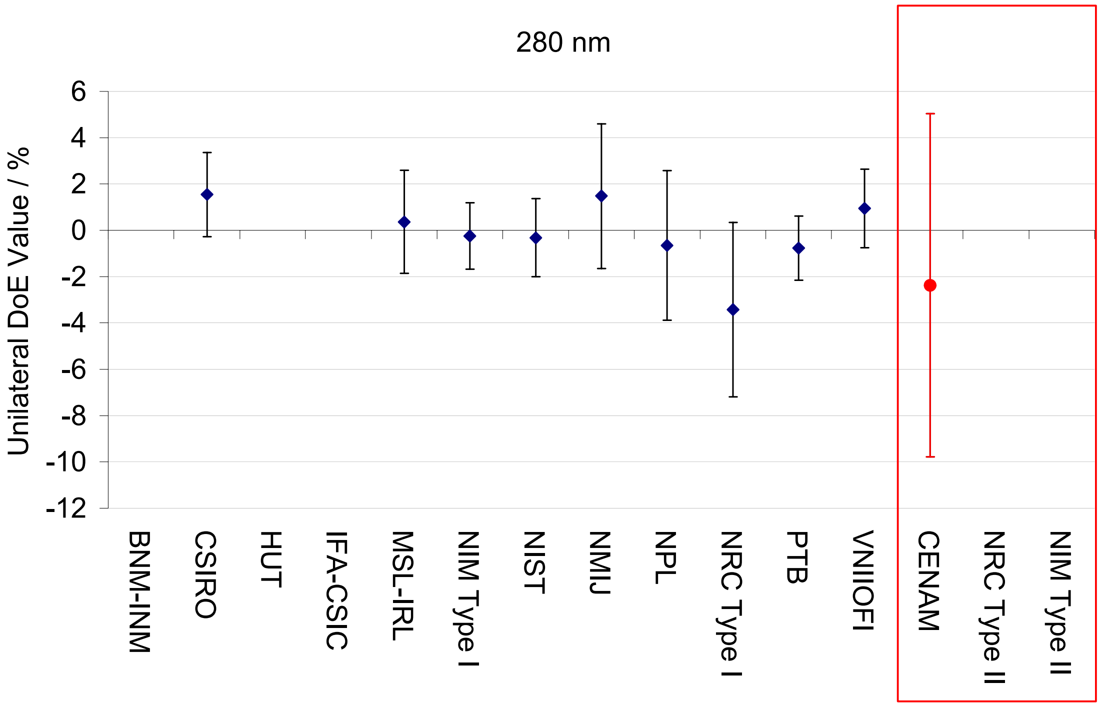
18.3.2 Results at 260 nm



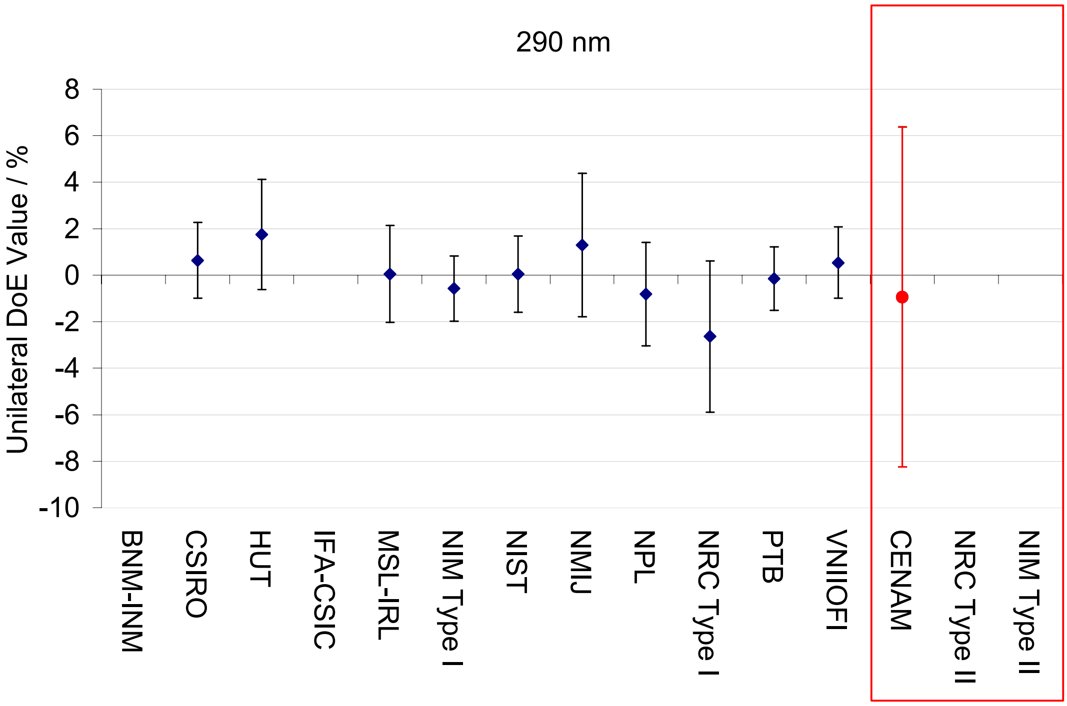
18.3.3 Results at 270 nm



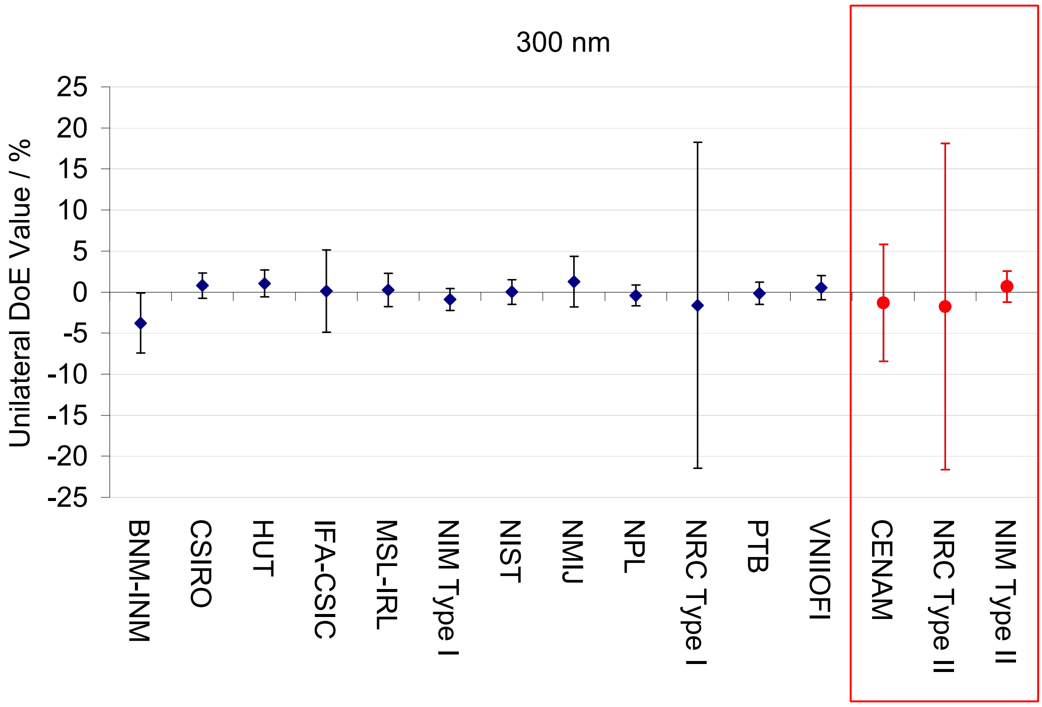
18.3.4 Results at 280 nm



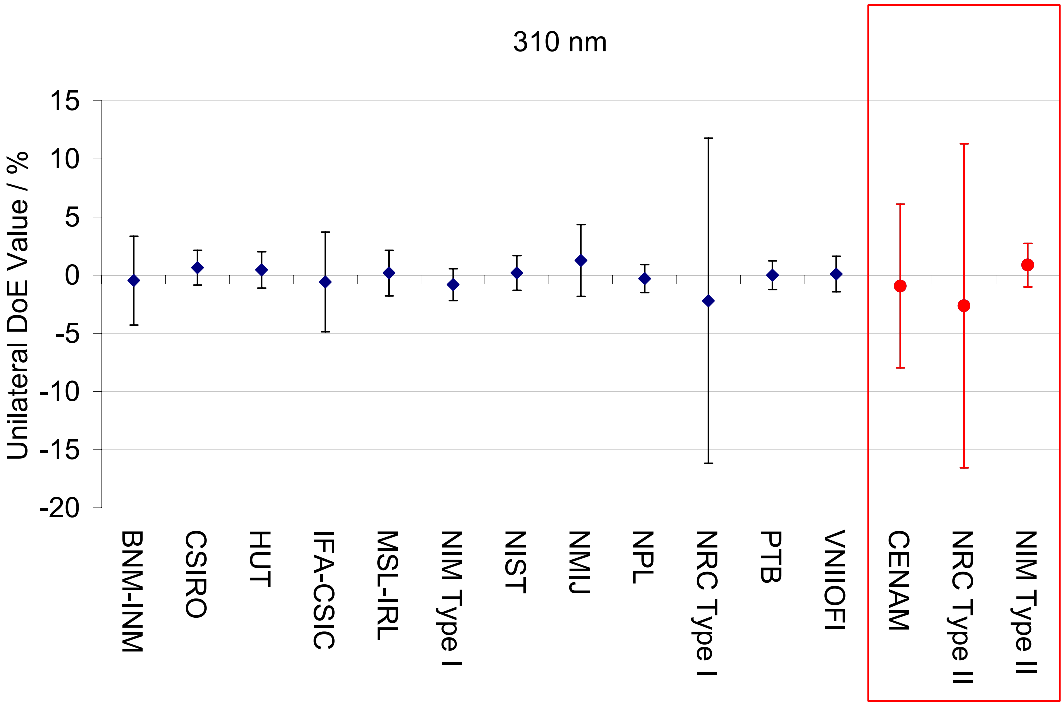
18.3.5 Results at 290 nm



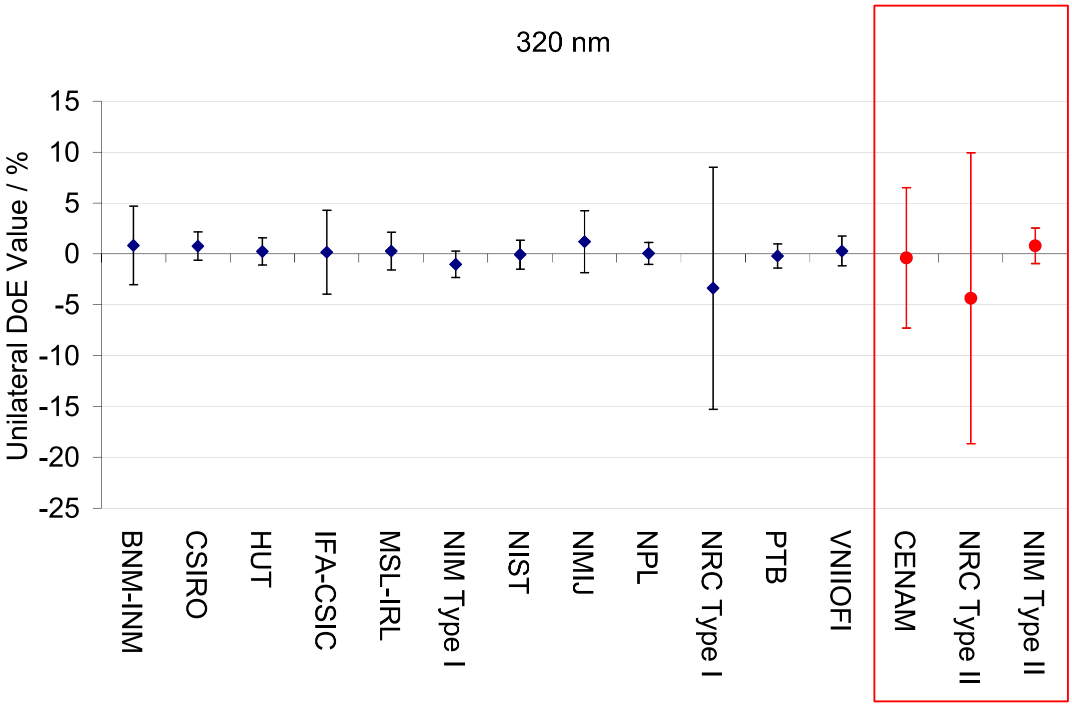
18.3.6 Results at 300 nm



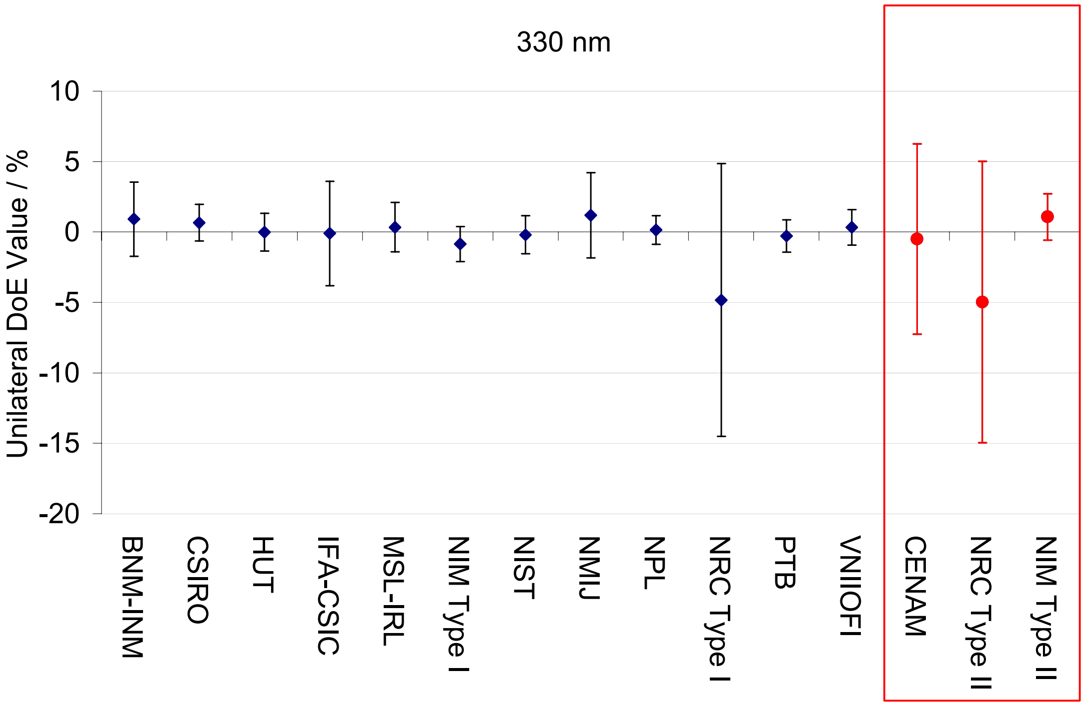
18.3.7 Results at 310 nm



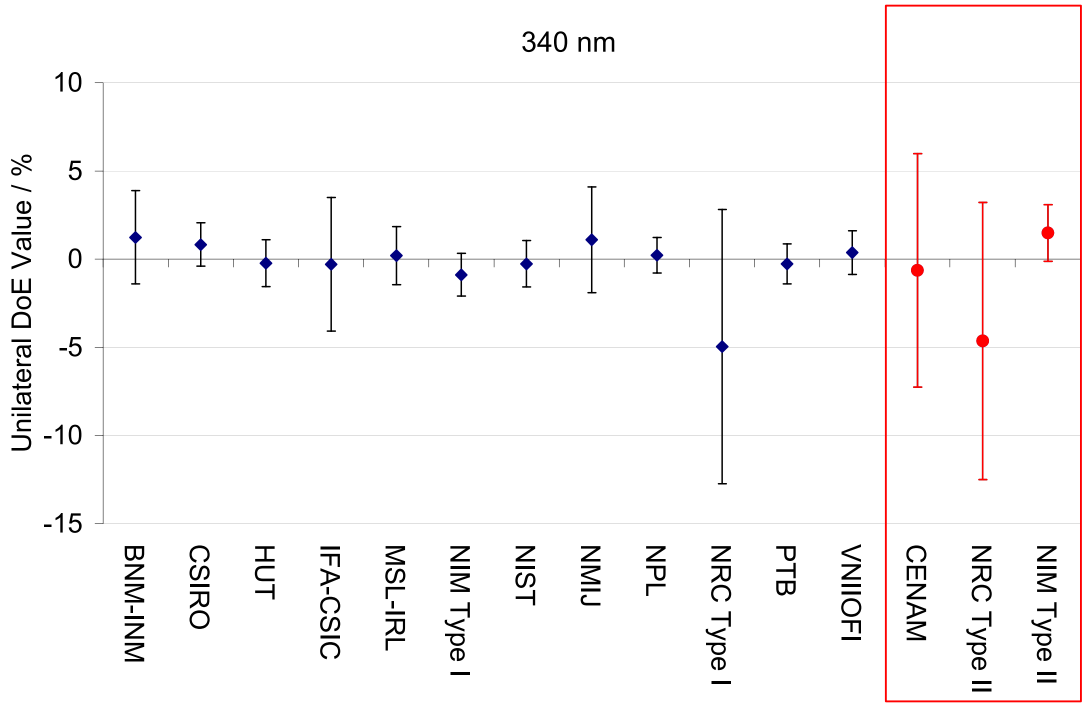
18.3.8 Results at 320 nm



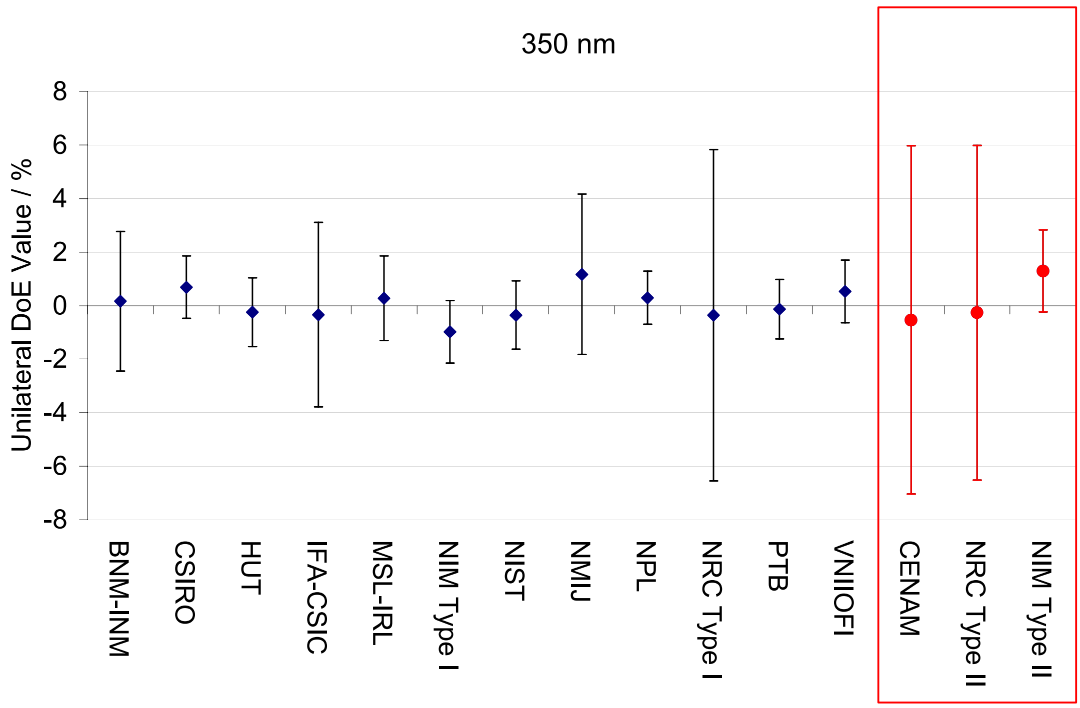
18.3.9 Results at 330 nm



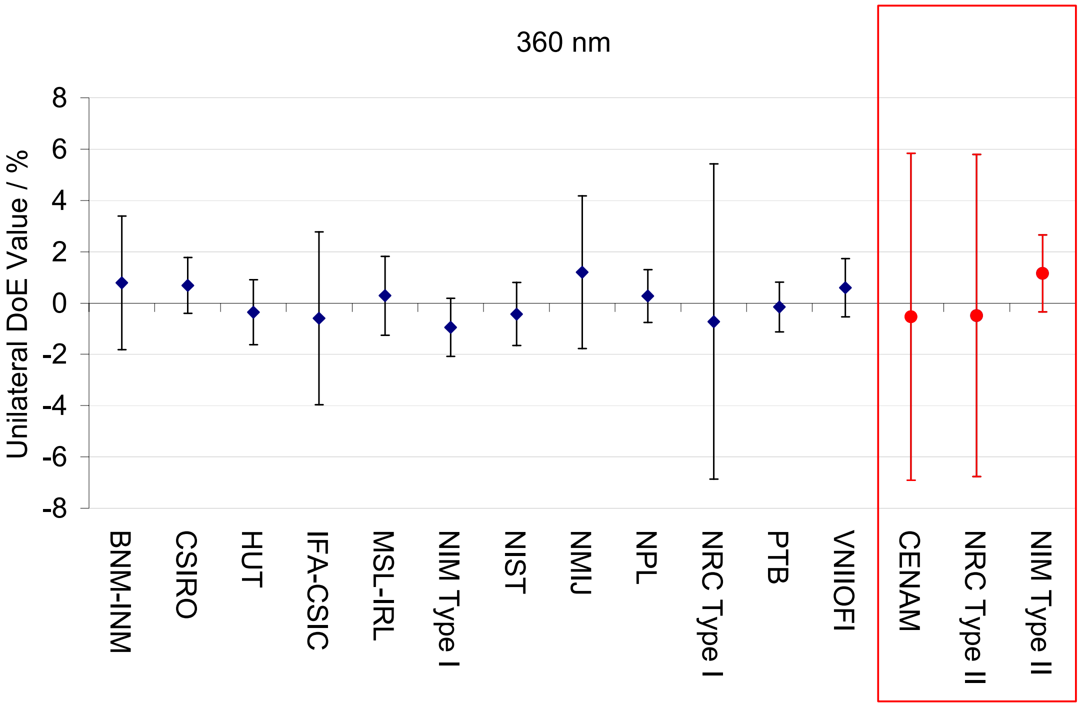
18.3.10 Results at 340 nm



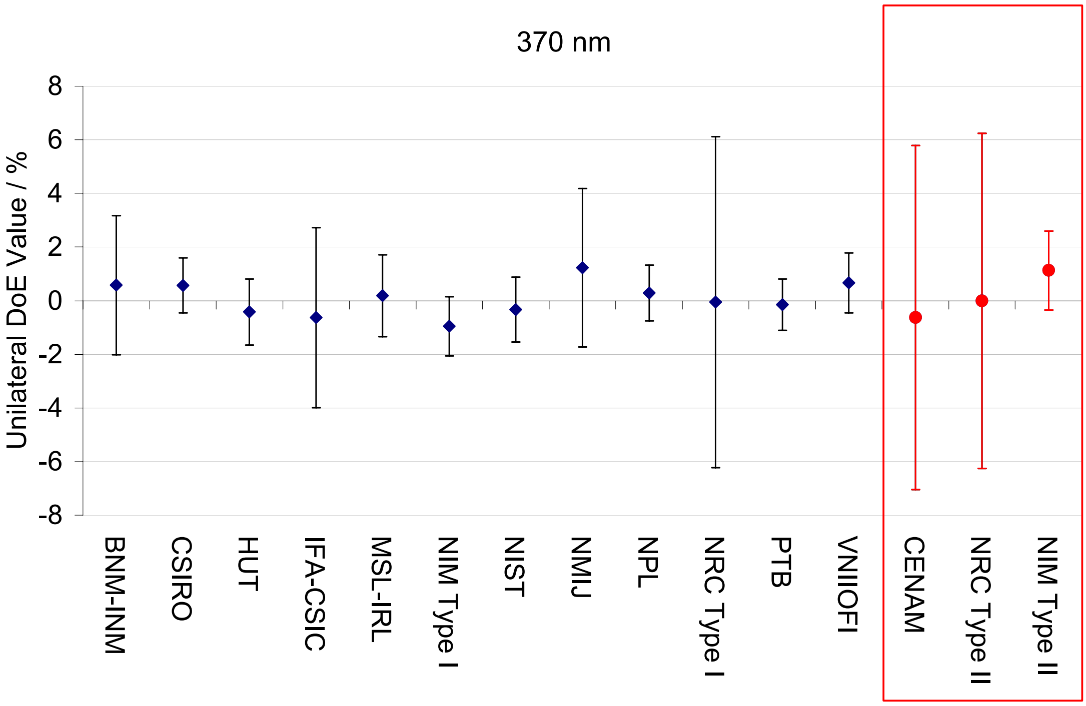
18.3.11 Results at 350 nm



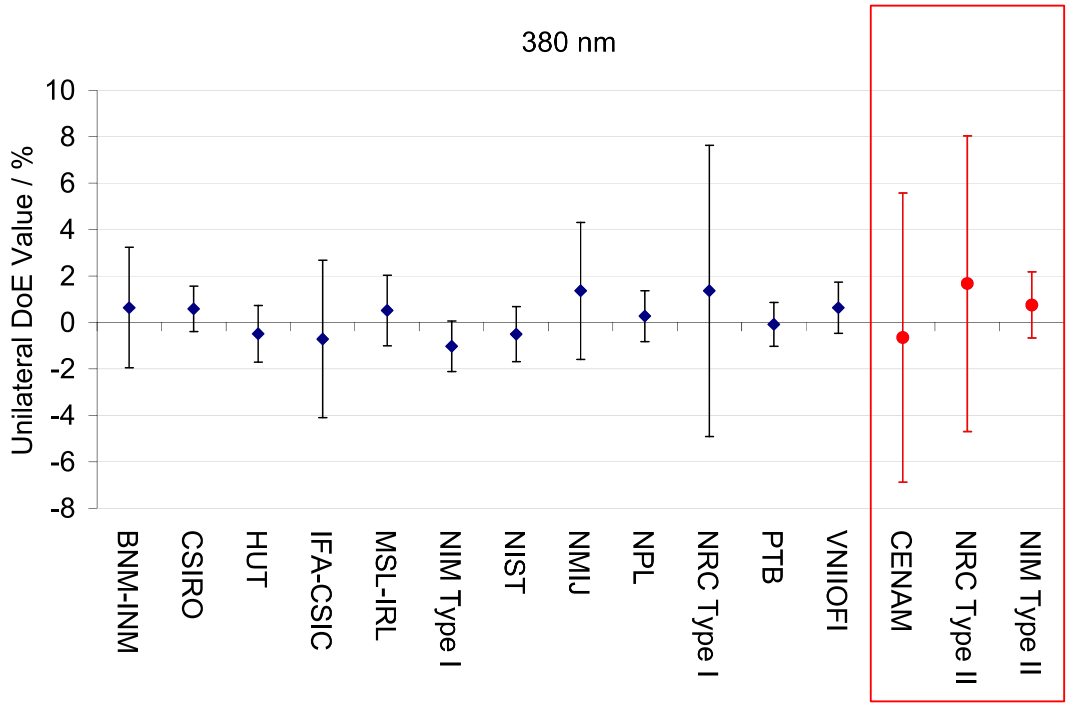
18.3.12 Results at 360 nm



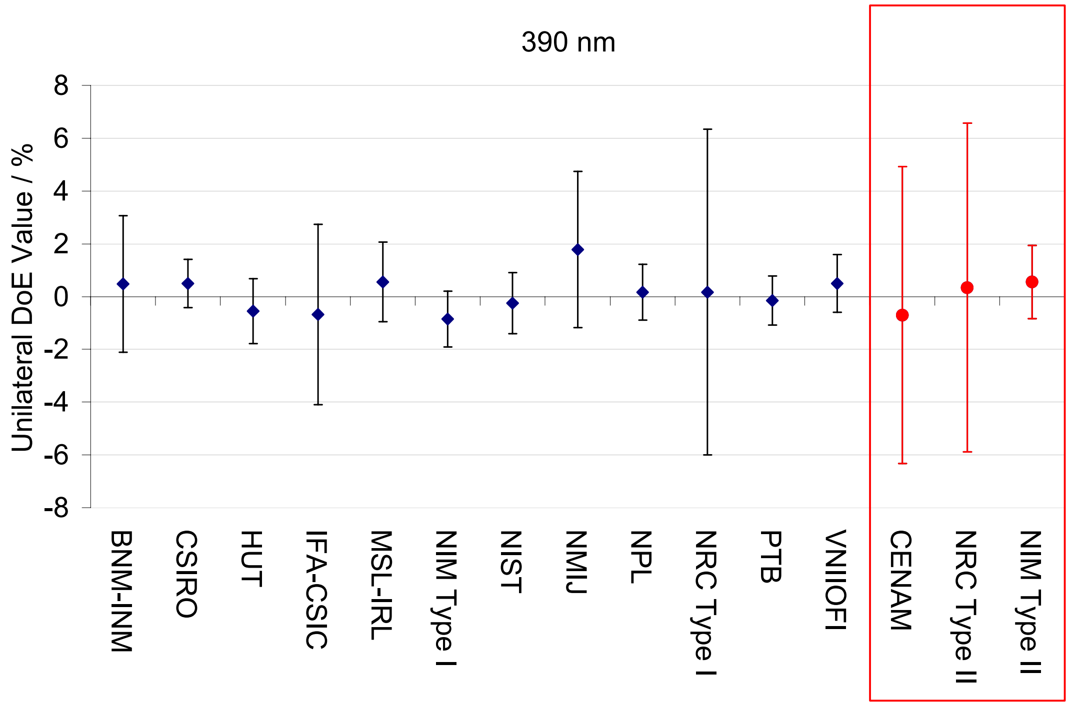
18.3.13 Results at 370 nm



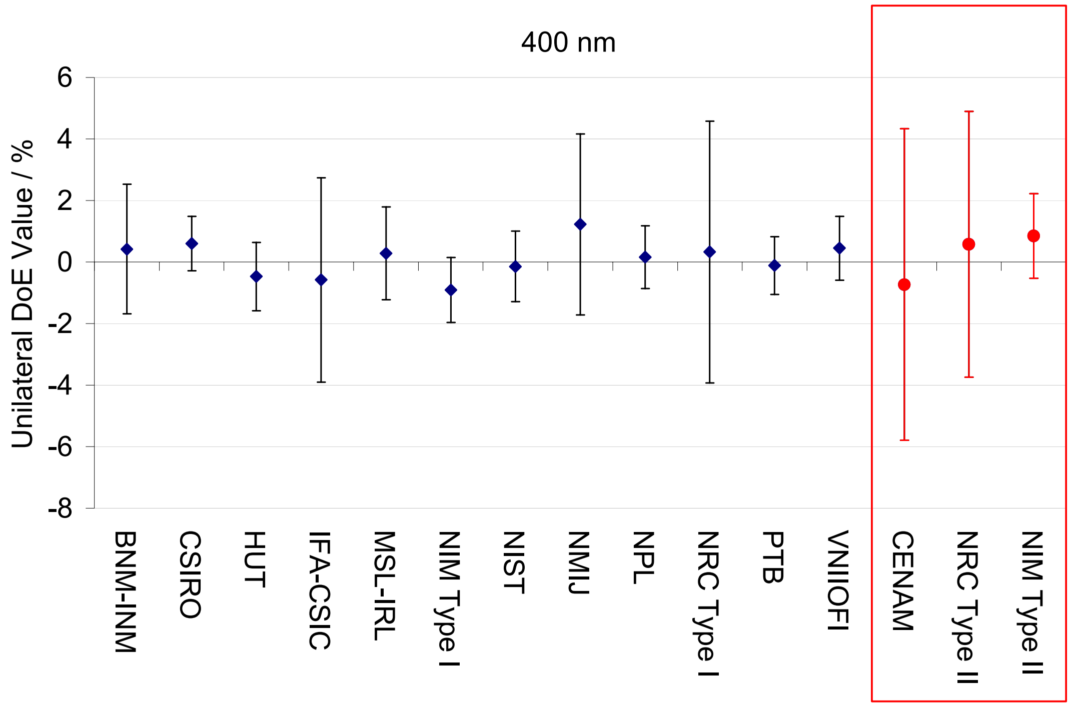
18.3.14 Results at 380 nm



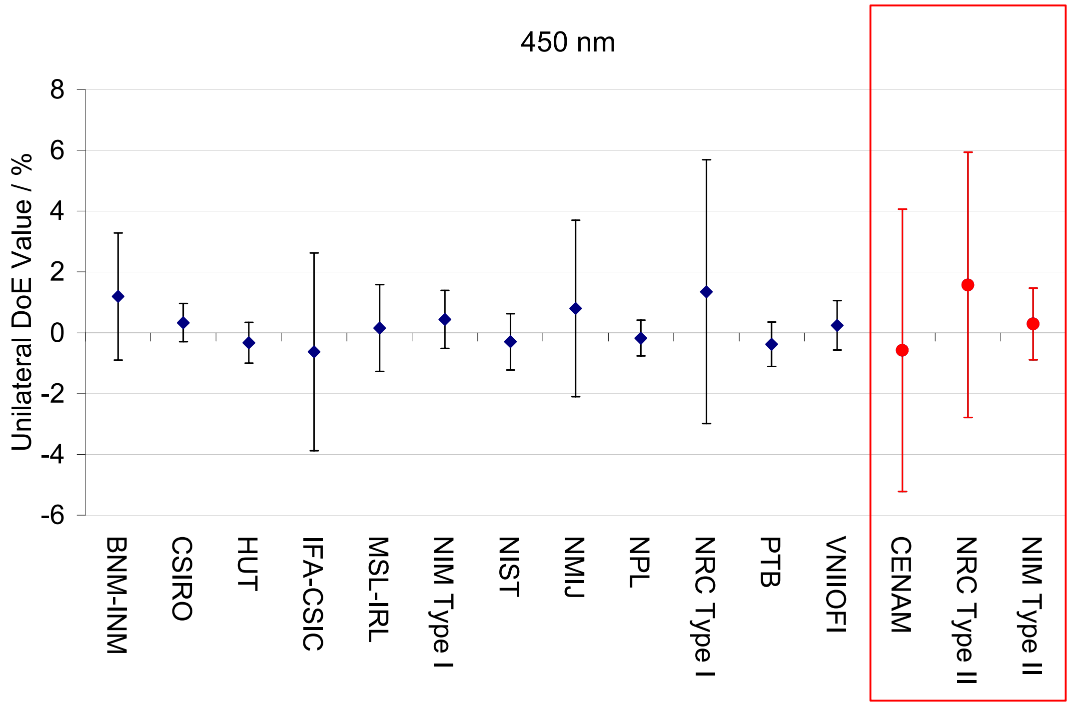
18.3.15 Results at 390 nm



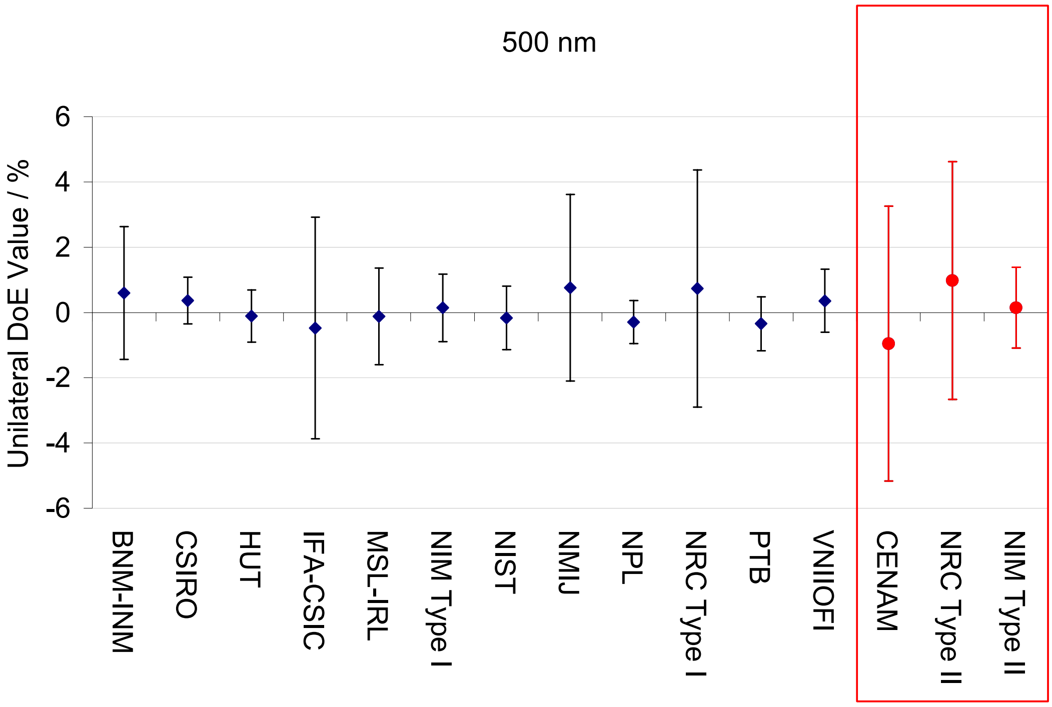
18.3.16 Results at 400 nm



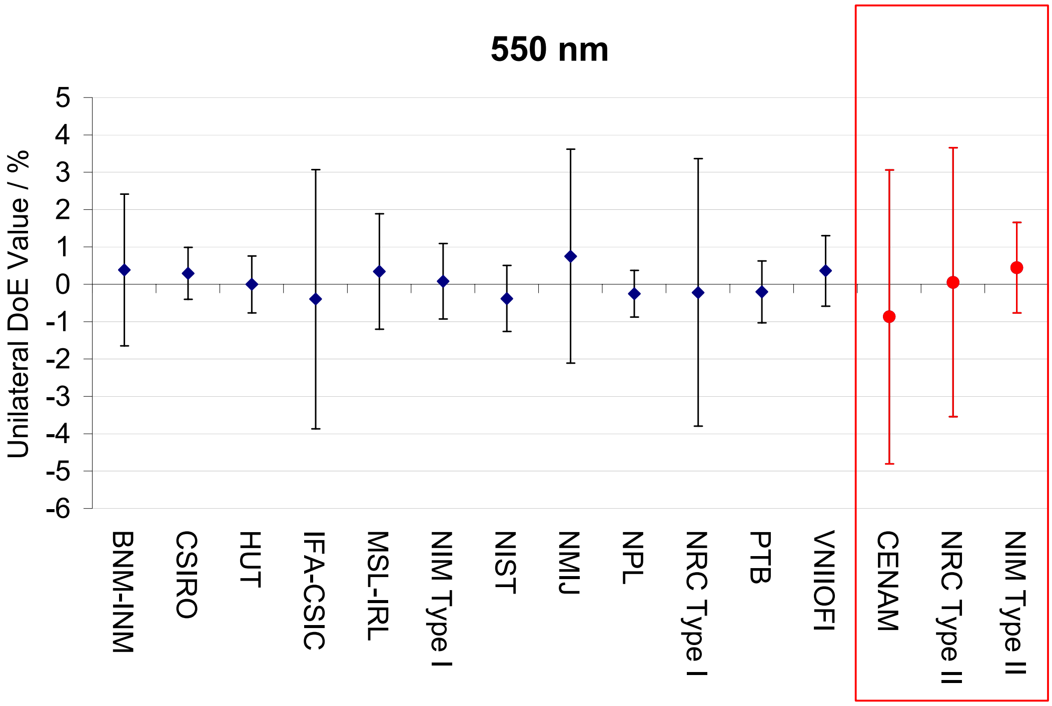
18.3.17 Results at 450 nm



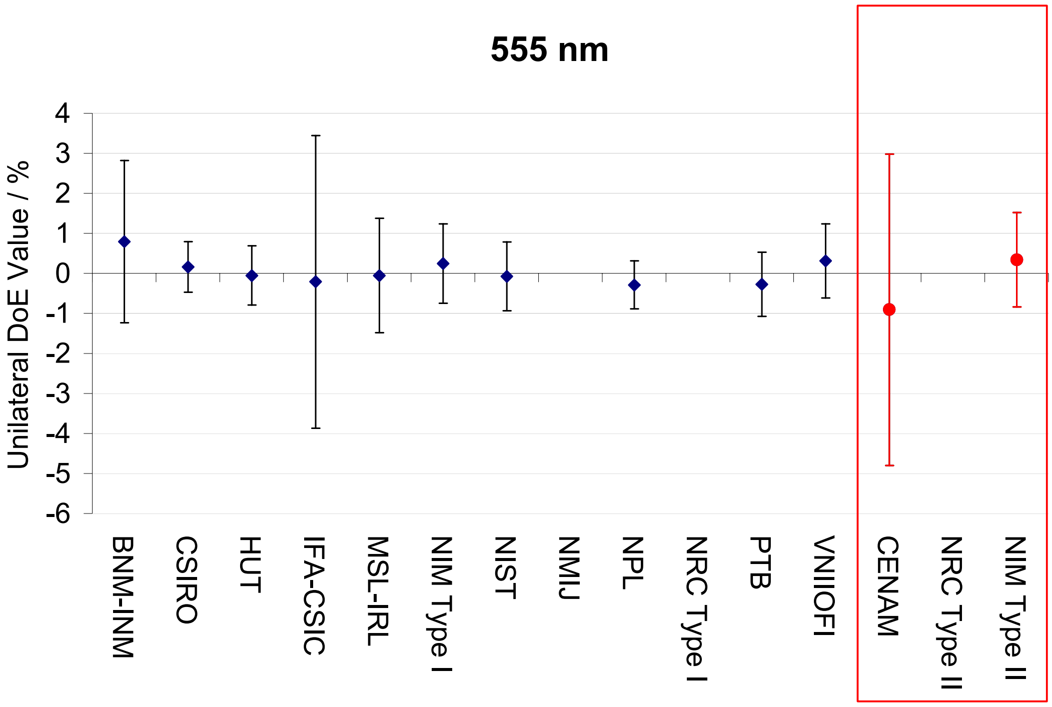
18.3.18 Results at 500 nm



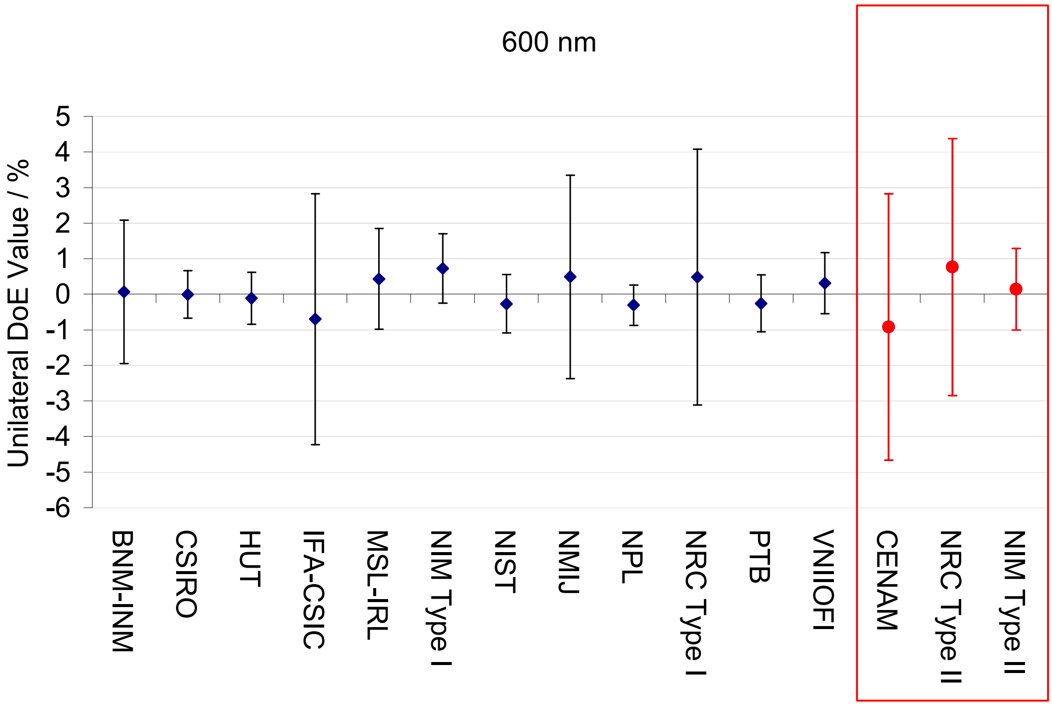
18.3.19 Results at 550 nm



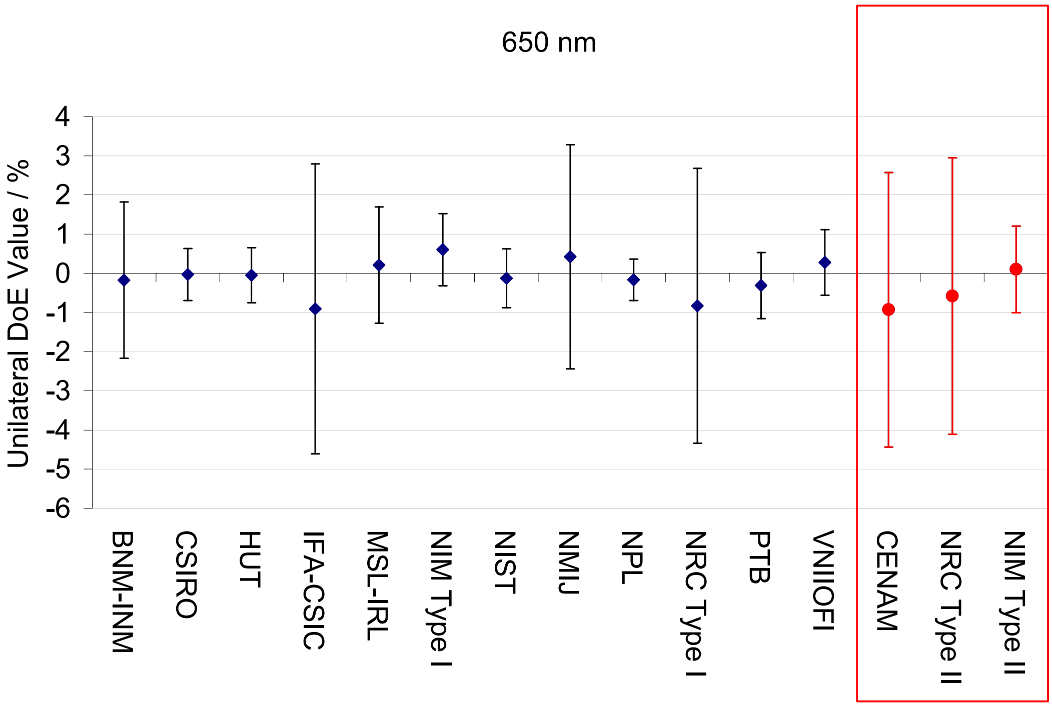
18.3.20 Results at 555 nm



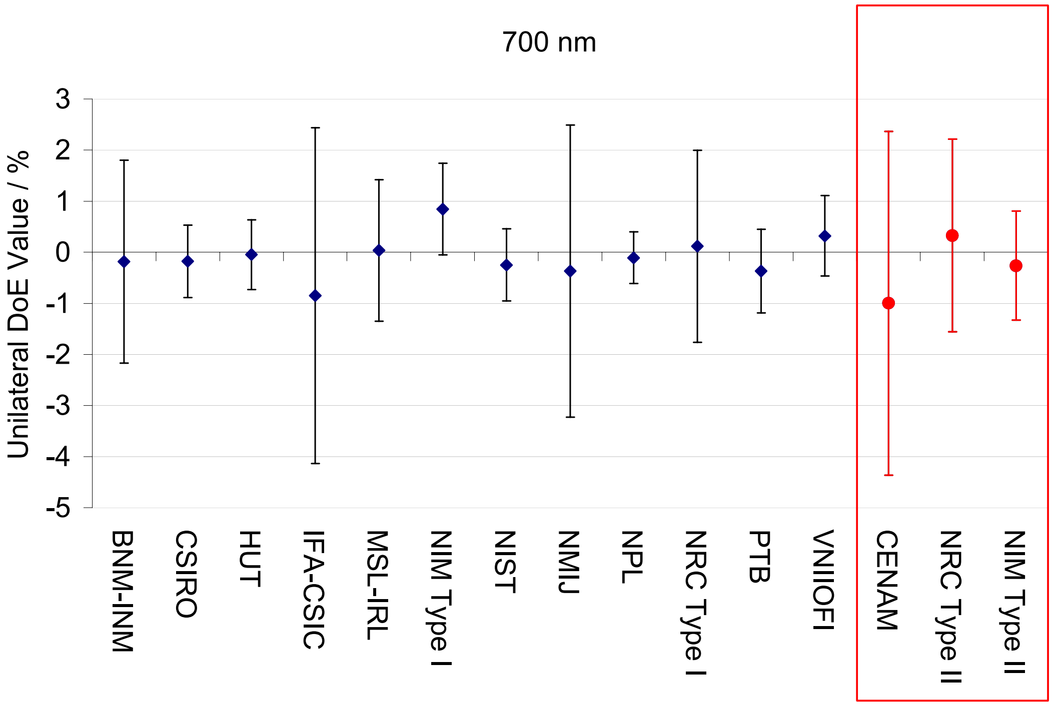
18.3.21 Results at 600 nm



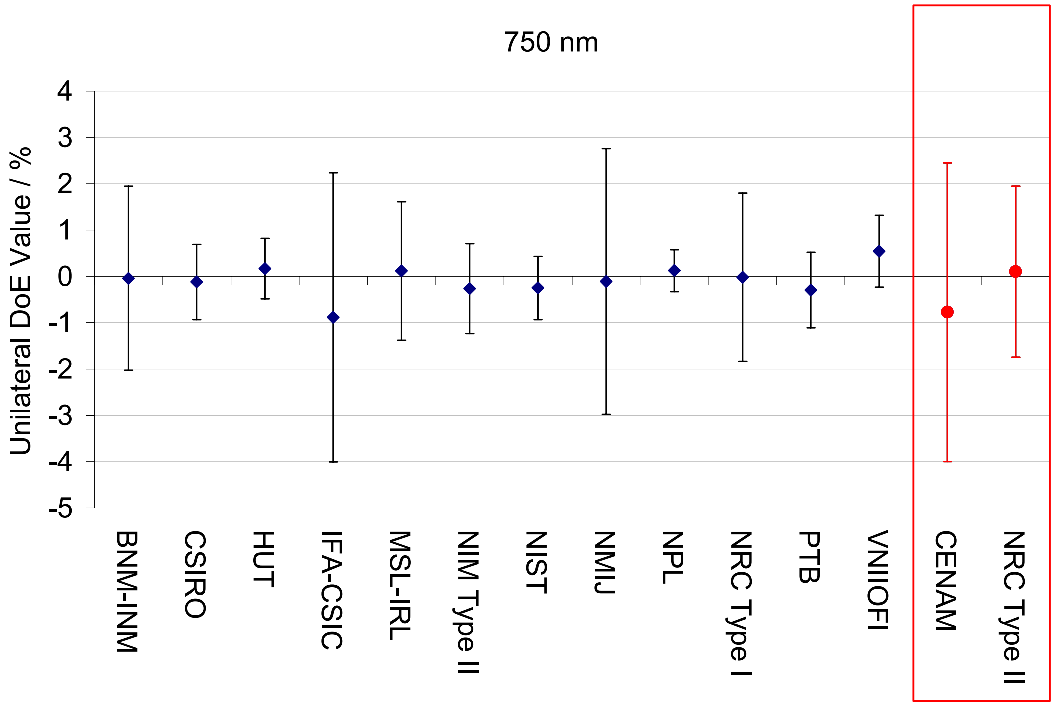
18.3.22 Results at 650 nm



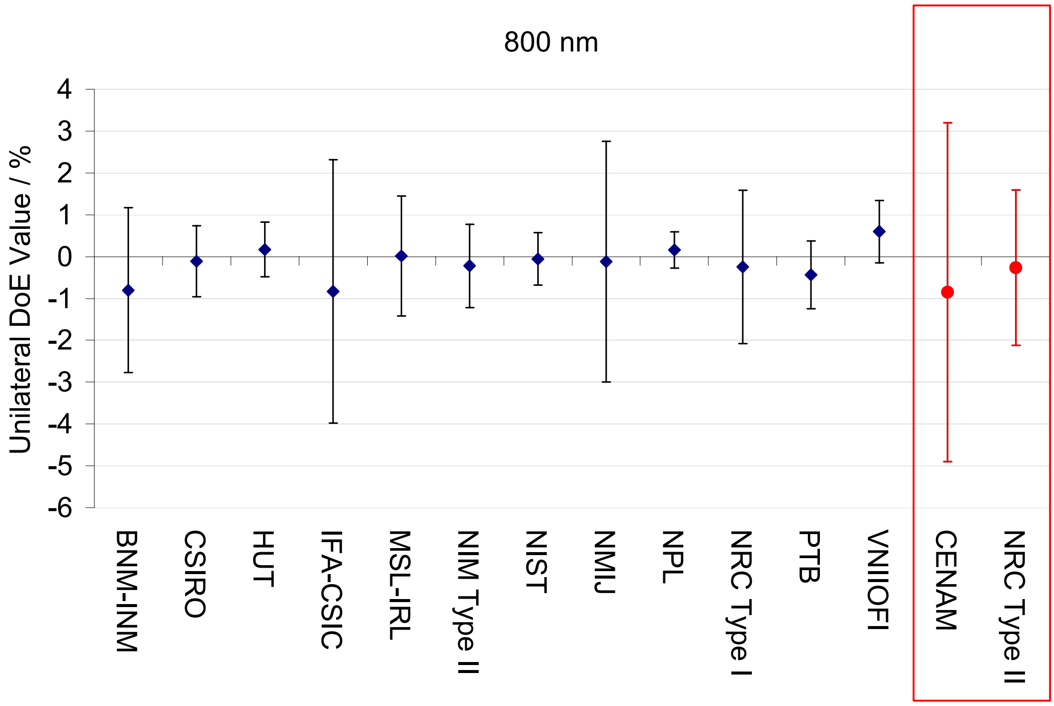
18.3.23 Results at 700 nm



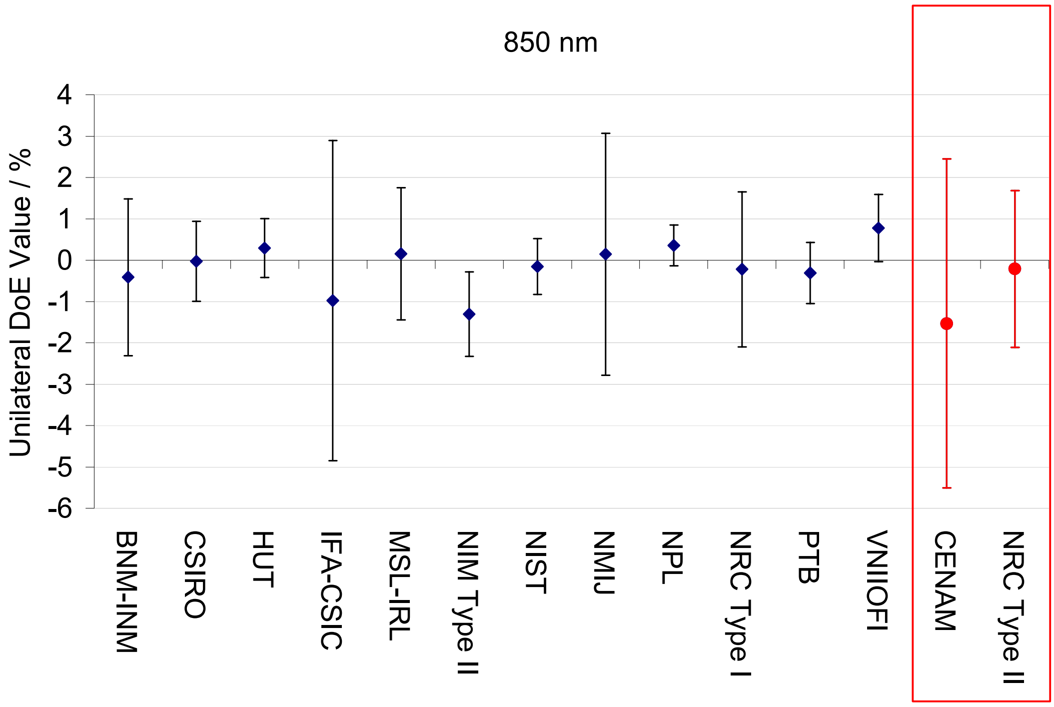
18.3.24 Results at 750 nm



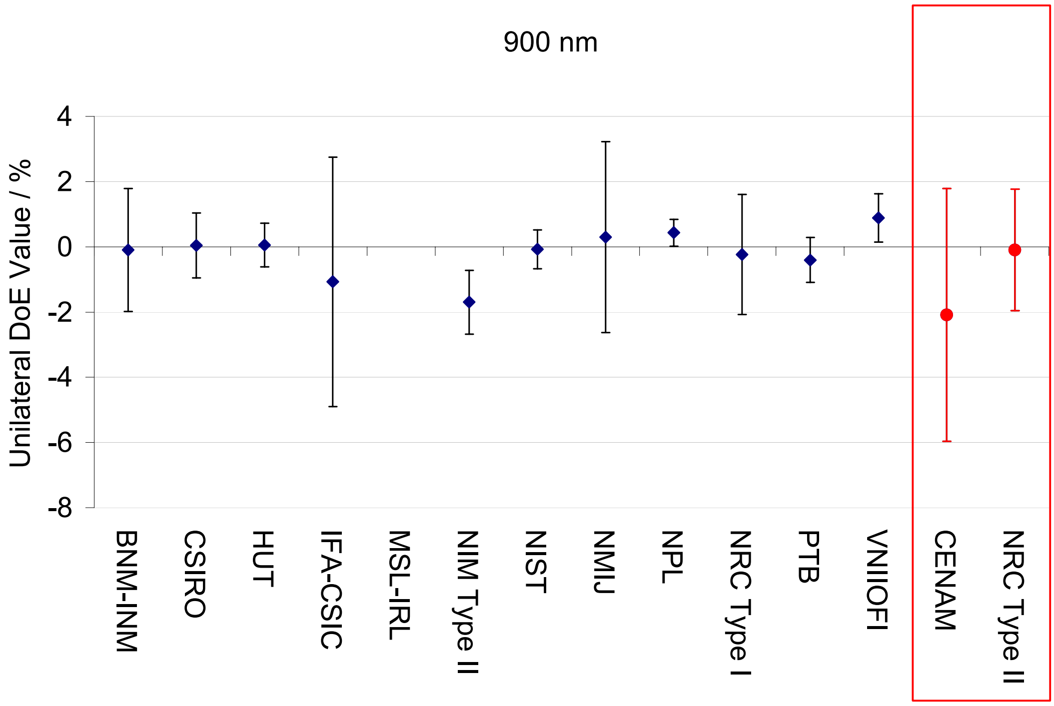
18.3.25 Results at 800 nm



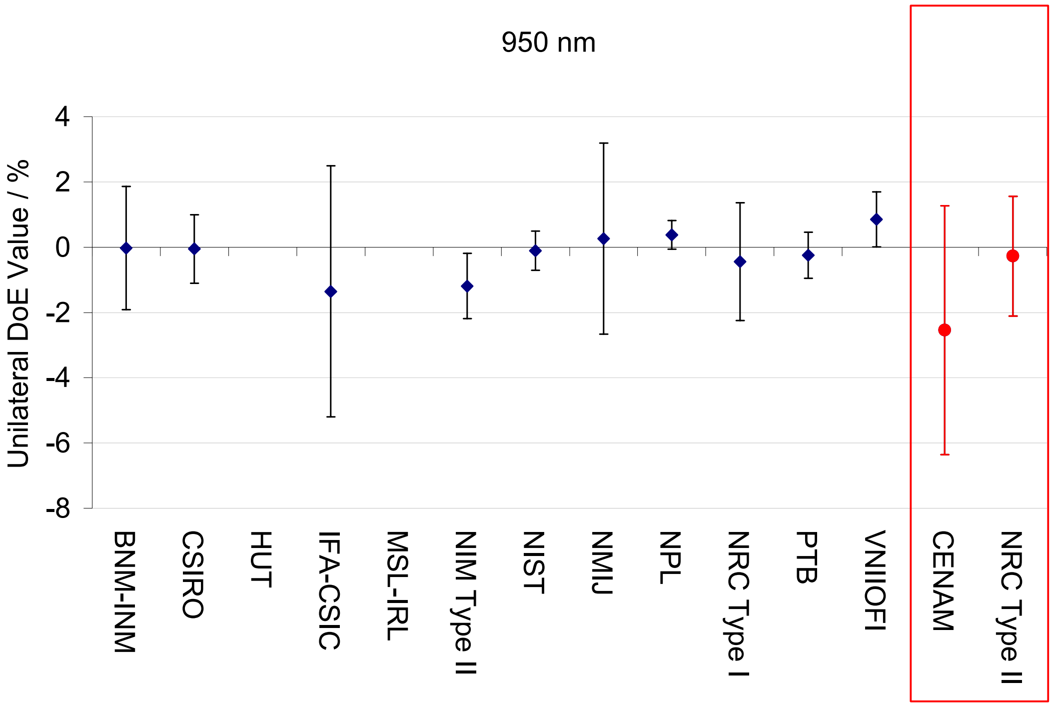
18.3.26 Results at 850 nm



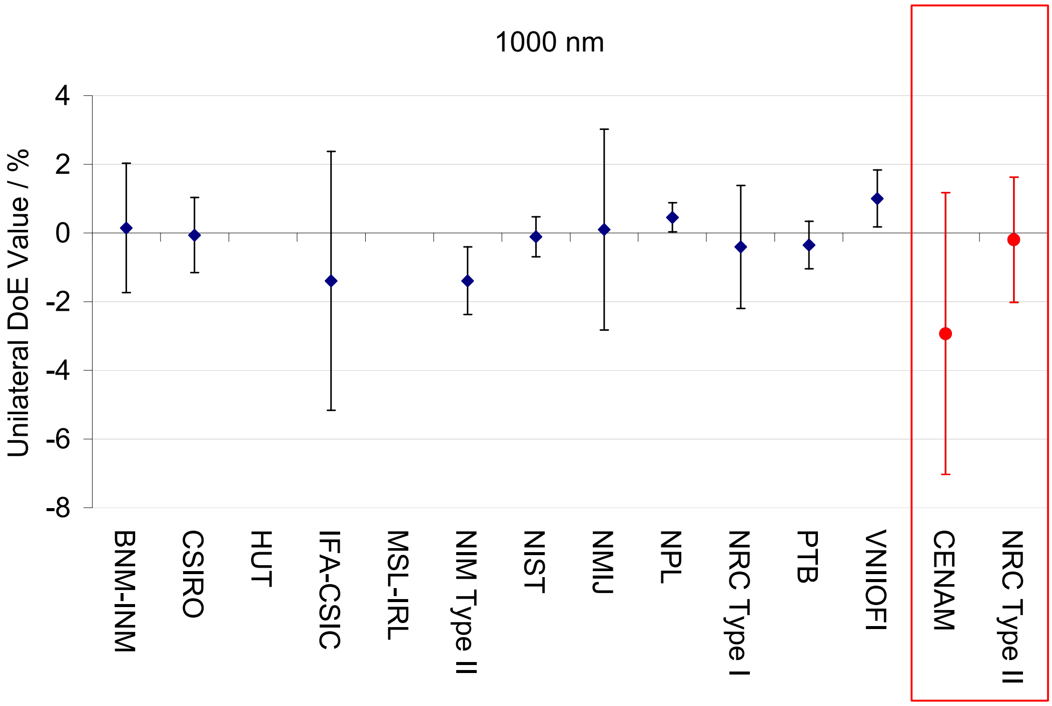
18.3.27 Results at 900 nm



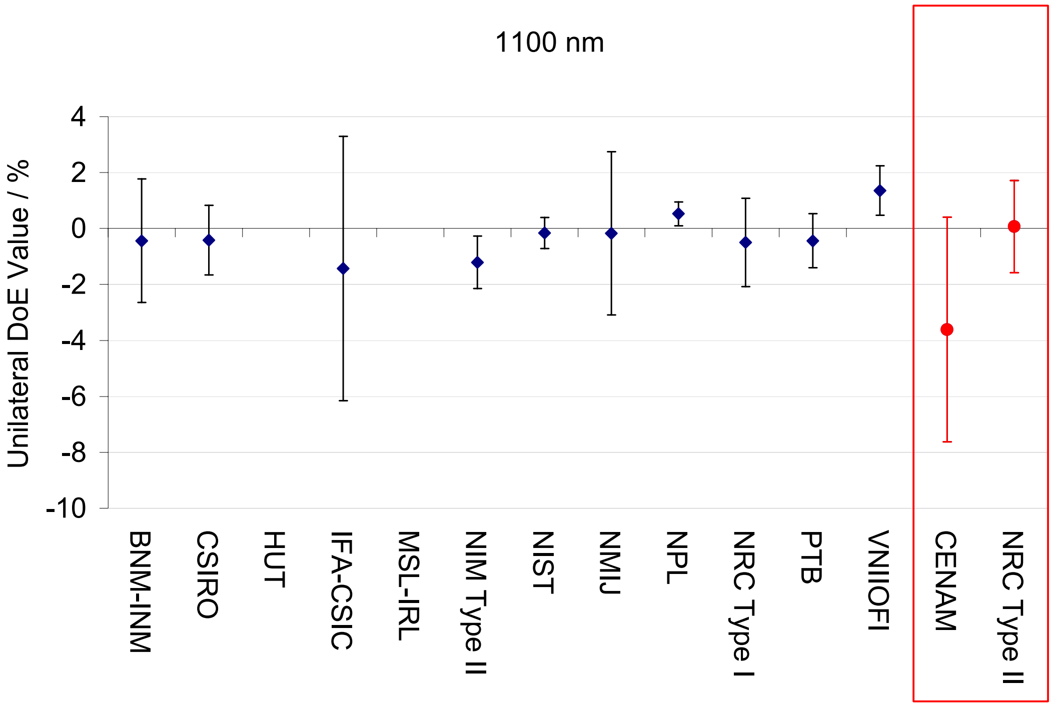
18.3.28 Results at 950 nm



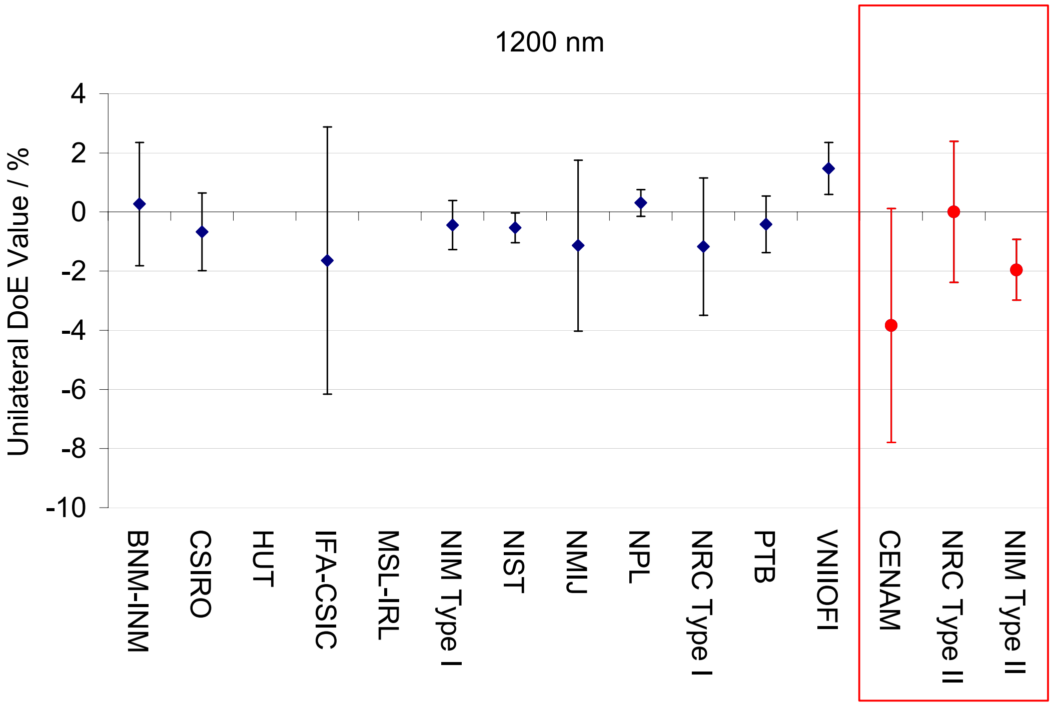
18.3.29 Results at 1000 nm



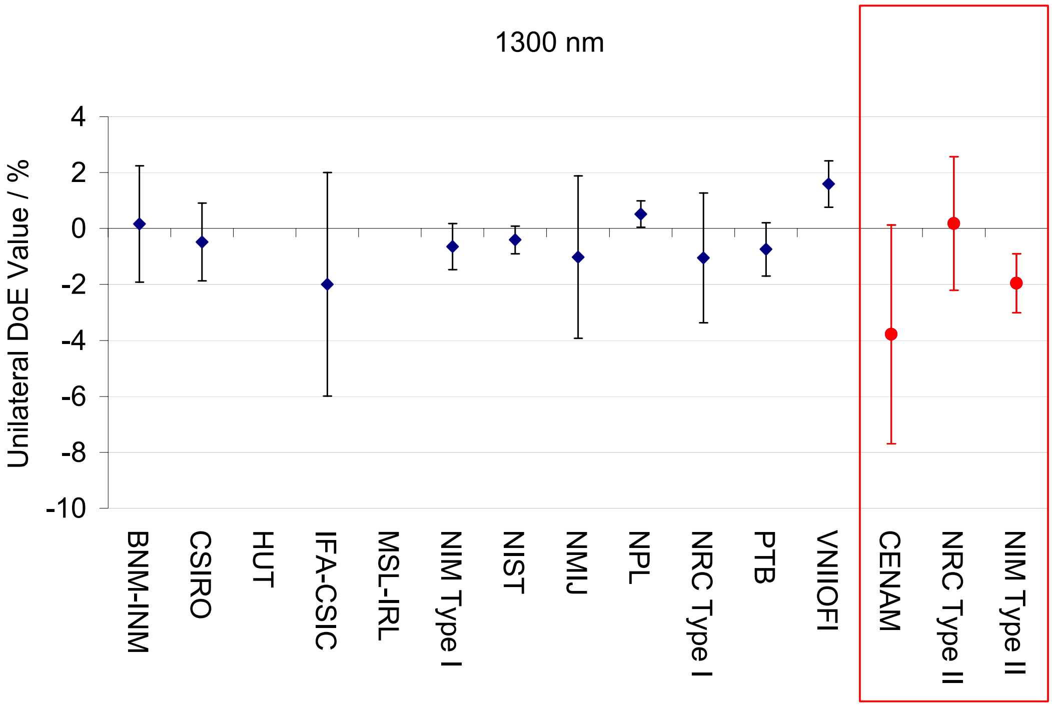
18.3.30 Results at 1100 nm



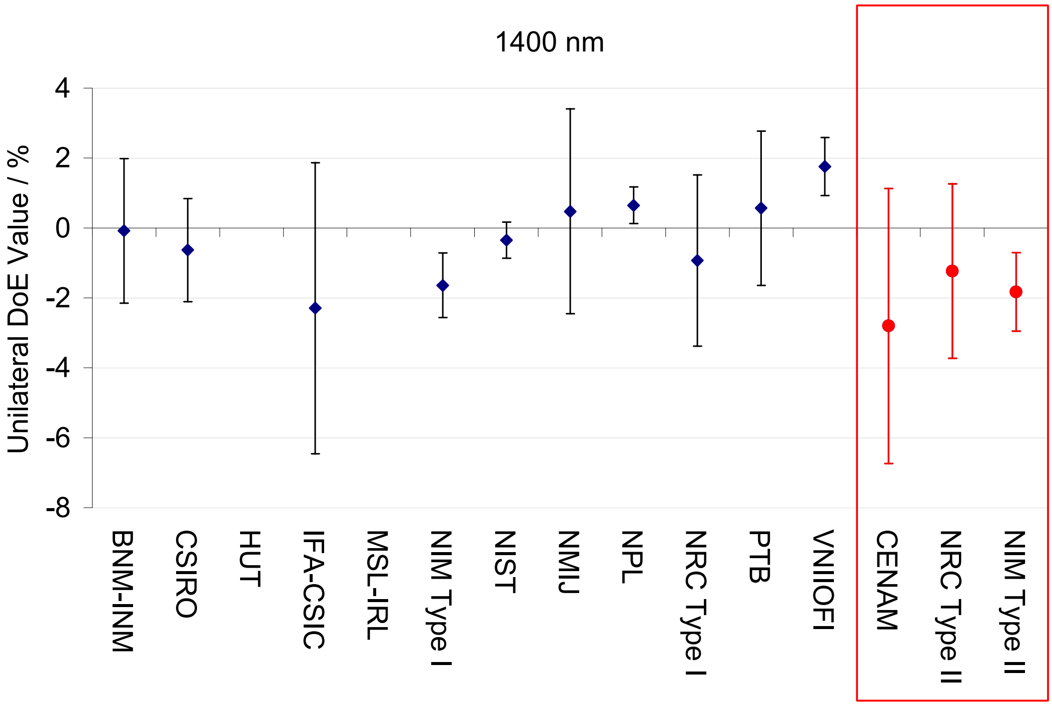
18.3.31 Results at 1200 nm



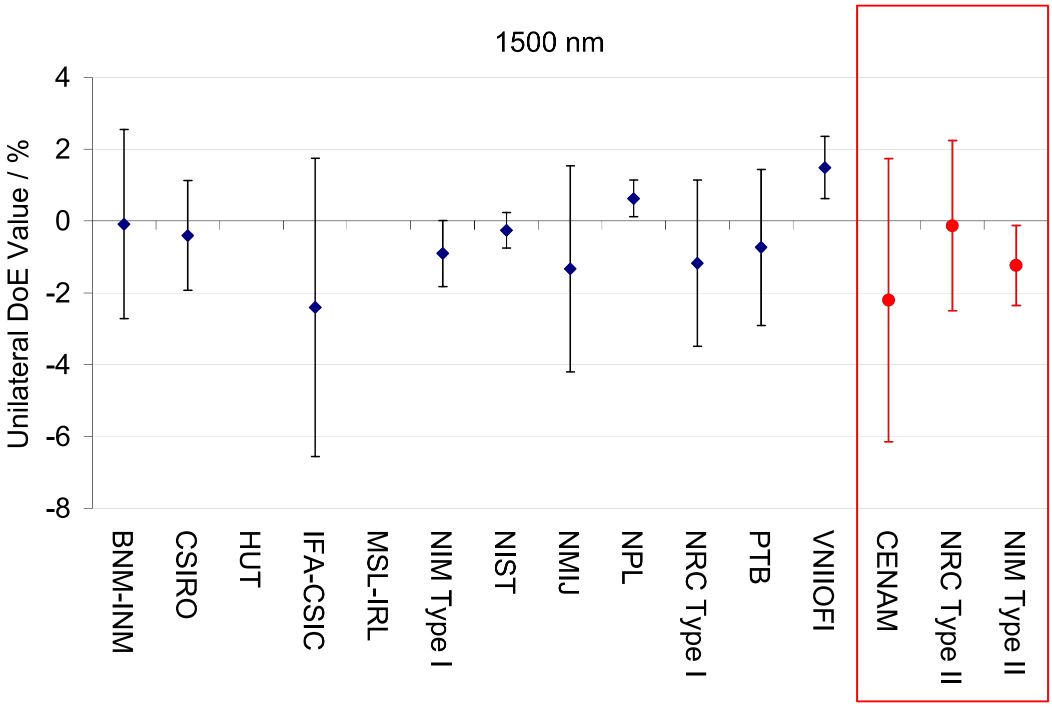
18.3.32 Results at 1300 nm



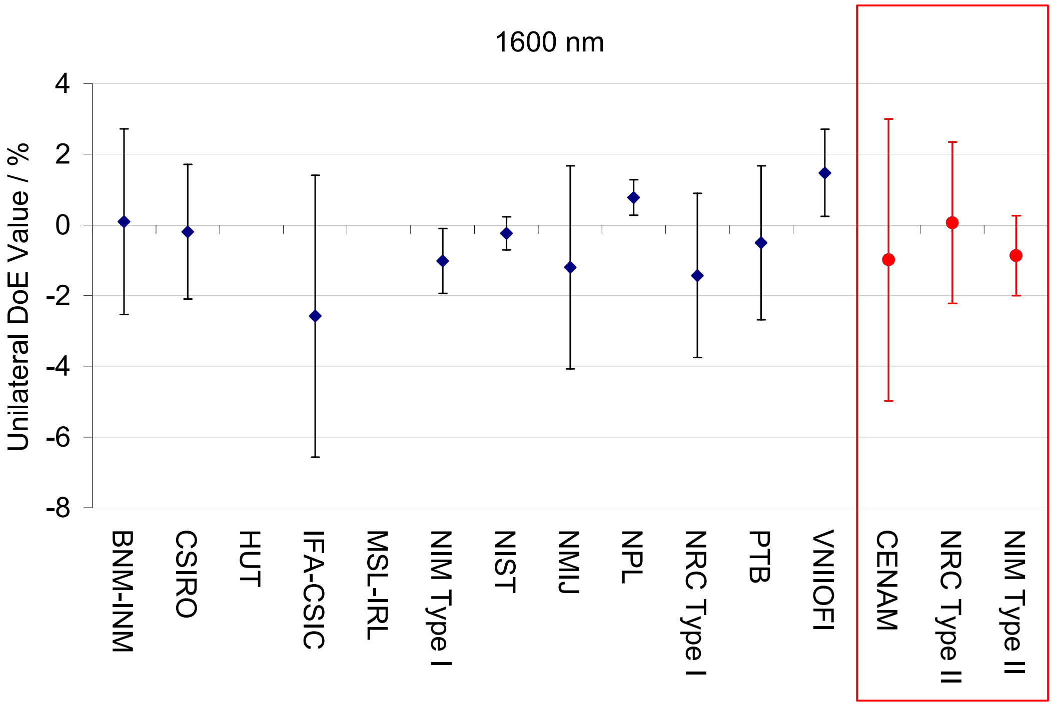
18.3.33 Results at 1400 nm



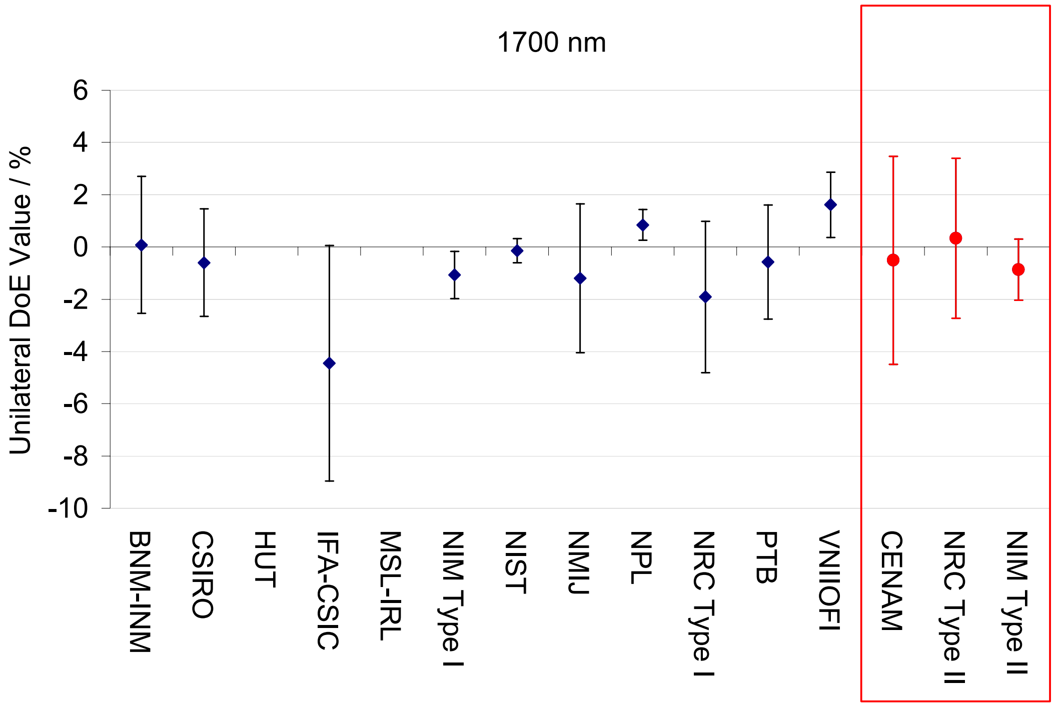
18.3.34 Results at 1500 nm



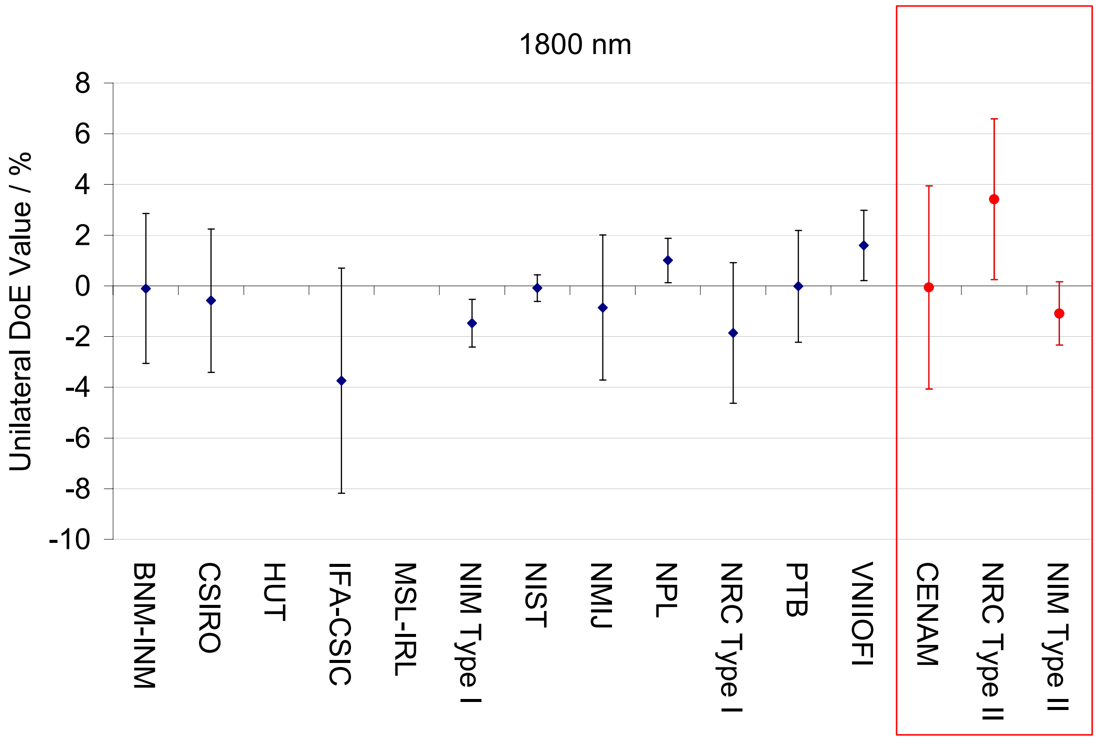
18.3.35 Results at 1600 nm



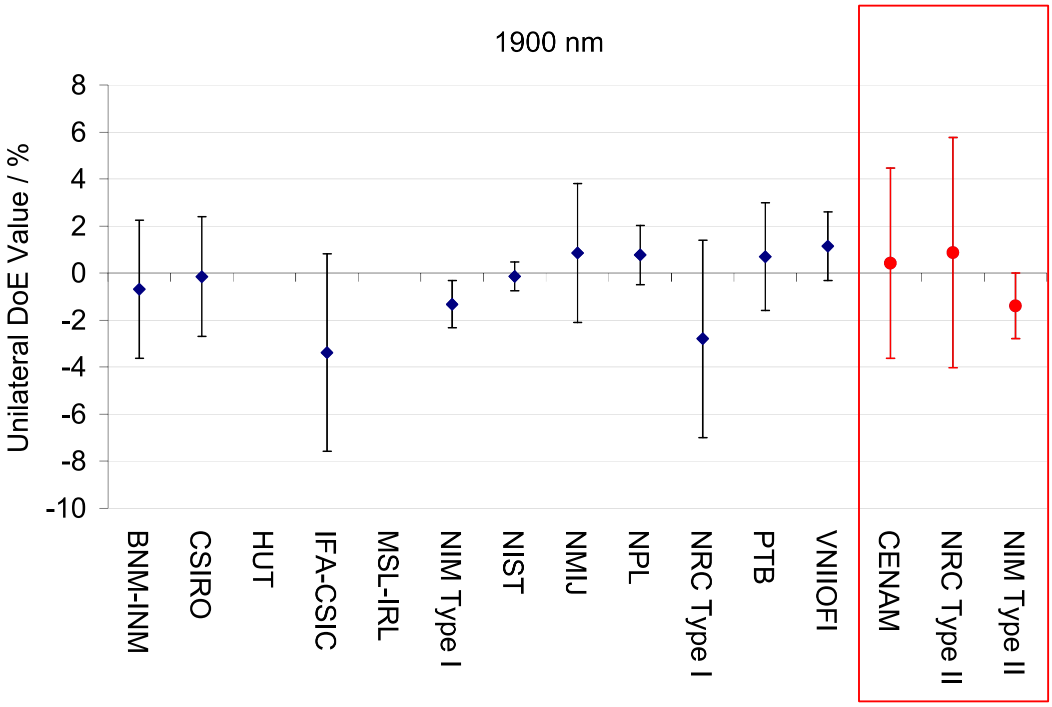
18.3.36 Results at 1700 nm



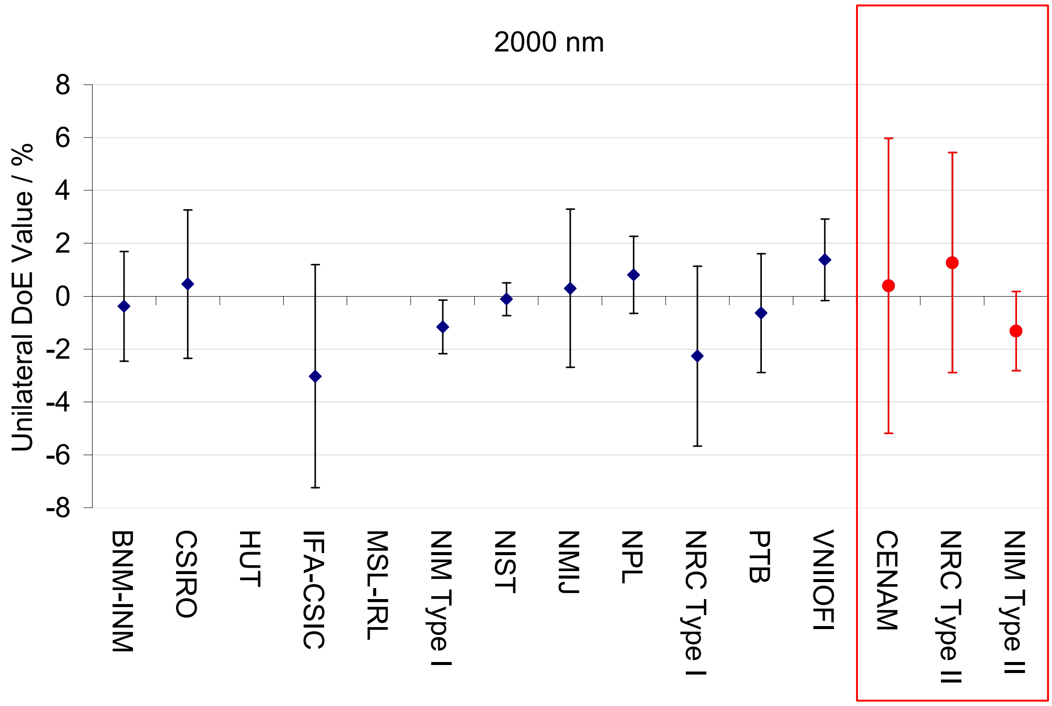
18.3.37 Results at 1800 nm



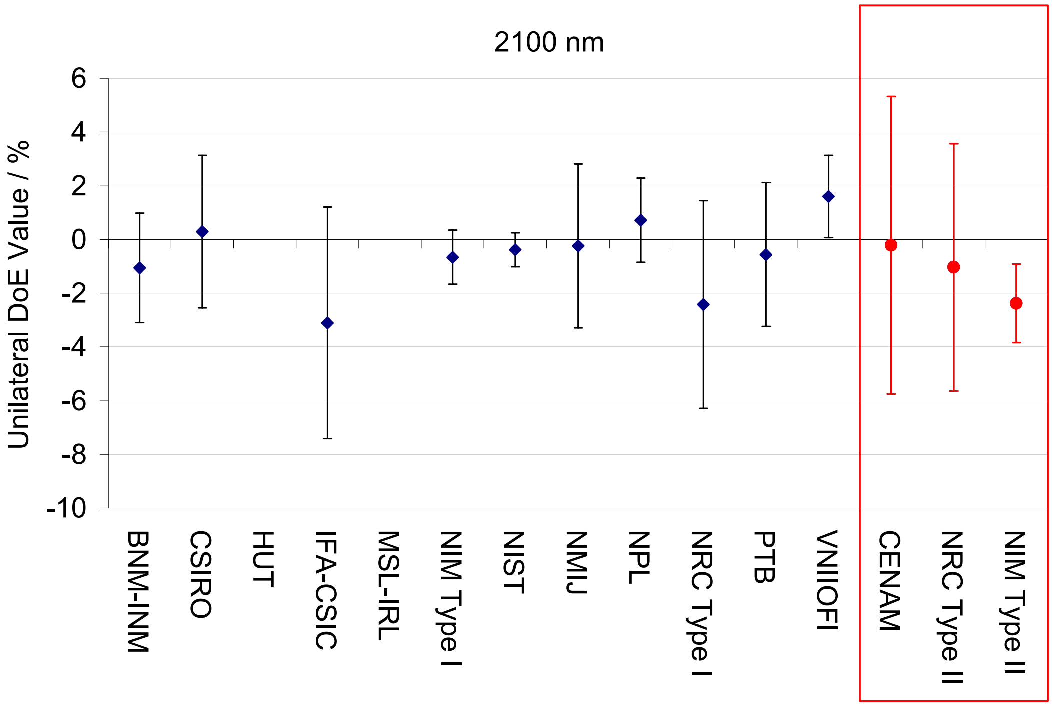
18.3.38 Results at 1900 nm



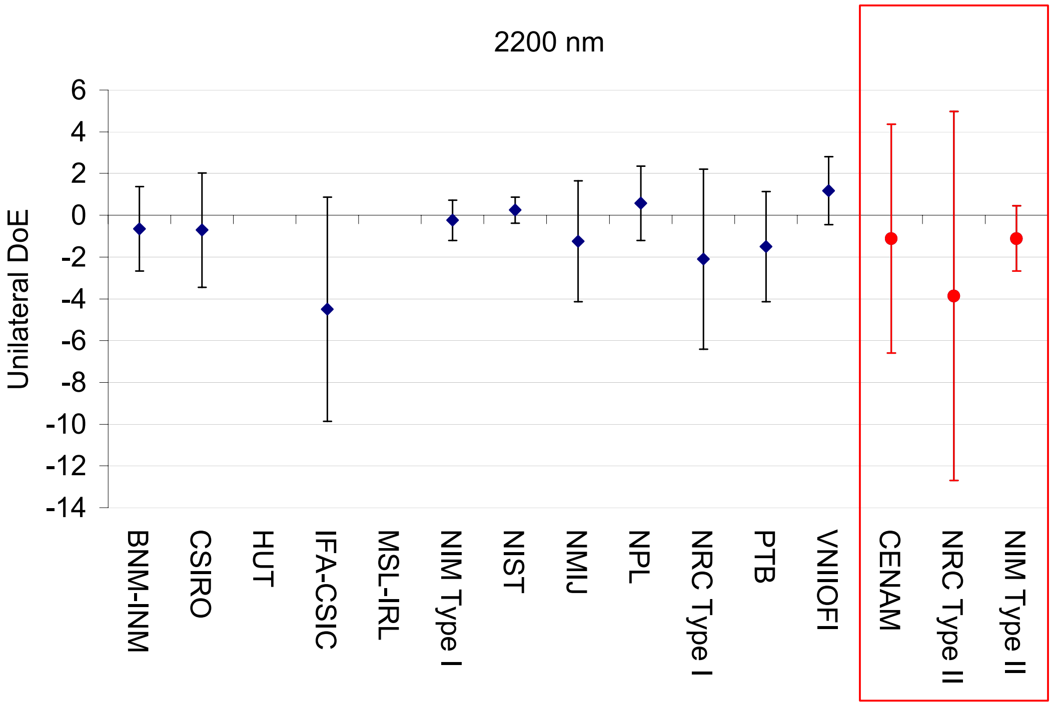
18.3.39 Results at 2000 nm



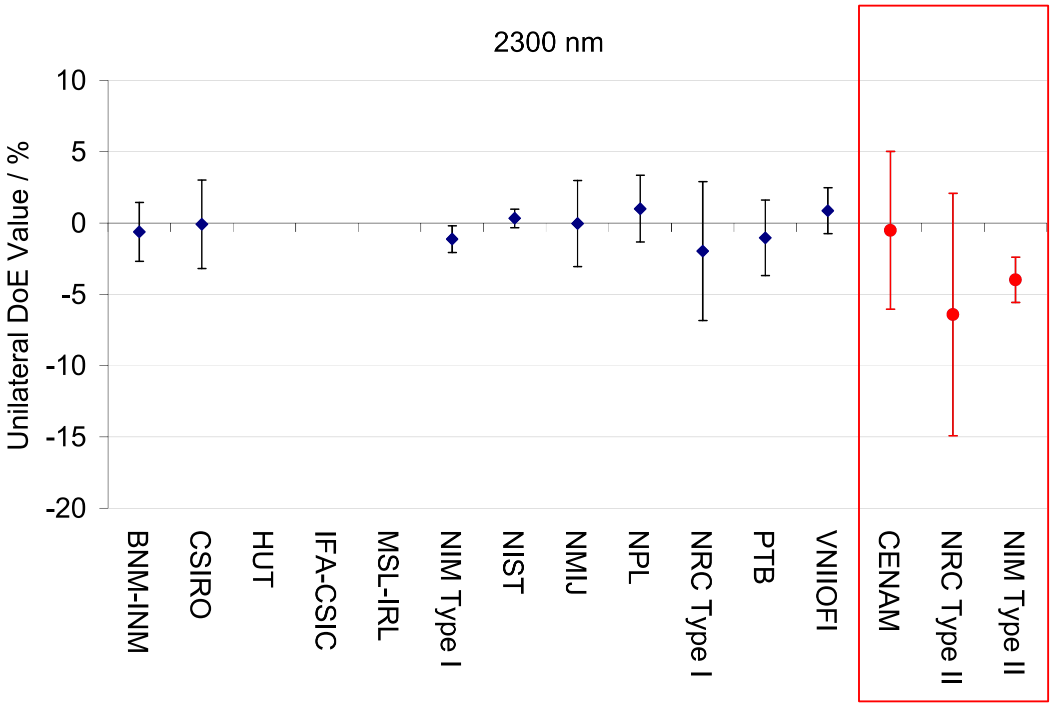
18.3.40 Results at 2100 nm



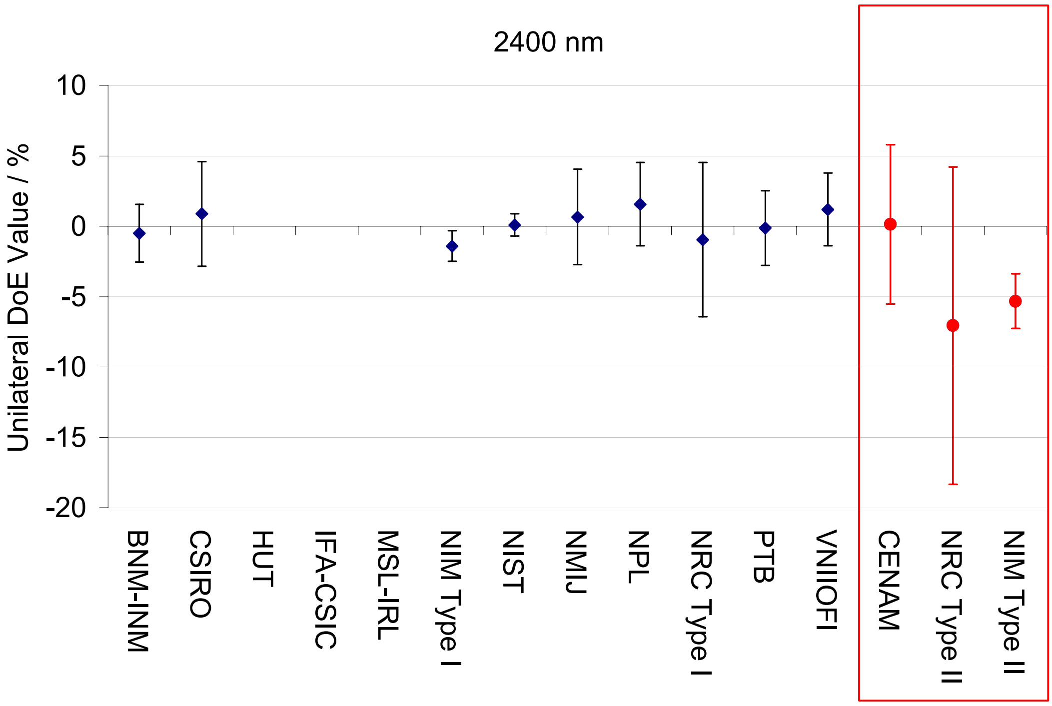
18.3.41 Results at 2200 nm



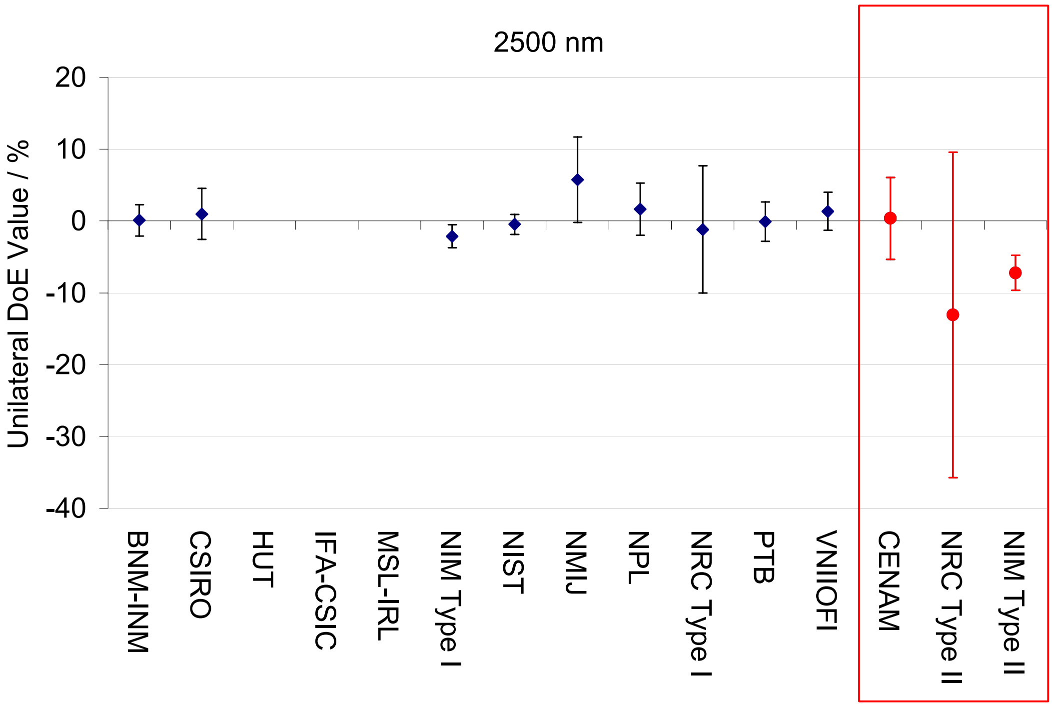
18.3.42 Results at 2300 nm



18.3.43 Results at 2400 nm



18.3.44 Results at 2500 nm



18.4 Tabulated results

Results for those participants that were included in the KCRV (in the constraint equation). For NIM this included Type I lamps only from 250 to 700 nm and from 1200 to 2500 nm, and Type II lamps for intermediate wavelengths. All results are given as a percentage and uncertainties are at the 95 % level of confidence.

Wavelength / nm	BNM-INM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI		*CENAM*	
	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	*DoE*	*U(DoE)*
250			0.4	3.4					-0.2	2.7	0.9	2.1	-0.7	2.0	2.7	3.5	0.5	4.9	-1.3	8.2	-0.6	1.7	-0.6	3.2	*-1.4*	*13.7*
260			0.5	2.1					0.3	2.4	-1.2	1.5	0.0	1.8	1.9	3.2	-0.1	4.5	-3.9	5.5	0.0	1.4	1.1	2.1	*-1.2*	*9.6*
270			0.4	1.9					0.4	2.3	-0.8	1.4	0.0	1.7	1.2	3.1	-1.0	4.2	-2.7	4.7	0.0	1.3	0.8	1.8	*-0.7*	*7.8*
280			1.5	1.8					0.4	2.2	-0.3	1.4	-0.3	1.7	1.5	3.1	-0.7	3.2	-3.4	3.8	-0.8	1.4	1.0	1.7	*-2.4*	*7.4*
290			0.6	1.6	1.8	2.4			0.1	2.1	-0.6	1.4	0.0	1.6	1.3	3.1	-0.8	2.2	-2.6	3.3	-0.2	1.4	0.5	1.5	*-0.9*	*7.3*
300	-3.8	3.7	0.8	1.5	1.1	1.6	0.1	5.0	0.3	2.0	-0.9	1.3	0.0	1.5	1.3	3.1	-0.4	1.3	-1.6	19.9	-0.2	1.4	0.6	1.5	*-1.3*	*7.1*
310	-0.5	3.8	0.6	1.5	0.5	1.6	-0.6	4.3	0.2	2.0	-0.8	1.4	0.2	1.5	1.3	3.1	-0.3	1.2	-2.2	14.0	0.0	1.2	0.1	1.5	*-0.9*	*7.0*
320	0.8	3.9	0.8	1.4	0.2	1.4	0.2	4.1	0.3	1.9	-1.0	1.3	-0.1	1.4	1.2	3.0	0.0	1.1	-3.4	11.9	-0.2	1.2	0.3	1.5	*-0.4*	*6.9*
330	0.9	2.6	0.7	1.3	0.0	1.3	-0.1	3.7	0.3	1.8	-0.9	1.2	-0.2	1.4	1.2	3.0	0.1	1.0	-4.8	9.7	-0.3	1.1	0.3	1.3	*-0.5*	*6.8*
340	1.2	2.6	0.8	1.2	-0.2	1.3	-0.3	3.8	0.2	1.7	-0.9	1.2	-0.3	1.3	1.1	3.0	0.2	1.0	-5.0	7.8	-0.3	1.1	0.4	1.2	*-0.6*	*6.6*
350	0.2	2.6	0.7	1.2	-0.2	1.3	-0.3	3.4	0.3	1.6	-1.0	1.2	-0.4	1.3	1.2	3.0	0.3	1.0	-0.4	6.2	-0.1	1.1	0.5	1.2	*-0.5*	*6.5*
360	0.8	2.6	0.7	1.1	-0.4	1.3	-0.6	3.4	0.3	1.5	-1.0	1.1	-0.4	1.2	1.2	3.0	0.3	1.0	-0.7	6.1	-0.2	1.0	0.6	1.1	*-0.5*	*6.4*
370	0.6	2.6	0.6	1.0	-0.4	1.2	-0.6	3.4	0.2	1.5	-1.0	1.1	-0.3	1.2	1.2	3.0	0.3	1.0	-0.1	6.2	-0.2	1.0	0.7	1.1	*-0.6*	*6.4*
380	0.6	2.6	0.6	1.0	-0.5	1.2	-0.7	3.4	0.5	1.5	-1.0	1.1	-0.5	1.2	1.4	3.0	0.3	1.1	1.4	6.3	-0.1	1.0	0.6	1.1	*-0.7*	*6.2*
390	0.5	2.6	0.5	0.9	-0.6	1.2	-0.7	3.4	0.6	1.5	-0.9	1.1	-0.3	1.2	1.8	3.0	0.2	1.1	0.2	6.2	-0.2	0.9	0.5	1.1	*-0.7*	*5.6*
400	0.4	2.1	0.6	0.9	-0.5	1.1	-0.6	3.3	0.3	1.5	-0.9	1.1	-0.1	1.2	1.2	2.9	0.2	1.0	0.3	4.3	-0.1	0.9	0.5	1.0	*-0.7*	*5.1*
450	1.2	2.2	0.3	0.8	-0.3	0.8	-0.6	3.3	0.2	1.5	0.4	1.1	-0.3	1.0	0.8	2.9	-0.2	0.7	1.4	4.4	-0.4	0.9	0.3	1.0	*-0.6*	*4.7*
500	0.6	2.0	0.4	0.7	-0.1	0.8	-0.5	3.4	-0.1	1.5	0.1	1.0	-0.2	1.0	0.8	2.9	-0.3	0.7	0.7	3.6	-0.4	0.8	0.4	1.0	*-1.0*	*4.2*
550	0.4	2.0	0.3	0.7	0.0	0.8	-0.4	3.5	0.4	1.6	0.1	1.0	-0.4	0.9	0.8	2.9	-0.3	0.6	-0.2	3.6	-0.2	0.8	0.4	0.9	*-0.9*	*3.9*
555	0.8	2.0	0.2	0.6	-0.1	0.7	-0.2	3.7	-0.1	1.4	0.2	1.0	-0.1	0.9			-0.3	0.6			-0.3	0.8	0.3	0.9	*-0.9*	*3.9*
600	0.1	2.0	0.0	0.7	-0.1	0.7	-0.7	3.5	0.4	1.4	0.7	1.0	-0.3	0.8	0.5	2.9	-0.3	0.6	0.5	3.6	-0.3	0.8	0.3	0.9	*-0.9*	*3.8*
650	-0.2	2.0	0.0	0.7	-0.1	0.7	-0.9	3.7	0.2	1.5	0.6	0.9	-0.1	0.8	0.4	2.9	-0.2	0.5	-0.8	3.5	-0.3	0.8	0.3	0.8	*-0.9*	*3.5*
700	-0.2	2.0	-0.2	0.7	-0.1	0.7	-0.9	3.3	0.0	1.4	0.9	0.9	-0.3	0.7	-0.4	2.9	-0.1	0.5	0.1	1.9	-0.4	0.8	0.3	0.8	*-1.0*	*3.4*
750	0.0	2.0	-0.1	0.8	0.2	0.7	-0.9	3.1	0.1	1.5	-0.3	1.0	-0.3	0.7	-0.1	2.9	0.1	0.5	0.0	1.8	-0.3	0.8	0.5	0.8	*-0.8*	*3.2*

Wavelength / nm	BNM-INM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI		*CENAM*	
	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	DoE	U(DoE)	*DoE*	*U(DoE)*
800	-0.8	2.0	-0.1	0.9	0.2	0.7	-0.8	3.2	0.0	1.4	-0.2	1.0	-0.1	0.6	-0.1	2.9	0.2	0.4	-0.3	1.8	-0.4	0.8	0.6	0.8	*-0.9*	*4.1*
850	-0.4	1.9	0.0	1.0	0.3	0.7	-1.0	3.9	0.2	1.6	-1.3	1.0	-0.2	0.7	0.1	2.9	0.4	0.5	-0.2	1.9	-0.3	0.7	0.8	0.8	*-1.5*	*4.0*
900	-0.1	1.9	0.0	1.0	0.1	0.7	-1.1	3.8			-1.7	1.0	-0.1	0.6	0.3	2.9	0.4	0.4	-0.2	1.8	-0.4	0.7	0.9	0.7	*-2.1*	*3.9*
950	0.0	1.9	-0.1	1.1			-1.4	3.9			-1.2	1.0	-0.1	0.6	0.3	2.9	0.4	0.4	-0.4	1.8	-0.2	0.7	0.9	0.8	*-2.5*	*3.8*
1000	0.2	1.9	-0.1	1.1			-1.4	3.8			-1.4	1.0	-0.1	0.6	0.1	2.9	0.5	0.4	-0.4	1.8	-0.4	0.7	1.0	0.8	*-2.9*	*4.1*
1100	-0.4	2.2	-0.4	1.2			-1.4	4.7			-1.2	0.9	-0.2	0.6	-0.2	2.9	0.5	0.4	-0.5	1.6	-0.4	1.0	1.4	0.9	*-3.6*	*4.0*
1200	0.3	2.1	-0.7	1.3			-1.6	4.5			-0.4	0.8	-0.5	0.5	-1.1	2.9	0.3	0.5	-1.2	2.3	-0.4	1.0	1.5	0.9	*-3.8*	*4.0*
1300	0.2	2.1	-0.5	1.4			-2.0	4.0			-0.6	0.8	-0.4	0.5	-1.0	2.9	0.5	0.5	-1.1	2.3	-0.7	1.0	1.6	0.8	*-3.8*	*3.9*
1400	-0.1	2.1	-0.6	1.5			-2.3	4.2			-1.6	0.9	-0.4	0.5	0.5	2.9	0.7	0.5	-0.9	2.5	0.6	2.2	1.8	0.8	*-2.8*	*3.9*
1500	-0.1	2.6	-0.4	1.5			-2.4	4.2			-0.9	0.9	-0.3	0.5	-1.3	2.9	0.6	0.5	-1.2	2.3	-0.7	2.2	1.5	0.9	*-2.2*	*3.9*
1600	0.1	2.6	-0.2	1.9			-2.6	4.0			-1.0	0.9	-0.2	0.5	-1.2	2.9	0.8	0.5	-1.4	2.3	-0.5	2.2	1.5	1.2	*-1.0*	*4.0*
1700	0.1	2.6	-0.6	2.1			-4.5	4.5			-1.1	0.9	-0.2	0.5	-1.2	2.9	0.8	0.6	-1.9	2.9	-0.6	2.2	1.6	1.3	*-0.5*	*4.0*
1800	-0.1	3.0	-0.6	2.8			-3.7	4.5			-1.5	0.9	-0.1	0.5	-0.9	2.9	1.0	0.9	-1.9	2.8	0.0	2.2	1.6	1.4	*-0.1*	*4.0*
1900	-0.7	3.0	-0.2	2.5			-3.4	4.2			-1.3	1.0	-0.1	0.6	0.9	3.0	0.8	1.3	-2.8	4.2	0.7	2.3	1.2	1.5	*0.4*	*4.1*
2000	-0.4	2.1	0.5	2.8			-3.0	4.2			-1.2	1.0	-0.1	0.6	0.3	3.0	0.8	1.5	-2.3	3.4	-0.6	2.3	1.4	1.5	*0.4*	*5.6*
2100	-1.1	2.0	0.3	2.8			-3.1	4.3			-0.7	1.0	-0.4	0.6	-0.2	3.1	0.7	1.6	-2.4	3.9	-0.6	2.7	1.6	1.5	*-0.2*	*5.5*
2200	-0.7	2.0	-0.7	2.7			-4.5	5.4			-0.2	1.0	0.3	0.6	-1.2	2.9	0.6	1.8	-2.1	4.3	-1.5	2.6	1.2	1.6	*-1.1*	*5.5*
2300	-0.6	2.1	-0.1	3.1							-1.1	0.9	0.3	0.7	0.0	3.0	1.0	2.3	-2.0	4.9	-1.0	2.7	0.9	1.6	*-0.5*	*5.5*
2400	-0.5	2.1	0.9	3.7							-1.4	1.1	0.1	0.8	0.7	3.4	1.6	3.0	-1.0	5.5	-0.1	2.7	1.2	2.6	*0.1*	*5.7*
2500	0.1	2.2	1.0	3.5							-2.1	1.6	-0.5	1.4	5.8	5.9	1.7	3.7	-1.2	8.9	-0.1	2.8	1.4	2.7	*0.4*	*5.7*

19 Conclusions

The CCPR K1-a comparison involved measurements made by 13 participants of 39 lamps. The measurements were made between the years 2000 and 2004. All participants supplied detailed reports of their measurements including full uncertainty statements. These uncertainty statements have been reviewed by all participants and in some cases revised or clarified following comments in accordance with the draft procedure developed by the CCPR KCWG. The results of this comparison have been analysed according to the procedure discussed in Chapter 17, which was also subject to discussion and approval by all participants prior to the publication of the Draft A report, and have been presented in Chapter 18. The bilateral DoEs are presented in the Appendix following this chapter.

It has been possible to complete the analysis of this comparison without excluding any participant from the KCRV with the exception of one, which requested exclusion due to the nature of its own analysis. For wavelengths from 250 to 800 nm (apart from 300 nm) all participants had unilateral DoEs with values consistent with their uncertainties at the $k = 2$ level. At all other wavelengths (apart from 1400 nm) all participants achieved consistency at the $k = 4$ level for their unilateral DoEs and the vast majority within $k = 3$.

These results are a significant improvement when compared to those of the previous comparison in 1990, especially since the declared uncertainties of most participants have also been substantially reduced over the intervening decade. This is evidence of the value of the effort that has gone into developing improved spectral irradiance scales by many NMIs in recent years.

The comparison also highlights the difficulty facing the user community with respect to dissemination and the availability of suitable transfer standards. Whilst the use of multiple transfer standard artefacts (tungsten halogen lamps) allowed sufficient redundancy to ensure that all participants had a satisfactory representation of their unit, it is noticeable that overall, it is their stability which has limited the uncertainty with which this comparison has been carried out. It is therefore important information to the users of these lamps that great care must be taken in interpretation of results if only one lamp is used as a transfer standard artefact.

Appendix A Unilateral and Bilateral Degrees of Equivalence

This appendix gives the unilateral and bilateral degrees of equivalence and the associated uncertainties at the 95 % confidence level for the CCPR K1-a Key Comparison of spectral irradiance. The details of the analysis technique are described in Chapter 17. The analysis was based on a model that assumes that each lamp has a stable spectral irradiance and that the measurements of each NMI are systematically biased by a factor applied to all that NMI's measurements. The measurement by an NMI is an estimate, (hopefully) consistent with the declared uncertainty associated with the NMI's random effects, of the lamp irradiance multiplied by the systematic bias factor. The aim of the analysis was to determine an estimate of the systematic factor for each NMI. This was achieved by solving, by least squares adjustment, a set of linked equations that relate the NMI measurements to the lamp irradiances and systematic factors under a constraint that ensures that these systematic factors have a weighted geometric mean (with cut-off) of unity.

The unilateral DoE for an NMI is the difference from unity of the typical ratio of the measurement according to that NMI's scale and the spectral irradiance of a lamp. The best estimate of the value of this unilateral DoE for any NMI is the difference between the estimated systematic factor for that NMI and unity. The unilateral DoE uncertainty (which is quoted at a 95 % level of confidence) can also be evaluated from the model. Since the comparison consists of many separate artefacts, the KCRV is itself unrelated to a physical artefact. The choice of KCRV is mathematically arbitrary, but to meet the metrological requirements of the CCPR KCWG, it is assigned here as the value unity, corresponding to the weighted geometric mean (with cut-off) of these estimated systematic factors. The unilateral DoE is given here as D_i and its associated uncertainty, at the 95 % level of confidence, is given as U_i. In particular, see section 17.6.2.

Bilateral DoEs are calculated from the unilateral DoEs. The bilateral DoE between participant NMI i and participant NMI j, D_{ij} is calculated as the difference between the unilateral DoEs, $D_{ij} = D_i - D_j$. Its associated uncertainty, at the 95 % level, and accounting for covariance, is given as U_{ij}. In particular, see section 17.6.4.

In the tables that follow, the results have been rounded to one decimal place, consistent with the uncertainties. This sometimes leads to apparent, but not real, discrepancies between the difference between the unilateral DoEs quoted here and the bilateral DoEs. For example, the bilateral between NIM and MSL-IRL at 250 nm is given by $0.87-(-0.17)=1.04$, which is rounded to 1.0, which is not the same as $0.9-(-0.2)$.

250 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM																												
CENAM	-1.3	13.7					-1.7	14.1					-1.2	14.0	-2.2	13.9	-0.6	13.8	-4.0	14.2	-1.8	14.6	-0.1	16.0	-0.7	13.8	-0.8	14.1
CSIRO	0.4	3.4			1.7	14.1							0.5	4.5	-0.5	4.2	1.1	4.0	-2.3	5.0	-0.1	6.1	1.7	8.9	1.0	3.9	0.9	4.9
HUT																												
IFA-CSIC																												
MSL-IRL	-0.2	2.7			1.2	14.0	-0.5	4.5							-1.0	3.7	0.5	3.3	-2.8	4.6	-0.7	5.8	1.1	8.7	0.5	3.3	0.4	4.4
NIM	0.9	2.1			2.2	13.9	0.5	4.2					1.0	3.7			1.6	3.0	-1.8	4.2	0.4	5.5	2.2	8.5	1.5	2.8	1.4	4.1
NIST	-0.7	2.0			0.6	13.8	-1.1	4.0					-0.5	3.3	-1.6	3.0			-3.4	4.1	-1.2	5.4	0.6	8.4	-0.1	2.6	-0.2	3.9
NMIJ	2.7	3.5			4.0	14.2	2.3	5.0					2.8	4.6	1.8	4.2	3.4	4.1			2.2	6.1	4.0	9.0	3.3	3.9	3.2	4.9
NPL	0.5	5.0			1.8	14.6	0.1	6.1					0.7	5.8	-0.4	5.5	1.2	5.4	-2.2	6.1			1.8	9.6	1.1	5.3	1.0	6.0
NRC	-1.3	8.2			0.1	16.0	-1.7	8.9					-1.1	8.7	-2.2	8.5	-0.6	8.4	-4.0	9.0	-1.8	9.6			-0.7	8.4	-0.8	8.9
PTB	-0.6	1.7			0.7	13.8	-1.0	3.9					-0.5	3.3	-1.5	2.8	0.1	2.6	-3.3	3.9	-1.1	5.3	0.7	8.4			-0.1	3.8
VNIIOFI	-0.5	3.2			0.8	14.1	-0.9	4.9					-0.4	4.4	-1.4	4.1	0.2	3.9	-3.2	4.9	-1.0	6.0	0.8	8.9	0.1	3.8		

260 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM																												
CENAM	-1.2	9.6					-1.7	9.8					-1.5	9.9	0.0	9.8	-1.2	9.8	-3.1	10.1	-1.1	10.6	2.7	11.1	-1.2	9.7	-2.4	9.9
CSIRO	0.5	2.1			1.7	9.8							0.2	3.4	1.8	2.7	0.6	2.8	-1.3	3.9	0.6	5.0	4.4	5.9	0.6	2.6	-0.6	3.1
HUT																												
IFA-CSIC																												

MSL-IRL	0.3	2.4			1.5	9.9	-0.2	3.4							1.5	3.1	0.3	3.0	-1.6	4.1	0.4	5.2	4.2	6.1	0.3	2.9	-0.9	3.4
NIM	-1.2	1.5			0.0	9.8	-1.8	2.7					-1.5	3.1			-1.2	2.5	-3.1	3.7	-1.1	4.8	2.6	5.8	-1.2	2.2	-2.4	2.8
NIST	0.0	1.8			1.2	9.8	-0.6	2.8					-0.3	3.0	1.2	2.5			-1.9	3.7	0.1	4.8	3.8	5.8	0.0	2.3	-1.2	2.9
NMIJ	1.9	3.2			3.1	10.1	1.3	3.9					1.6	4.1	3.1	3.7	1.9	3.7			2.0	5.6	5.7	6.4	1.9	3.5	0.7	4.0
NPL	-0.1	4.5			1.1	10.6	-0.6	5.0					-0.4	5.2	1.1	4.8	-0.1	4.8	-2.0	5.6			3.8	7.1	-0.1	4.7	-1.3	5.1
NRC	-3.9	5.5			-2.7	11.1	-4.4	5.9					-4.2	6.1	-2.6	5.8	-3.8	5.8	-5.7	6.4	-3.8	7.1			-3.9	5.7	-5.0	6.0
PTB	0.0	1.4			1.2	9.7	-0.6	2.6					-0.3	2.9	1.2	2.2	0.0	2.3	-1.9	3.5	0.1	4.7	3.9	5.7			-1.2	2.7
VNIIOFI	1.1	2.1			2.4	9.9	0.6	3.1					0.9	3.4	2.4	2.8	1.2	2.9	-0.7	4.0	1.3	5.1	5.0	6.0	1.2	2.7		

270 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM																												
CENAM	-0.7	7.8					-1.0	8.0					-1.1	8.1	0.1	7.9	-0.7	7.9	-1.9	8.4	0.3	8.8	2.0	9.0	-0.7	7.8	-1.5	8.0
CSIRO	0.4	1.8			1.0	8.0							0.0	3.1	1.2	2.5	0.4	2.6	-0.9	3.7	1.3	4.7	3.0	5.1	0.4	2.3	-0.4	2.7
HUT																												
IFA-CSIC																												
MSL-IRL	0.4	2.3			1.1	8.1	0.0	3.1							1.2	2.8	0.4	2.8	-0.8	4.0	1.4	4.9	3.0	5.3	0.4	2.7	-0.4	3.0
NIM	-0.8	1.4			-0.1	7.9	-1.2	2.5					-1.2	2.8			-0.8	2.3	-2.0	3.5	0.2	4.5	1.9	4.9	-0.8	2.0	-1.6	2.4
NIST	0.0	1.7			0.7	7.9	-0.4	2.6					-0.4	2.8	0.8	2.3			-1.2	3.6	1.0	4.6	2.6	5.0	0.0	2.1	-0.8	2.5
NMIJ	1.2	3.1			1.9	8.4	0.9	3.7					0.8	4.0	2.0	3.5	1.2	3.6			2.2	5.3	3.9	5.7	1.2	3.4	0.4	3.7
NPL	-1.0	4.2			-0.3	8.8	-1.3	4.7					-1.4	4.9	-0.2	4.5	-1.0	4.6	-2.2	5.3			1.7	6.3	-1.0	4.5	-1.8	4.7
NRC	-2.7	4.7			-2.0	9.0	-3.0	5.1					-3.0	5.3	-1.9	4.9	-2.6	5.0	-3.9	5.7	-1.7	6.3			-2.6	4.9	-3.5	5.1
PTB	0.0	1.3			0.7	7.8	-0.4	2.3					-0.4	2.7	0.8	2.0	0.0	2.1	-1.2	3.4	1.0	4.5	2.6	4.9			-0.8	2.3
VNIIOFI	0.8	1.8			1.5	8.0	0.4	2.7					0.4	3.0	1.6	2.4	0.8	2.5	-0.4	3.7	1.8	4.7	3.5	5.1	0.8	2.3		

280 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM																												
CENAM	-2.4	7.4					-3.9	7.6					-2.7	7.7	-2.1	7.6	-2.1	7.6	-3.9	8.1	-1.7	8.1	1.0	8.3	-1.6	7.5	-3.3	7.6
CSIRO	1.5	1.8			3.9	7.6							1.2	3.0	1.8	2.5	1.9	2.6	0.1	3.7	2.2	3.8	5.0	4.2	2.3	2.3	0.6	2.6
HUT																												
IFA-CSIC																												
MSL-IRL	0.4	2.2			2.7	7.7	-1.2	3.0							0.6	2.8	0.7	2.8	-1.1	4.0	1.0	4.0	3.8	4.4	1.1	2.7	-0.6	3.0
NIM	-0.2	1.4			2.1	7.6	-1.8	2.5					-0.6	2.8			0.1	2.3	-1.7	3.6	0.4	3.6	3.2	4.1	0.5	2.1	-1.2	2.4
NIST	-0.3	1.7			2.1	7.6	-1.9	2.6					-0.7	2.8	-0.1	2.3			-1.8	3.6	0.3	3.7	3.1	4.2	0.4	2.2	-1.3	2.5
NMIJ	1.5	3.1			3.9	8.1	-0.1	3.7					1.1	4.0	1.7	3.6	1.8	3.6			2.1	4.6	4.9	5.0	2.2	3.5	0.5	3.7
NPL	-0.7	3.2			1.7	8.1	-2.2	3.8					-1.0	4.0	-0.4	3.6	-0.3	3.7	-2.1	4.6			2.8	5.0	0.1	3.6	-1.6	3.8
NRC	-3.4	3.8			-1.0	8.3	-5.0	4.2					-3.8	4.4	-3.2	4.1	-3.1	4.2	-4.9	5.0	-2.8	5.0			-2.7	4.0	-4.4	4.2
PTB	-0.8	1.4			1.6	7.5	-2.3	2.3					-1.1	2.7	-0.5	2.1	-0.4	2.2	-2.2	3.5	-0.1	3.6	2.7	4.0			-1.7	2.3
VNIIOFI	0.9	1.7			3.3	7.6	-0.6	2.6					0.6	3.0	1.2	2.4	1.3	2.5	-0.5	3.7	1.6	3.8	4.4	4.2	1.7	2.3		

290 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM																												
CENAM	-0.9	7.3					-1.6	7.5	-2.7	7.7			-1.0	7.6	-0.4	7.5	-1.0	7.5	-2.2	8.0	-0.1	7.7	1.7	8.0	-0.8	7.4	-1.5	7.5
CSIRO	0.6	1.6			1.6	7.5			-1.1	3.0			0.6	2.8	1.2	2.3	0.6	2.4	-0.7	3.6	1.5	2.9	3.3	3.7	0.8	2.2	0.1	2.4
HUT	1.8	2.4			2.7	7.7	1.1	3.0					1.7	3.3	2.3	2.9	1.7	2.9	0.5	4.0	2.6	3.3	4.4	4.1	1.9	2.8	1.2	2.9
IFA-CSIC																												

MSL-IRL	0.1	2.1			1.0	7.6	-0.6	2.8	-1.7	3.3					0.6	2.7	0.0	2.7	-1.2	3.8	0.9	3.2	2.7	3.9	0.2	2.6	-0.5	2.7
NIM	-0.6	1.4			0.4	7.5	-1.2	2.3	-2.3	2.9			-0.6	2.7			-0.6	2.2	-1.9	3.5	0.2	2.8	2.1	3.6	-0.4	2.0	-1.1	2.2
NIST	0.0	1.6			1.0	7.5	-0.6	2.4	-1.7	2.9			0.0	2.7	0.6	2.2			-1.3	3.5	0.9	2.8	2.7	3.7	0.2	2.1	-0.5	2.3
NMIJ	1.3	3.1			2.2	8.0	0.7	3.6	-0.5	4.0			1.2	3.8	1.9	3.5	1.3	3.5			2.1	3.9	3.9	4.6	1.4	3.4	0.8	3.6
NPL	-0.8	2.2			0.1	7.7	-1.5	2.9	-2.6	3.3			-0.9	3.2	-0.2	2.8	-0.9	2.8	-2.1	3.9			1.8	4.0	-0.7	2.7	-1.4	2.8
NRC	-2.6	3.2			-1.7	8.0	-3.3	3.7	-4.4	4.1			-2.7	3.9	-2.1	3.6	-2.7	3.7	-3.9	4.6	-1.8	4.0			-2.5	3.6	-3.2	3.7
PTB	-0.1	1.4			0.8	7.4	-0.8	2.2	-1.9	2.8			-0.2	2.6	0.4	2.0	-0.2	2.1	-1.4	3.4	0.7	2.7	2.5	3.6			-0.7	2.1
VNIIOFI	0.5	1.5			1.5	7.5	-0.1	2.4	-1.2	2.9			0.5	2.7	1.1	2.2	0.5	2.3	-0.8	3.6	1.4	2.8	3.2	3.7	0.7	2.1		

300 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-3.8	3.7			-2.5	8.0	-4.6	4.0	-4.8	4.1	-3.9	6.3	-4.0	4.3	-2.9	4.0	-3.8	4.0	-5.1	4.9	-3.4	3.9	-2.1	20.2	-3.6	3.9	-4.3	4.0
CENAM	-1.3	7.1	2.5	8.0			-2.1	7.3	-2.3	7.3	-1.4	8.7	-1.5	7.4	-0.4	7.3	-1.3	7.3	-2.6	7.8	-0.9	7.2	0.3	21.1	-1.1	7.2	-1.8	7.3
CSIRO	0.8	1.5	4.6	4.0	2.1	7.3			-0.3	2.3	0.7	5.3	0.5	2.7	1.7	2.2	0.8	2.2	-0.5	3.5	1.2	2.0	2.4	19.9	0.9	2.1	0.2	2.2
HUT	1.1	1.6	4.8	4.1	2.3	7.3	0.3	2.3			0.9	5.3	0.8	2.7	2.0	2.2	1.0	2.3	-0.2	3.6	1.5	2.1	2.7	19.9	1.2	2.2	0.5	2.3
IFA-CSIC	0.1	5.0	3.9	6.3	1.4	8.7	-0.7	5.3	-0.9	5.3			-0.1	5.5	1.0	5.2	0.1	5.3	-1.2	5.9	0.5	5.2	1.7	20.5	0.3	5.2	-0.4	5.3
MSL-IRL	0.2	2.0	4.0	4.3	1.5	7.4	-0.5	2.7	-0.8	2.7	0.1	5.5			1.1	2.6	0.2	2.3	-1.0	3.8	0.7	2.5	1.9	20.0	0.4	2.5	-0.3	2.6
NIM	-0.9	1.3	2.9	4.0	0.4	7.3	-1.7	2.2	-2.0	2.2	-1.0	5.2	-1.1	2.6			-0.9	2.1	-2.2	3.5	-0.5	1.9	0.7	19.9	-0.8	2.0	-1.4	2.1
NIST	0.0	1.5	3.8	4.0	1.3	7.3	-0.8	2.2	-1.0	2.3	-0.1	5.3	-0.2	2.3	0.9	2.1			-1.3	3.5	0.4	2.0	1.6	19.9	0.2	2.1	-0.5	2.2
NMIJ	1.3	3.1	5.1	4.9	2.6	7.8	0.5	3.5	0.2	3.6	1.2	5.9	1.0	3.8	2.2	3.5	1.3	3.5			1.7	3.4	2.9	20.1	1.4	3.4	0.7	3.5
NPL	-0.4	1.3	3.4	3.9	0.9	7.2	-1.2	2.0	-1.5	2.1	-0.5	5.2	-0.7	2.5	0.5	1.9	-0.4	2.0	-1.7	3.4			1.2	19.9	-0.3	1.8	-1.0	2.0
NRC	-1.6	19.9	2.1	20.2	-0.3	21.1	-2.4	19.9	-2.7	19.9	-1.7	20.5	-1.9	20.0	-0.7	19.9	-1.6	19.9	-2.9	20.1	-1.2	19.9			-1.5	19.9	-2.2	19.9
PTB	-0.1	1.3	3.6	3.9	1.1	7.2	-0.9	2.1	-1.2	2.2	-0.3	5.2	-0.4	2.5	0.8	2.0	-0.2	2.1	-1.4	3.4	0.3	1.8	1.5	19.9			-0.7	2.1
VNIIOFI	0.5	1.5	4.3	4.0	1.8	7.3	-0.2	2.2	-0.5	2.3	0.4	5.3	0.3	2.6	1.4	2.1	0.5	2.2	-0.7	3.5	1.0	2.0	2.2	19.9	0.7	2.1		

310 nm

NMI *i* \ NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.5	3.8			0.4	8.0	-1.1	4.2	-0.9	4.2	0.1	5.8	-0.6	4.4	0.4	4.1	-0.7	4.2	-1.7	5.0	-0.2	4.0	1.7	14.5	-0.5	4.0	-0.6	4.2
CENAM	-0.9	7.0	-0.4	8.0			-1.5	7.2	-1.4	7.2	-0.3	8.2	-1.1	7.3	-0.1	7.2	-1.1	7.2	-2.2	7.7	-0.6	7.1	1.3	15.6	-0.9	7.1	-1.0	7.2
CSIRO	0.6	1.5	1.1	4.2	1.5	7.2			0.2	2.2	1.2	4.6	0.5	2.6	1.5	2.1	0.4	2.2	-0.6	3.5	0.9	2.0	2.8	14.1	0.6	2.0	0.5	2.2
HUT	0.5	1.6	0.9	4.2	1.4	7.2	-0.2	2.2			1.0	4.6	0.3	2.6	1.3	2.2	0.3	2.2	-0.8	3.5	0.7	2.0	2.7	14.1	0.4	2.0	0.4	2.3
IFA-CSIC	-0.6	4.3	-0.1	5.8	0.3	8.2	-1.2	4.6	-1.0	4.6			-0.8	4.8	0.2	4.6	-0.8	4.6	-1.8	5.3	-0.3	4.5	1.6	14.6	-0.6	4.5	-0.7	4.6
MSL-IRL	0.2	2.0	0.6	4.4	1.1	7.3	-0.5	2.6	-0.3	2.6	0.8	4.8			1.0	2.5	0.0	2.3	-1.1	3.7	0.5	2.4	2.4	14.1	0.2	2.4	0.1	2.6
NIM	-0.8	1.4	-0.4	4.1	0.1	7.2	-1.5	2.1	-1.3	2.2	-0.2	4.6	-1.0	2.5			-1.0	2.1	-2.1	3.5	-0.5	1.9	1.4	14.1	-0.8	1.9	-0.9	2.2
NIST	0.2	1.5	0.7	4.2	1.1	7.2	-0.4	2.2	-0.3	2.2	0.8	4.6	0.0	2.3	1.0	2.1			-1.1	3.5	0.5	2.0	2.4	14.1	0.2	2.0	0.1	2.2
NMIJ	1.3	3.1	1.7	5.0	2.2	7.7	0.6	3.5	0.8	3.5	1.8	5.3	1.1	3.7	2.1	3.5	1.1	3.5			1.6	3.3	3.5	14.3	1.3	3.4	1.2	3.5
NPL	-0.3	1.2	0.2	4.0	0.6	7.1	-0.9	2.0	-0.7	2.0	0.3	4.5	-0.5	2.4	0.5	1.9	-0.5	2.0	-1.6	3.3			1.9	14.0	-0.3	1.7	-0.4	2.0
NRC	-2.2	14.0	-1.7	14.5	-1.3	15.6	-2.8	14.1	-2.7	14.1	-1.6	14.6	-2.4	14.1	-1.4	14.1	-2.4	14.1	-3.5	14.3	-1.9	14.0			-2.2	14.0	-2.3	14.1
PTB	0.0	1.2	0.5	4.0	0.9	7.1	-0.6	2.0	-0.4	2.0	0.6	4.5	-0.2	2.4	0.8	1.9	-0.2	2.0	-1.3	3.4	0.3	1.7	2.2	14.0			-0.1	2.0
VNIIOFI	0.1	1.5	0.6	4.2	1.0	7.2	-0.5	2.2	-0.4	2.3	0.7	4.6	-0.1	2.6	0.9	2.2	-0.1	2.2	-1.2	3.5	0.4	2.0	2.3	14.1	0.1	2.0		

320 nm

NMI *I* \ NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.8	3.9			1.2	7.9	0.1	4.2	0.6	4.1	0.7	5.7	0.6	4.3	1.8	4.1	0.9	4.2	-0.4	5.0	0.8	4.0	4.2	12.5	1.0	4.1	0.5	4.2
CENAM	-0.3	6.9	-1.2	7.9			-1.1	7.0	-0.6	7.0	-0.5	8.0	-0.6	7.2	0.7	7.0	-0.3	7.0	-1.5	7.6	-0.4	7.0	3.0	13.8	-0.1	7.0	-0.6	7.1
CSIRO	0.8	1.4	-0.1	4.2	1.1	7.0			0.5	2.0	0.6	4.4	0.5	2.4	1.8	2.0	0.8	2.1	-0.4	3.4	0.7	1.8	4.1	12.0	1.0	1.9	0.5	2.1
HUT	0.2	1.4	-0.6	4.1	0.6	7.0	-0.5	2.0			0.1	4.4	0.0	2.4	1.3	2.0	0.3	2.0	-0.9	3.4	0.2	1.8	3.6	12.0	0.5	1.8	0.0	2.1
IFA-CSIC	0.2	4.1	-0.7	5.7	0.5	8.0	-0.6	4.4	-0.1	4.4			-0.1	4.6	1.2	4.4	0.2	4.4	-1.0	5.2	0.1	4.3	3.5	12.6	0.4	4.3	-0.1	4.4

MSL-IRL	0.2	1.9	-0.6	4.3	0.6	7.2	-0.5	2.4	0.0	2.4	0.1	4.6			1.3	2.4	0.3	2.2	-0.9	3.6	0.2	2.2	3.6	12.1	0.5	2.3	0.0	2.5
NIM	-1.0	1.3	-1.8	4.1	-0.7	7.0	-1.8	2.0	-1.3	2.0	-1.2	4.4	-1.3	2.4			-0.9	2.0	-2.2	3.4	-1.1	1.8	2.4	12.0	-0.8	1.8	-1.3	2.1
NIST	-0.1	1.4	-0.9	4.2	0.3	7.0	-0.8	2.1	-0.3	2.0	-0.2	4.4	-0.3	2.2	0.9	2.0			-1.3	3.4	-0.1	1.8	3.3	12.0	0.2	1.9	-0.3	2.2
NMIJ	1.2	3.0	0.4	5.0	1.5	7.6	0.4	3.4	0.9	3.4	1.0	5.2	0.9	3.6	2.2	3.4	1.3	3.4			1.2	3.3	4.6	12.3	1.4	3.3	0.9	3.5
NPL	0.0	1.1	-0.8	4.0	0.4	7.0	-0.7	1.8	-0.2	1.8	-0.1	4.3	-0.2	2.2	1.1	1.8	0.1	1.8	-1.2	3.3			3.4	12.0	0.3	1.6	-0.2	1.9
NRC	-3.4	11.9	-4.2	12.5	-3.0	13.8	-4.1	12.0	-3.6	12.0	-3.5	12.6	-3.6	12.1	-2.4	12.0	-3.3	12.0	-4.6	12.3	-3.4	12.0			-3.1	12.0	-3.6	12.0
PTB	-0.2	1.2	-1.0	4.1	0.1	7.0	-1.0	1.9	-0.5	1.8	-0.4	4.3	-0.5	2.3	0.8	1.8	-0.2	1.9	-1.4	3.3	-0.3	1.6	3.1	12.0			-0.5	2.0
VNIIOFI	0.3	1.5	-0.5	4.2	0.6	7.1	-0.5	2.1	0.0	2.1	0.1	4.4	0.0	2.5	1.3	2.1	0.3	2.2	-0.9	3.5	0.2	1.9	3.6	12.0	0.5	2.0		

330 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.9	2.6			1.4	7.2	0.3	3.0	0.9	3.0	1.0	4.6	0.6	3.2	1.8	3.0	1.1	3.0	-0.3	4.1	0.8	2.8	5.7	10.0	1.2	2.9	0.6	3.0
CENAM	-0.4	6.7	-1.4	7.2			-1.1	6.9	-0.4	6.9	-0.3	7.7	-0.7	7.0	0.4	6.9	-0.2	6.9	-1.6	7.4	-0.6	6.8	4.4	11.8	-0.2	6.8	-0.8	6.9
CSIRO	0.7	1.3	-0.3	3.0	1.1	6.9			0.7	1.9	0.8	4.0	0.3	2.3	1.5	1.9	0.9	1.9	-0.5	3.4	0.5	1.7	5.5	9.8	0.9	1.8	0.3	1.9
HUT	0.0	1.3	-0.9	3.0	0.4	6.9	-0.7	1.9			0.1	4.0	-0.4	2.3	0.8	1.9	0.2	2.0	-1.2	3.4	-0.2	1.7	4.8	9.8	0.3	1.8	-0.4	1.9
IFA-CSIC	-0.1	3.7	-1.0	4.6	0.3	7.7	-0.8	4.0	-0.1	4.0			-0.4	4.1	0.7	4.0	0.1	4.0	-1.3	4.8	-0.2	3.9	4.7	10.4	0.2	3.9	-0.4	4.0
MSL-IRL	0.3	1.8	-0.6	3.2	0.7	7.0	-0.3	2.3	0.4	2.3	0.4	4.1			1.2	2.3	0.5	2.1	-0.8	3.6	0.2	2.1	5.2	9.9	0.6	2.2	0.0	2.3
NIM	-0.8	1.2	-1.8	3.0	-0.4	6.9	-1.5	1.9	-0.8	1.9	-0.7	4.0	-1.2	2.3			-0.7	1.9	-2.0	3.3	-1.0	1.7	4.0	9.8	-0.6	1.8	-1.2	1.9
NIST	-0.2	1.4	-1.1	3.0	0.2	6.9	-0.9	1.9	-0.2	2.0	-0.1	4.0	-0.5	2.1	0.7	1.9			-1.4	3.4	-0.3	1.7	4.6	9.8	0.1	1.8	-0.5	1.9
NMIJ	1.2	3.0	0.3	4.1	1.6	7.4	0.5	3.4	1.2	3.4	1.3	4.8	0.8	3.6	2.0	3.3	1.4	3.4			1.0	3.2	6.0	10.2	1.5	3.3	0.8	3.4
NPL	0.1	1.0	-0.8	2.8	0.6	6.8	-0.5	1.7	0.2	1.7	0.2	3.9	-0.2	2.1	1.0	1.7	0.3	1.7	-1.0	3.2			5.0	9.7	0.4	1.5	-0.2	1.7
NRC	-4.8	9.7	-5.7	10.0	-4.4	11.8	-5.5	9.8	-4.8	9.8	-4.7	10.4	-5.2	9.9	-4.0	9.8	-4.6	9.8	-6.0	10.2	-5.0	9.7			-4.5	9.8	-5.2	9.8
PTB	-0.3	1.1	-1.2	2.9	0.2	6.8	-0.9	1.8	-0.3	1.8	-0.2	3.9	-0.6	2.2	0.6	1.8	-0.1	1.8	-1.5	3.3	-0.4	1.5	4.5	9.8			-0.6	1.8
VNIIOFI	0.3	1.3	-0.6	3.0	0.8	6.9	-0.3	1.9	0.4	1.9	0.4	4.0	0.0	2.3	1.2	1.9	0.5	1.9	-0.8	3.4	0.2	1.7	5.2	9.8	0.6	1.8		

340 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	1.2	2.6			1.8	7.1	0.4	3.0	1.5	3.0	1.5	4.7	1.0	3.2	2.1	3.0	1.5	3.0	0.1	4.0	1.0	2.8	6.2	8.2	1.5	2.9	0.9	3.0
CENAM	-0.5	6.6	-1.8	7.1			-1.4	6.7	-0.3	6.7	-0.2	7.6	-0.7	6.8	0.3	6.7	-0.3	6.7	-1.7	7.3	-0.8	6.7	4.4	10.2	-0.3	6.7	-0.9	6.7
CSIRO	0.8	1.2	-0.4	3.0	1.4	6.7			1.1	1.9	1.1	4.0	0.6	2.1	1.7	1.8	1.1	1.9	-0.3	3.3	0.6	1.6	5.8	7.9	1.1	1.7	0.5	1.8
HUT	-0.2	1.3	-1.5	3.0	0.3	6.7	-1.1	1.9			0.1	4.0	-0.4	2.2	0.7	1.9	0.0	1.9	-1.3	3.3	-0.5	1.7	4.7	7.9	0.0	1.8	-0.6	1.9
IFA-CSIC	-0.3	3.8	-1.5	4.7	0.2	7.6	-1.1	4.0	-0.1	4.0			-0.5	4.2	0.6	4.0	0.0	4.0	-1.4	4.9	-0.5	3.9	4.7	8.7	0.0	4.0	-0.7	4.0
MSL-IRL	0.2	1.7	-1.0	3.2	0.7	6.8	-0.6	2.1	0.4	2.2	0.5	4.2			1.1	2.2	0.5	2.0	-0.9	3.5	0.0	2.0	5.2	8.0	0.5	2.1	-0.2	2.2
NIM	-0.9	1.2	-2.1	3.0	-0.3	6.7	-1.7	1.8	-0.7	1.9	-0.6	4.0	-1.1	2.2			-0.6	1.9	-2.0	3.3	-1.1	1.7	4.1	7.9	-0.6	1.7	-1.2	1.9
NIST	-0.3	1.3	-1.5	3.0	0.3	6.7	-1.1	1.9	0.0	1.9	0.0	4.0	-0.5	2.0	0.6	1.9			-1.4	3.3	-0.5	1.7	4.7	7.9	0.0	1.7	-0.6	1.9
NMIJ	1.1	3.0	-0.1	4.0	1.7	7.3	0.3	3.3	1.3	3.3	1.4	4.9	0.9	3.5	2.0	3.3	1.4	3.3			0.9	3.2	6.1	8.4	1.4	3.2	0.7	3.3
NPL	0.2	1.0	-1.0	2.8	0.8	6.7	-0.6	1.6	0.5	1.7	0.5	3.9	0.0	2.0	1.1	1.7	0.5	1.7	-0.9	3.2			5.2	7.9	0.5	1.5	-0.1	1.7
NRC	-5.0	7.8	-6.2	8.2	-4.4	10.2	-5.8	7.9	-4.7	7.9	-4.7	8.7	-5.2	8.0	-4.1	7.9	-4.7	7.9	-6.1	8.4	-5.2	7.9			-4.7	7.9	-5.3	7.9
PTB	-0.3	1.1	-1.5	2.9	0.3	6.7	-1.1	1.7	0.0	1.8	0.0	4.0	-0.5	2.1	0.6	1.7	0.0	1.7	-1.4	3.2	-0.5	1.5	4.7	7.9			-0.6	1.7
VNIIOFI	0.3	1.2	-0.9	3.0	0.9	6.7	-0.5	1.8	0.6	1.9	0.7	4.0	0.2	2.2	1.2	1.9	0.6	1.9	-0.7	3.3	0.1	1.7	5.3	7.9	0.6	1.7		

350 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.2	2.6			0.6	7.0	-0.5	2.9	0.4	2.9	0.5	4.4	-0.1	3.1	1.1	2.9	0.5	2.9	-1.0	4.0	-0.1	2.8	0.5	6.7	0.3	2.9	-0.4	2.9
CENAM	-0.5	6.5	-0.6	7.0			-1.1	6.6	-0.2	6.6	-0.1	7.4	-0.7	6.7	0.5	6.6	-0.1	6.6	-1.6	7.2	-0.7	6.6	-0.1	9.0	-0.3	6.6	-1.0	6.6
CSIRO	0.7	1.2	0.5	2.9	1.1	6.6			0.9	1.8	1.0	3.7	0.4	2.1	1.7	1.8	1.0	1.8	-0.5	3.3	0.4	1.6	1.0	6.3	0.8	1.6	0.2	1.7
HUT	-0.2	1.3	-0.4	2.9	0.2	6.6	-0.9	1.8			0.1	3.7	-0.5	2.1	0.7	1.8	0.1	1.9	-1.4	3.3	-0.5	1.7	0.1	6.4	-0.1	1.7	-0.8	1.8
IFA-CSIC	-0.4	3.4	-0.5	4.4	0.1	7.4	-1.0	3.7	-0.1	3.7			-0.6	3.8	0.6	3.7	0.0	3.7	-1.5	4.6	-0.6	3.6	0.0	7.1	-0.2	3.6	-0.9	3.7

MSL-IRL	0.2	1.6	0.1	3.1	0.7	6.7	-0.4	2.1	0.5	2.1	0.6	3.8			1.3	2.1	0.6	2.0	-0.9	3.5	0.0	1.9	0.6	6.4	0.4	2.0	-0.3	2.1
NIM	-1.0	1.2	-1.1	2.9	-0.5	6.6	-1.7	1.8	-0.7	1.8	-0.6	3.7	-1.3	2.1			-0.6	1.8	-2.1	3.3	-1.3	1.6	-0.6	6.3	-0.8	1.7	-1.5	1.8
NIST	-0.3	1.3	-0.5	2.9	0.1	6.6	-1.0	1.8	-0.1	1.9	0.0	3.7	-0.6	2.0	0.6	1.8			-1.5	3.3	-0.7	1.6	0.0	6.3	-0.2	1.7	-0.9	1.8
NMIJ	1.2	3.0	1.0	4.0	1.6	7.2	0.5	3.3	1.4	3.3	1.5	4.6	0.9	3.5	2.1	3.3	1.5	3.3			0.9	3.2	1.5	6.9	1.3	3.2	0.6	3.3
NPL	0.3	1.0	0.1	2.8	0.7	6.6	-0.4	1.6	0.5	1.7	0.6	3.6	0.0	1.9	1.3	1.6	0.7	1.6	-0.9	3.2			0.7	6.3	0.4	1.5	-0.2	1.6
NRC	-0.4	6.2	-0.5	6.7	0.1	9.0	-1.0	6.3	-0.1	6.4	0.0	7.1	-0.6	6.4	0.6	6.3	0.0	6.3	-1.5	6.9	-0.7	6.3			-0.2	6.3	-0.9	6.3
PTB	-0.1	1.1	-0.3	2.9	0.3	6.6	-0.8	1.6	0.1	1.7	0.2	3.6	-0.4	2.0	0.8	1.7	0.2	1.7	-1.3	3.2	-0.4	1.5	0.2	6.3			-0.7	1.7
VNIIOFI	0.5	1.2	0.4	2.9	1.0	6.6	-0.2	1.7	0.8	1.8	0.9	3.7	0.3	2.1	1.5	1.8	0.9	1.8	-0.6	3.3	0.2	1.6	0.9	6.3	0.7	1.7		

360 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.8	2.6			1.3	6.9	0.1	2.9	1.1	2.9	1.4	4.3	0.5	3.1	1.7	2.9	1.2	2.9	-0.4	4.0	0.5	2.8	1.5	6.7	0.9	2.8	0.2	2.9
CENAM	-0.5	6.4	-1.3	6.9			-1.1	6.5	-0.1	6.5	0.2	7.2	-0.7	6.6	0.5	6.5	0.0	6.5	-1.7	7.0	-0.7	6.4	0.3	8.9	-0.3	6.4	-1.0	6.5
CSIRO	0.7	1.1	-0.1	2.9	1.1	6.5			1.0	1.7	1.3	3.6	0.4	2.0	1.6	1.7	1.1	1.7	-0.5	3.2	0.4	1.6	1.4	6.3	0.8	1.5	0.1	1.7
HUT	-0.3	1.3	-1.1	2.9	0.1	6.5	-1.0	1.7			0.2	3.6	-0.6	2.1	0.6	1.8	0.1	1.8	-1.6	3.3	-0.6	1.7	0.4	6.3	-0.2	1.6	-0.9	1.8
IFA-CSIC	-0.6	3.4	-1.4	4.3	-0.2	7.2	-1.3	3.6	-0.2	3.6			-0.9	3.8	0.4	3.6	-0.2	3.6	-1.8	4.5	-0.9	3.6	0.1	7.0	-0.4	3.5	-1.2	3.6
MSL-IRL	0.3	1.5	-0.5	3.1	0.7	6.6	-0.4	2.0	0.6	2.1	0.9	3.8			1.2	2.0	0.7	1.9	-0.9	3.4	0.0	1.9	1.0	6.4	0.4	1.9	-0.3	2.0
NIM	-0.9	1.1	-1.7	2.9	-0.5	6.5	-1.6	1.7	-0.6	1.8	-0.4	3.6	-1.2	2.0			-0.5	1.8	-2.1	3.3	-1.2	1.6	-0.2	6.3	-0.8	1.6	-1.5	1.7
NIST	-0.4	1.2	-1.2	2.9	0.0	6.5	-1.1	1.7	-0.1	1.8	0.2	3.6	-0.7	1.9	0.5	1.8			-1.6	3.3	-0.7	1.6	0.3	6.3	-0.3	1.6	-1.0	1.7
NMIJ	1.2	3.0	0.4	4.0	1.7	7.0	0.5	3.2	1.6	3.3	1.8	4.5	0.9	3.4	2.1	3.3	1.6	3.3			0.9	3.2	1.9	6.9	1.4	3.2	0.6	3.2
NPL	0.3	1.0	-0.5	2.8	0.7	6.4	-0.4	1.6	0.6	1.7	0.9	3.6	0.0	1.9	1.2	1.6	0.7	1.6	-0.9	3.2			1.0	6.3	0.4	1.4	-0.3	1.6
NRC	-0.8	6.1	-1.5	6.7	-0.3	8.9	-1.4	6.3	-0.4	6.3	-0.1	7.0	-1.0	6.4	0.2	6.3	-0.3	6.3	-1.9	6.9	-1.0	6.3			-0.6	6.2	-1.3	6.3
PTB	-0.1	1.0	-0.9	2.8	0.3	6.4	-0.8	1.5	0.2	1.6	0.4	3.5	-0.4	1.9	0.8	1.6	0.3	1.6	-1.4	3.2	-0.4	1.4	0.6	6.2			-0.8	1.5
VNIIOFI	0.6	1.1	-0.2	2.9	1.0	6.5	-0.1	1.7	0.9	1.8	1.2	3.6	0.3	2.0	1.5	1.7	1.0	1.7	-0.6	3.2	0.3	1.6	1.3	6.3	0.8	1.5		

370 nm

NMI j			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI I	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.6	2.6			1.2	6.9	0.0	2.8	1.0	2.9	1.2	4.3	0.4	3.1	1.5	2.9	0.9	2.9	-0.7	4.0	0.3	2.8	0.6	6.7	0.7	2.8	-0.1	2.9
CENAM	-0.6	6.4	-1.2	6.9			-1.1	6.5	-0.2	6.5	0.1	7.2	-0.7	6.6	0.4	6.5	-0.2	6.5	-1.8	7.1	-0.8	6.5	-0.5	8.9	-0.4	6.5	-1.2	6.5
CSIRO	0.6	1.0	0.0	2.8	1.1	6.5			1.0	1.7	1.2	3.6	0.4	1.9	1.5	1.6	0.9	1.6	-0.7	3.2	0.3	1.5	0.6	6.3	0.7	1.4	-0.1	1.6
HUT	-0.4	1.2	-1.0	2.9	0.2	6.5	-1.0	1.7			0.2	3.6	-0.6	2.0	0.5	1.8	-0.1	1.8	-1.7	3.3	-0.7	1.7	-0.4	6.3	-0.3	1.6	-1.1	1.8
IFA-CSIC	-0.7	3.3	-1.2	4.3	-0.1	7.2	-1.2	3.6	-0.2	3.6			-0.8	3.7	0.3	3.6	-0.3	3.6	-1.9	4.5	-0.9	3.5	-0.6	7.1	-0.5	3.5	-1.3	3.6
MSL-IRL	0.2	1.5	-0.4	3.1	0.7	6.6	-0.4	1.9	0.6	2.0	0.8	3.7			1.1	2.0	0.5	1.9	-1.0	3.4	-0.1	1.9	0.2	6.4	0.3	1.9	-0.5	2.0
NIM	-0.9	1.1	-1.5	2.9	-0.4	6.5	-1.5	1.6	-0.5	1.8	-0.3	3.6	-1.1	2.0			-0.6	1.7	-2.2	3.2	-1.2	1.6	-0.9	6.3	-0.8	1.5	-1.6	1.7
NIST	-0.3	1.2	-0.9	2.9	0.2	6.5	-0.9	1.6	0.1	1.8	0.3	3.6	-0.5	1.9	0.6	1.7			-1.6	3.2	-0.6	1.6	-0.3	6.3	-0.2	1.5	-1.0	1.7
NMIJ	1.2	3.0	0.7	4.0	1.8	7.1	0.7	3.2	1.7	3.3	1.9	4.5	1.0	3.4	2.2	3.2	1.6	3.2			0.9	3.2	1.3	6.9	1.4	3.1	0.6	3.2
NPL	0.3	1.0	-0.3	2.8	0.8	6.5	-0.3	1.5	0.7	1.7	0.9	3.5	0.1	1.9	1.2	1.6	0.6	1.6	-0.9	3.2			0.3	6.3	0.4	1.4	-0.4	1.6
NRC	-0.1	6.2	-0.6	6.7	0.5	8.9	-0.6	6.3	0.4	6.3	0.6	7.1	-0.2	6.4	0.9	6.3	0.3	6.3	-1.3	6.9	-0.3	6.3			0.1	6.3	-0.7	6.3
PTB	-0.1	1.0	-0.7	2.8	0.4	6.5	-0.7	1.4	0.3	1.6	0.5	3.5	-0.3	1.9	0.8	1.5	0.2	1.5	-1.4	3.1	-0.4	1.4	-0.1	6.3			-0.8	1.5
VNIIOFI	0.6	1.1	0.1	2.9	1.2	6.5	0.1	1.6	1.1	1.8	1.3	3.6	0.5	2.0	1.6	1.7	1.0	1.7	-0.6	3.2	0.4	1.6	0.7	6.3	0.8	1.5		

380 nm

NMI j			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI i	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.7	2.6			1.2	6.7	0.1	2.8	1.1	2.9	1.4	4.3	0.1	3.1	1.7	2.9	1.1	2.9	-0.7	4.0	0.4	2.9	-0.7	6.8	0.7	2.8	0.0	2.9
CENAM	-0.6	6.2	-1.2	6.7			-1.2	6.3	-0.1	6.3	0.1	7.1	-1.1	6.4	0.4	6.3	-0.1	6.3	-2.0	6.9	-0.9	6.3	-1.9	8.8	-0.5	6.3	-1.2	6.3
CSIRO	0.6	1.0	-0.1	2.8	1.2	6.3			1.1	1.6	1.3	3.6	0.1	1.9	1.6	1.6	1.1	1.6	-0.8	3.2	0.3	1.5	-0.8	6.4	0.7	1.4	-0.1	1.6
HUT	-0.5	1.2	-1.1	2.9	0.1	6.3	-1.1	1.6			0.2	3.6	-1.0	2.0	0.5	1.7	0.0	1.7	-1.8	3.2	-0.8	1.7	-1.8	6.4	-0.4	1.6	-1.1	1.7
IFA-CSIC	-0.7	3.4	-1.4	4.3	-0.1	7.1	-1.3	3.6	-0.2	3.6			-1.2	3.8	0.3	3.6	-0.2	3.6	-2.1	4.5	-1.0	3.6	-2.1	7.2	-0.6	3.5	-1.3	3.6

MSL-IRL	0.5	1.5	-0.1	3.1	1.1	6.4	-0.1	1.9	1.0	2.0	1.2	3.8			1.5	2.0	1.0	1.9	-0.8	3.4	0.2	1.9	-0.8	6.5	0.6	1.8	-0.1	2.0
NIM	-1.0	1.1	-1.7	2.9	-0.4	6.3	-1.6	1.6	-0.5	1.7	-0.3	3.6	-1.5	2.0			-0.5	1.7	-2.4	3.2	-1.3	1.6	-2.4	6.4	-0.9	1.5	-1.7	1.7
NIST	-0.5	1.2	-1.1	2.9	0.1	6.3	-1.1	1.6	0.0	1.7	0.2	3.6	-1.0	1.9	0.5	1.7			-1.9	3.2	-0.8	1.6	-1.9	6.4	-0.4	1.5	-1.1	1.7
NMIJ	1.4	3.0	0.7	4.0	2.0	6.9	0.8	3.2	1.8	3.2	2.1	4.5	0.8	3.4	2.4	3.2	1.9	3.2			1.1	3.2	0.0	7.0	1.4	3.1	0.7	3.2
NPL	0.3	1.1	-0.4	2.9	0.9	6.3	-0.3	1.5	0.8	1.7	1.0	3.6	-0.2	1.9	1.3	1.6	0.8	1.6	-1.1	3.2			-1.1	6.4	0.4	1.5	-0.4	1.6
NRC	1.3	6.3	0.7	6.8	1.9	8.8	0.8	6.4	1.8	6.4	2.1	7.2	0.8	6.5	2.4	6.4	1.9	6.4	0.0	7.0	1.1	6.4			1.4	6.4	0.7	6.4
PTB	-0.1	0.9	-0.7	2.8	0.5	6.3	-0.7	1.4	0.4	1.6	0.6	3.5	-0.6	1.8	0.9	1.5	0.4	1.5	-1.4	3.1	-0.4	1.5	-1.4	6.4			-0.7	1.5
VNIIOFI	0.6	1.1	0.0	2.9	1.2	6.3	0.1	1.6	1.1	1.7	1.3	3.6	0.1	2.0	1.7	1.7	1.1	1.7	-0.7	3.2	0.4	1.6	-0.7	6.4	0.7	1.5		

390 nm

NMI j			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI I	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.5	2.6			1.1	6.2	0.0	2.8	1.0	2.9	1.2	4.3	-0.1	3.1	1.3	2.9	0.7	2.9	-1.3	4.0	0.3	2.8	0.3	6.7	0.6	2.8	0.0	2.9
CENAM	-0.6	5.6	-1.1	6.2			-1.1	5.7	-0.1	5.8	0.1	6.6	-1.2	5.8	0.2	5.7	-0.4	5.7	-2.4	6.4	-0.8	5.7	-0.8	8.3	-0.5	5.7	-1.1	5.7
CSIRO	0.5	0.9	0.0	2.8	1.1	5.7			1.0	1.6	1.2	3.6	-0.1	1.8	1.3	1.5	0.7	1.5	-1.3	3.2	0.3	1.5	0.3	6.3	0.6	1.3	0.0	1.5
HUT	-0.5	1.2	-1.0	2.9	0.1	5.8	-1.0	1.6			0.1	3.7	-1.1	2.0	0.3	1.7	-0.3	1.7	-2.3	3.3	-0.7	1.7	-0.7	6.3	-0.4	1.6	-1.1	1.7
IFA-CSIC	-0.7	3.4	-1.2	4.3	-0.1	6.6	-1.2	3.6	-0.1	3.7			-1.2	3.8	0.2	3.6	-0.4	3.6	-2.5	4.6	-0.9	3.6	-0.8	7.1	-0.5	3.6	-1.2	3.6
MSL-IRL	0.5	1.5	0.1	3.1	1.2	5.8	0.1	1.8	1.1	2.0	1.2	3.8			1.4	2.0	0.8	1.9	-1.2	3.4	0.4	1.9	0.4	6.4	0.7	1.8	0.1	2.0
NIM	-0.8	1.1	-1.3	2.9	-0.2	5.7	-1.3	1.5	-0.3	1.7	-0.2	3.6	-1.4	2.0			-0.6	1.6	-2.6	3.2	-1.0	1.6	-1.0	6.3	-0.7	1.5	-1.4	1.7
NIST	-0.2	1.2	-0.7	2.9	0.4	5.7	-0.7	1.5	0.3	1.7	0.4	3.6	-0.8	1.9	0.6	1.6			-2.0	3.2	-0.4	1.6	-0.4	6.3	-0.1	1.5	-0.8	1.6
NMIJ	1.8	3.0	1.3	4.0	2.4	6.4	1.3	3.2	2.3	3.3	2.5	4.6	1.2	3.4	2.6	3.2	2.0	3.2			1.6	3.2	1.6	6.9	1.9	3.1	1.3	3.2
NPL	0.2	1.1	-0.3	2.8	0.8	5.7	-0.3	1.5	0.7	1.7	0.9	3.6	-0.4	1.9	1.0	1.6	0.4	1.6	-1.6	3.2			0.0	6.3	0.3	1.4	-0.3	1.6
NRC	0.1	6.2	-0.3	6.7	0.8	8.3	-0.3	6.3	0.7	6.3	0.8	7.1	-0.4	6.4	1.0	6.3	0.4	6.3	-1.6	6.9	0.0	6.3			0.3	6.3	-0.3	6.3
PTB	-0.1	0.9	-0.6	2.8	0.5	5.7	-0.6	1.3	0.4	1.6	0.5	3.6	-0.7	1.8	0.7	1.5	0.1	1.5	-1.9	3.1	-0.3	1.4	-0.3	6.3			-0.6	1.5
VNIIOFI	0.5	1.1	0.0	2.9	1.1	5.7	0.0	1.5	1.1	1.7	1.2	3.6	-0.1	2.0	1.4	1.7	0.8	1.6	-1.3	3.2	0.3	1.6	0.3	6.3	0.6	1.5		

400 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.4	2.1			1.1	5.5	-0.2	2.3	0.9	2.4	1.0	4.0	0.1	2.6	1.3	2.4	0.6	2.4	-0.8	3.7	0.3	2.4	0.1	4.8	0.5	2.3	0.0	2.4
CENAM	-0.7	5.1	-1.1	5.5			-1.3	5.1	-0.2	5.2	-0.1	6.1	-0.9	5.3	0.2	5.2	-0.5	5.2	-1.9	5.9	-0.8	5.2	-1.0	6.6	-0.6	5.1	-1.1	5.2
CSIRO	0.6	0.9	0.2	2.3	1.3	5.1			1.1	1.5	1.2	3.5	0.3	1.8	1.5	1.5	0.7	1.5	-0.6	3.1	0.4	1.4	0.3	4.4	0.7	1.3	0.1	1.4
HUT	-0.5	1.1	-0.9	2.4	0.2	5.2	-1.1	1.5			0.1	3.5	-0.8	1.9	0.4	1.6	-0.3	1.6	-1.7	3.2	-0.6	1.5	-0.8	4.4	-0.4	1.5	-0.9	1.6
IFA-CSIC	-0.6	3.3	-1.0	4.0	0.1	6.1	-1.2	3.5	-0.1	3.5			-0.9	3.7	0.3	3.5	-0.4	3.5	-1.8	4.5	-0.7	3.5	-0.9	5.4	-0.5	3.5	-1.0	3.5
MSL-IRL	0.3	1.5	-0.1	2.6	0.9	5.3	-0.3	1.8	0.8	1.9	0.9	3.7			1.2	1.9	0.4	1.9	-0.9	3.4	0.1	1.9	0.0	4.6	0.4	1.8	-0.2	1.9
NIM	-0.9	1.1	-1.3	2.4	-0.2	5.2	-1.5	1.5	-0.4	1.6	-0.3	3.5	-1.2	1.9			-0.8	1.6	-2.1	3.2	-1.1	1.6	-1.2	4.4	-0.8	1.5	-1.4	1.6
NIST	-0.1	1.1	-0.6	2.4	0.5	5.2	-0.7	1.5	0.3	1.6	0.4	3.5	-0.4	1.9	0.8	1.6			-1.4	3.2	-0.3	1.5	-0.5	4.4	0.0	1.5	-0.6	1.6
NMIJ	1.2	2.9	0.8	3.7	1.9	5.9	0.6	3.1	1.7	3.2	1.8	4.5	0.9	3.4	2.1	3.2	1.4	3.2			1.1	3.2	0.9	5.2	1.3	3.1	0.8	3.2
NPL	0.2	1.0	-0.3	2.4	0.8	5.2	-0.4	1.4	0.6	1.5	0.7	3.5	-0.1	1.9	1.1	1.6	0.3	1.5	-1.1	3.2			-0.2	4.4	0.3	1.4	-0.3	1.5
NRC	0.3	4.3	-0.1	4.8	1.0	6.6	-0.3	4.4	0.8	4.4	0.9	5.4	0.0	4.6	1.2	4.4	0.5	4.4	-0.9	5.2	0.2	4.4			0.4	4.4	-0.1	4.4
PTB	-0.1	0.9	-0.5	2.3	0.6	5.1	-0.7	1.3	0.4	1.5	0.5	3.5	-0.4	1.8	0.8	1.5	0.0	1.5	-1.3	3.1	-0.3	1.4	-0.4	4.4			-0.6	1.4
VNIIOFI	0.4	1.0	0.0	2.4	1.1	5.2	-0.1	1.4	0.9	1.6	1.0	3.5	0.2	1.9	1.4	1.6	0.6	1.6	-0.8	3.2	0.3	1.5	0.1	4.4	0.6	1.4		

450 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	1.2	2.2			1.7	5.1	0.9	2.3	1.5	2.3	1.8	4.0	1.0	2.7	0.8	2.5	1.5	2.4	0.4	3.7	1.4	2.3	-0.2	4.9	1.6	2.3	0.9	2.4
CENAM	-0.5	4.7	-1.7	5.1			-0.9	4.7	-0.2	4.7	0.1	5.7	-0.7	4.9	-1.0	4.8	-0.3	4.8	-1.4	5.5	-0.4	4.7	-1.9	6.4	-0.2	4.8	-0.8	4.8
CSIRO	0.3	0.8	-0.9	2.3	0.9	4.7			0.7	1.2	1.0	3.4	0.2	1.8	-0.1	1.4	0.6	1.4	-0.5	3.1	0.5	1.1	-1.0	4.5	0.7	1.2	0.1	1.4
HUT	-0.3	0.8	-1.5	2.3	0.2	4.7	-0.7	1.2			0.3	3.4	-0.5	1.8	-0.8	1.4	0.0	1.4	-1.1	3.1	-0.2	1.1	-1.7	4.5	0.1	1.2	-0.6	1.4
IFA-CSIC	-0.6	3.3	-1.8	4.0	-0.1	5.7	-1.0	3.4	-0.3	3.4			-0.8	3.7	-1.1	3.5	-0.3	3.5	-1.4	4.4	-0.4	3.4	-2.0	5.5	-0.2	3.4	-0.9	3.5

MSL-IRL	0.1	1.5	-1.0	2.7	0.7	4.9	-0.2	1.8	0.5	1.8	0.8	3.7			-0.3	2.0	0.5	1.8	-0.6	3.3	0.3	1.7	-1.2	4.7	0.5	1.8	-0.1	1.9
NIM	0.4	1.1	-0.8	2.5	1.0	4.8	0.1	1.4	0.8	1.4	1.1	3.5	0.3	2.0			0.7	1.6	-0.4	3.2	0.6	1.4	-0.9	4.6	0.8	1.5	0.2	1.6
NIST	-0.3	1.0	-1.5	2.4	0.3	4.8	-0.6	1.4	0.0	1.4	0.3	3.5	-0.5	1.8	-0.7	1.6			-1.1	3.1	-0.1	1.3	-1.6	4.5	0.1	1.4	-0.5	1.5
NMIJ	0.8	2.9	-0.4	3.7	1.4	5.5	0.5	3.1	1.1	3.1	1.4	4.4	0.6	3.3	0.4	3.2	1.1	3.1			1.0	3.0	-0.6	5.3	1.2	3.1	0.6	3.1
NPL	-0.2	0.7	-1.4	2.3	0.4	4.7	-0.5	1.1	0.2	1.1	0.4	3.4	-0.3	1.7	-0.6	1.4	0.1	1.3	-1.0	3.0			-1.5	4.5	0.2	1.1	-0.4	1.3
NRC	1.3	4.4	0.2	4.9	1.9	6.4	1.0	4.5	1.7	4.5	2.0	5.5	1.2	4.7	0.9	4.6	1.6	4.5	0.6	5.3	1.5	4.5			1.7	4.5	1.1	4.5
PTB	-0.4	0.9	-1.6	2.3	0.2	4.8	-0.7	1.2	-0.1	1.2	0.2	3.4	-0.5	1.8	-0.8	1.5	-0.1	1.4	-1.2	3.1	-0.2	1.1	-1.7	4.5			-0.6	1.4
VNIIOFI	0.2	1.0	-0.9	2.4	0.8	4.8	-0.1	1.4	0.6	1.4	0.9	3.5	0.1	1.9	-0.2	1.6	0.5	1.5	-0.6	3.1	0.4	1.3	-1.1	4.5	0.6	1.4		

500 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.6	2.0			1.5	4.7	0.2	2.2	0.7	2.2	1.1	4.0	0.7	2.6	0.5	2.3	0.8	2.3	-0.2	3.5	0.9	2.1	-0.1	4.2	0.9	2.2	0.2	2.3
CENAM	-0.9	4.2	-1.5	4.7			-1.3	4.3	-0.8	4.3	-0.5	5.4	-0.8	4.5	-1.1	4.3	-0.8	4.3	-1.7	5.1	-0.7	4.3	-1.7	5.6	-0.6	4.3	-1.3	4.3
CSIRO	0.4	0.7	-0.2	2.2	1.3	4.3			0.5	1.1	0.8	3.5	0.5	1.7	0.2	1.3	0.5	1.2	-0.4	3.0	0.7	1.0	-0.4	3.7	0.7	1.1	0.0	1.3
HUT	-0.1	0.8	-0.7	2.2	0.8	4.3	-0.5	1.1			0.4	3.5	0.0	1.7	-0.3	1.4	0.1	1.3	-0.9	3.0	0.2	1.0	-0.8	3.7	0.2	1.2	-0.5	1.3
IFA-CSIC	-0.5	3.4	-1.1	4.0	0.5	5.4	-0.8	3.5	-0.4	3.5			-0.4	3.7	-0.6	3.6	-0.3	3.5	-1.2	4.5	-0.2	3.5	-1.2	5.0	-0.1	3.5	-0.8	3.6
MSL-IRL	-0.1	1.5	-0.7	2.6	0.8	4.5	-0.5	1.7	0.0	1.7	0.4	3.7			-0.3	1.9	0.0	1.8	-0.9	3.3	0.2	1.7	-0.9	3.9	0.2	1.7	-0.5	1.8
NIM	0.1	1.0	-0.5	2.3	1.1	4.3	-0.2	1.3	0.3	1.4	0.6	3.6	0.3	1.9			0.3	1.5	-0.6	3.1	0.4	1.3	-0.6	3.8	0.5	1.4	-0.2	1.5
NIST	-0.2	1.0	-0.8	2.3	0.8	4.3	-0.5	1.2	-0.1	1.3	0.3	3.5	0.0	1.8	-0.3	1.5			-0.9	3.0	0.1	1.2	-0.9	3.8	0.2	1.3	-0.5	1.4
NMIJ	0.8	2.9	0.2	3.5	1.7	5.1	0.4	3.0	0.9	3.0	1.2	4.5	0.9	3.3	0.6	3.1	0.9	3.0			1.1	2.9	0.0	4.6	1.1	3.0	0.4	3.1
NPL	-0.3	0.7	-0.9	2.1	0.7	4.3	-0.7	1.0	-0.2	1.0	0.2	3.5	-0.2	1.7	-0.4	1.3	-0.1	1.2	-1.1	2.9			-1.0	3.7	0.0	1.1	-0.7	1.2
NRC	0.7	3.6	0.1	4.2	1.7	5.6	0.4	3.7	0.8	3.7	1.2	5.0	0.9	3.9	0.6	3.8	0.9	3.8	0.0	4.6	1.0	3.7			1.1	3.7	0.4	3.8
PTB	-0.3	0.8	-0.9	2.2	0.6	4.3	-0.7	1.1	-0.2	1.2	0.1	3.5	-0.2	1.7	-0.5	1.4	-0.2	1.3	-1.1	3.0	0.0	1.1	-1.1	3.7			-0.7	1.3
VNIIOFI	0.3	1.0	-0.2	2.3	1.3	4.3	0.0	1.3	0.5	1.3	0.8	3.6	0.5	1.8	0.2	1.5	0.5	1.4	-0.4	3.1	0.7	1.2	-0.4	3.8	0.7	1.3		

550 nm

NMI *j* → NMI *I* ↓	D_i / 10^{-2}	U_i / 10^{-2}	BNM-INM D_{ij} / 10^{-2}	BNM-INM U_{ij} / 10^{-2}	CENAM D_{ij} / 10^{-2}	CENAM U_{ij} / 10^{-2}	CSIRO D_{ij} / 10^{-2}	CSIRO U_{ij} / 10^{-2}	HUT D_{ij} / 10^{-2}	HUT U_{ij} / 10^{-2}	IFA-CSIC D_{ij} / 10^{-2}	IFA-CSIC U_{ij} / 10^{-2}	MSL-IRL D_{ij} / 10^{-2}	MSL-IRL U_{ij} / 10^{-2}	NIM D_{ij} / 10^{-2}	NIM U_{ij} / 10^{-2}	NIST D_{ij} / 10^{-2}	NIST U_{ij} / 10^{-2}	NMIJ D_{ij} / 10^{-2}	NMIJ U_{ij} / 10^{-2}	NPL D_{ij} / 10^{-2}	NPL U_{ij} / 10^{-2}	NRC D_{ij} / 10^{-2}	NRC U_{ij} / 10^{-2}	PTB D_{ij} / 10^{-2}	PTB U_{ij} / 10^{-2}	VNIIOFI D_{ij} / 10^{-2}	VNIIOFI U_{ij} / 10^{-2}
BNM-INM	0.4	2.0			1.3	4.4	0.1	2.2	0.4	2.2	0.8	4.0	0.0	2.6	0.3	2.3	0.8	2.2	-0.4	3.5	0.6	2.1	0.6	4.1	0.6	2.2	0.0	2.3
CENAM	-0.9	3.9	-1.3	4.4			-1.2	4.0	-0.9	4.0	-0.5	5.2	-1.2	4.2	-1.0	4.1	-0.5	4.0	-1.6	4.9	-0.6	4.0	-0.6	5.3	-0.7	4.0	-1.2	4.1
CSIRO	0.3	0.7	-0.1	2.2	1.2	4.0			0.3	1.1	0.7	3.6	-0.1	1.7	0.2	1.3	0.7	1.2	-0.5	3.0	0.5	0.9	0.5	3.7	0.5	1.1	-0.1	1.2
HUT	0.0	0.8	-0.4	2.2	0.9	4.0	-0.3	1.1			0.4	3.6	-0.4	1.8	-0.1	1.3	0.4	1.2	-0.8	3.0	0.2	1.0	0.2	3.7	0.2	1.2	-0.4	1.3
IFA-CSIC	-0.4	3.5	-0.8	4.0	0.5	5.2	-0.7	3.6	-0.4	3.6			-0.7	3.8	-0.5	3.6	0.0	3.6	-1.1	4.5	-0.1	3.5	-0.2	5.0	-0.2	3.6	-0.8	3.6
MSL-IRL	0.3	1.5	0.0	2.6	1.2	4.2	0.1	1.7	0.4	1.8	0.7	3.8			0.3	1.9	0.7	1.8	-0.4	3.3	0.6	1.7	0.6	3.9	0.5	1.8	0.0	1.9
NIM	0.1	1.0	-0.3	2.3	1.0	4.1	-0.2	1.3	0.1	1.3	0.5	3.6	-0.3	1.9			0.5	1.4	-0.7	3.1	0.3	1.2	0.3	3.8	0.3	1.4	-0.3	1.5
NIST	-0.4	0.9	-0.8	2.2	0.5	4.0	-0.7	1.2	-0.4	1.2	0.0	3.6	-0.7	1.8	-0.5	1.4			-1.1	3.0	-0.1	1.1	-0.2	3.7	-0.2	1.2	-0.7	1.4
NMIJ	0.8	2.9	0.4	3.5	1.6	4.9	0.5	3.0	0.8	3.0	1.1	4.5	0.4	3.3	0.7	3.1	1.1	3.0			1.0	2.9	1.0	4.6	1.0	3.0	0.4	3.1
NPL	-0.2	0.6	-0.6	2.1	0.6	4.0	-0.5	0.9	-0.2	1.0	0.1	3.5	-0.6	1.7	-0.3	1.2	0.1	1.1	-1.0	2.9			0.0	3.6	-0.1	1.0	-0.6	1.2
NRC	-0.2	3.6	-0.6	4.1	0.6	5.3	-0.5	3.7	-0.2	3.7	0.2	5.0	-0.6	3.9	-0.3	3.8	0.2	3.7	-1.0	4.6	0.0	3.6			0.0	3.7	-0.6	3.7
PTB	-0.2	0.8	-0.6	2.2	0.7	4.0	-0.5	1.1	-0.2	1.2	0.2	3.6	-0.5	1.8	-0.3	1.4	0.2	1.2	-1.0	3.0	0.1	1.0	0.0	3.7			-0.6	1.3
VNIIOFI	0.4	0.9	0.0	2.3	1.2	4.1	0.1	1.2	0.4	1.3	0.8	3.6	0.0	1.9	0.3	1.5	0.7	1.4	-0.4	3.1	0.6	1.2	0.6	3.7	0.6	1.3		

555 nm

NMI *j* → NMI *i* ↓	D_i / 10^{-2}	U_i / 10^{-2}	BNM-INM D_{ij} / 10^{-2}	BNM-INM U_{ij} / 10^{-2}	CENAM D_{ij} / 10^{-2}	CENAM U_{ij} / 10^{-2}	CSIRO D_{ij} / 10^{-2}	CSIRO U_{ij} / 10^{-2}	HUT D_{ij} / 10^{-2}	HUT U_{ij} / 10^{-2}	IFA-CSIC D_{ij} / 10^{-2}	IFA-CSIC U_{ij} / 10^{-2}	MSL-IRL D_{ij} / 10^{-2}	MSL-IRL U_{ij} / 10^{-2}	NIM D_{ij} / 10^{-2}	NIM U_{ij} / 10^{-2}	NIST D_{ij} / 10^{-2}	NIST U_{ij} / 10^{-2}	NMIJ D_{ij} / 10^{-2}	NMIJ U_{ij} / 10^{-2}	NPL D_{ij} / 10^{-2}	NPL U_{ij} / 10^{-2}	NRC D_{ij} / 10^{-2}	NRC U_{ij} / 10^{-2}	PTB D_{ij} / 10^{-2}	PTB U_{ij} / 10^{-2}	VNIIOFI D_{ij} / 10^{-2}	VNIIOFI U_{ij} / 10^{-2}
BNM-INM	0.8	2.0			1.7	4.4	0.6	2.1	0.8	2.2	1.0	4.2	0.8	2.5	0.5	2.3	0.9	2.2			1.1	2.1			1.1	2.2	0.5	2.3
CENAM	-0.9	3.9	-1.7	4.4			-1.0	3.9	-0.8	4.0	-0.7	5.3	-0.8	4.2	-1.1	4.0	-0.8	4.0			-0.6	3.9			-0.6	4.0	-1.2	4.0
CSIRO	0.2	0.6	-0.6	2.1	1.0	3.9			0.2	1.0	0.4	3.7	0.2	1.6	-0.1	1.2	0.2	1.1			0.4	0.9			0.4	1.0	-0.2	1.2
HUT	0.0	0.7	-0.8	2.2	0.8	4.0	-0.2	1.0			0.2	3.7	0.0	1.7	-0.3	1.3	0.0	1.2			0.2	1.0			0.2	1.1	-0.4	1.3
IFA-CSIC	-0.2	3.7	-1.0	4.2	0.7	5.3	-0.4	3.7	-0.2	3.7			-0.2	3.9	-0.5	3.8	-0.1	3.8			0.1	3.7			0.1	3.8	-0.5	3.8

MSL-IRL	-0.1	1.4	-0.8	2.5	0.8	4.2	-0.2	1.6	0.0	1.7	0.2	3.9			-0.3	1.8	0.0	1.6			0.2	1.6			0.2	1.7	-0.4	1.8
NIM	0.2	1.0	-0.5	2.3	1.1	4.0	0.1	1.2	0.3	1.3	0.5	3.8	0.3	1.8			0.3	1.4			0.5	1.2			0.5	1.3	-0.1	1.4
NIST	-0.1	0.9	-0.9	2.2	0.8	4.0	-0.2	1.1	0.0	1.2	0.1	3.8	0.0	1.6	-0.3	1.4					0.2	1.1			0.2	1.2	-0.4	1.3
NMIJ																												
NPL	-0.3	0.6	-1.1	2.1	0.6	3.9	-0.4	0.9	-0.2	1.0	-0.1	3.7	-0.2	1.6	-0.5	1.2	-0.2	1.1							0.0	1.0	-0.6	1.2
NRC																												
PTB	-0.3	0.8	-1.1	2.2	0.6	4.0	-0.4	1.0	-0.2	1.1	-0.1	3.8	-0.2	1.7	-0.5	1.3	-0.2	1.2			0.0	1.0					-0.6	1.3
VNIIOFI	0.3	0.9	-0.5	2.3	1.2	4.0	0.2	1.2	0.4	1.3	0.5	3.8	0.4	1.8	0.1	1.4	0.4	1.3			0.6	1.2			0.6	1.3		

600 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.1	2.0			1.0	4.3	0.1	2.1	0.2	2.2	0.8	4.1	-0.4	2.5	-0.7	2.3	0.3	2.2	-0.4	3.5	0.4	2.1	-0.4	4.1	0.3	2.2	-0.2	2.2
CENAM	-0.9	3.8	-1.0	4.3			-0.9	3.8	-0.8	3.8	-0.2	5.2	-1.3	4.0	-1.6	3.9	-0.7	3.8	-1.4	4.7	-0.6	3.8	-1.4	5.2	-0.7	3.8	-1.2	3.9
CSIRO	0.0	0.7	-0.1	2.1	0.9	3.8			0.1	1.0	0.7	3.6	-0.4	1.6	-0.7	1.2	0.3	1.1	-0.5	3.0	0.3	0.9	-0.5	3.7	0.3	1.1	-0.3	1.1
HUT	-0.1	0.7	-0.2	2.2	0.8	3.8	-0.1	1.0			0.6	3.6	-0.5	1.6	-0.8	1.3	0.2	1.1	-0.6	3.0	0.2	0.9	-0.6	3.7	0.1	1.1	-0.4	1.2
IFA-CSIC	-0.7	3.5	-0.8	4.1	0.2	5.2	-0.7	3.6	-0.6	3.6			-1.1	3.8	-1.4	3.7	-0.4	3.6	-1.2	4.6	-0.4	3.6	-1.2	5.1	-0.4	3.6	-1.0	3.7
MSL-IRL	0.4	1.4	0.4	2.5	1.3	4.0	0.4	1.6	0.5	1.6	1.1	3.8			-0.3	1.8	0.7	1.7	-0.1	3.2	0.7	1.6	0.0	3.9	0.7	1.7	0.1	1.7
NIM	0.7	1.0	0.7	2.3	1.6	3.9	0.7	1.2	0.8	1.3	1.4	3.7	0.3	1.8			1.0	1.3	0.2	3.1	1.0	1.2	0.2	3.8	1.0	1.3	0.4	1.4
NIST	-0.3	0.8	-0.3	2.2	0.7	3.8	-0.3	1.1	-0.2	1.1	0.4	3.6	-0.7	1.7	-1.0	1.3			-0.8	3.0	0.0	1.0	-0.7	3.7	0.0	1.2	-0.6	1.2
NMIJ	0.5	2.9	0.4	3.5	1.4	4.7	0.5	3.0	0.6	3.0	1.2	4.6	0.1	3.2	-0.2	3.1	0.8	3.0			0.8	2.9	0.0	4.6	0.7	3.0	0.2	3.0
NPL	-0.3	0.6	-0.4	2.1	0.6	3.8	-0.3	0.9	-0.2	0.9	0.4	3.6	-0.7	1.6	-1.0	1.2	0.0	1.0	-0.8	2.9			-0.8	3.7	-0.1	1.0	-0.6	1.1
NRC	0.5	3.6	0.4	4.1	1.4	5.2	0.5	3.7	0.6	3.7	1.2	5.1	0.0	3.9	-0.2	3.8	0.7	3.7	0.0	4.6	0.8	3.7			0.7	3.7	0.2	3.7
PTB	-0.3	0.8	-0.3	2.2	0.7	3.8	-0.3	1.1	-0.1	1.1	0.4	3.6	-0.7	1.7	-1.0	1.3	0.0	1.2	-0.7	3.0	0.1	1.0	-0.7	3.7			-0.6	1.2
VNIIOFI	0.3	0.9	0.2	2.2	1.2	3.9	0.3	1.1	0.4	1.2	1.0	3.7	-0.1	1.7	-0.4	1.4	0.6	1.2	-0.2	3.0	0.6	1.1	-0.2	3.7	0.6	1.2		

650 nm

NMI *j* → / NMI *I* ↓	D_i / 10^{-2}	U_i / 10^{-2}	BNM-INM D_{ij} / 10^{-2}	BNM-INM U_{ij} / 10^{-2}	CENAM D_{ij} / 10^{-2}	CENAM U_{ij} / 10^{-2}	CSIRO D_{ij} / 10^{-2}	CSIRO U_{ij} / 10^{-2}	HUT D_{ij} / 10^{-2}	HUT U_{ij} / 10^{-2}	IFA-CSIC D_{ij} / 10^{-2}	IFA-CSIC U_{ij} / 10^{-2}	MSL-IRL D_{ij} / 10^{-2}	MSL-IRL U_{ij} / 10^{-2}	NIM D_{ij} / 10^{-2}	NIM U_{ij} / 10^{-2}	NIST D_{ij} / 10^{-2}	NIST U_{ij} / 10^{-2}	NMIJ D_{ij} / 10^{-2}	NMIJ U_{ij} / 10^{-2}	NPL D_{ij} / 10^{-2}	NPL U_{ij} / 10^{-2}	NRC D_{ij} / 10^{-2}	NRC U_{ij} / 10^{-2}	PTB D_{ij} / 10^{-2}	PTB U_{ij} / 10^{-2}	VNIIOFI D_{ij} / 10^{-2}	VNIIOFI U_{ij} / 10^{-2}
BNM-INM	-0.2	2.0			0.8	4.0	-0.1	2.1	-0.1	2.1	0.7	4.2	-0.4	2.5	-0.8	2.2	-0.1	2.1	-0.6	3.5	0.0	2.1	0.7	4.1	0.1	2.2	-0.5	2.2
CENAM	-0.9	3.5	-0.8	4.0			-0.9	3.6	-0.9	3.6	0.0	5.1	-1.1	3.8	-1.5	3.6	-0.8	3.6	-1.4	4.5	-0.8	3.5	-0.1	5.0	-0.6	3.6	-1.2	3.6
CSIRO	0.0	0.7	0.1	2.1	0.9	3.6			0.0	1.0	0.9	3.8	-0.2	1.7	-0.6	1.2	0.1	1.0	-0.4	3.0	0.1	0.9	0.8	3.6	0.3	1.1	-0.3	1.1
HUT	-0.1	0.7	0.1	2.1	0.9	3.6	0.0	1.0			0.9	3.8	-0.3	1.7	-0.7	1.2	0.1	1.1	-0.5	3.0	0.1	0.9	0.8	3.6	0.3	1.1	-0.3	1.2
IFA-CSIC	-0.9	3.7	-0.7	4.2	0.0	5.1	-0.9	3.8	-0.9	3.8			-1.1	4.0	-1.5	3.8	-0.8	3.8	-1.3	4.7	-0.7	3.7	-0.1	5.1	-0.6	3.8	-1.2	3.8
MSL-IRL	0.2	1.5	0.4	2.5	1.1	3.8	0.2	1.7	0.3	1.7	1.1	4.0			-0.4	1.8	0.3	1.6	-0.2	3.3	0.4	1.6	1.0	3.8	0.5	1.7	-0.1	1.8
NIM	0.6	0.9	0.8	2.2	1.5	3.6	0.6	1.2	0.7	1.2	1.5	3.8	0.4	1.8			0.7	1.2	0.2	3.0	0.8	1.1	1.4	3.7	0.9	1.3	0.3	1.3
NIST	-0.1	0.8	0.1	2.1	0.8	3.6	-0.1	1.0	-0.1	1.1	0.8	3.8	-0.3	1.6	-0.7	1.2			-0.5	3.0	0.0	0.9	0.7	3.6	0.2	1.1	-0.4	1.2
NMIJ	0.4	2.9	0.6	3.5	1.4	4.5	0.4	3.0	0.5	3.0	1.3	4.7	0.2	3.3	-0.2	3.0	0.5	3.0			0.6	2.9	1.2	4.6	0.7	3.0	0.1	3.0
NPL	-0.2	0.5	0.0	2.1	0.8	3.5	-0.1	0.9	-0.1	0.9	0.7	3.7	-0.4	1.6	-0.8	1.1	0.0	0.9	-0.6	2.9			0.7	3.6	0.1	1.0	-0.4	1.0
NRC	-0.8	3.5	-0.7	4.1	0.1	5.0	-0.8	3.6	-0.8	3.6	0.1	5.1	-1.0	3.8	-1.4	3.7	-0.7	3.6	-1.2	4.6	-0.7	3.6			-0.5	3.6	-1.1	3.6
PTB	-0.3	0.8	-0.1	2.2	0.6	3.6	-0.3	1.1	-0.3	1.1	0.6	3.8	-0.5	1.7	-0.9	1.3	-0.2	1.1	-0.7	3.0	-0.1	1.0	0.5	3.6			-0.6	1.2
VNIIOFI	0.3	0.8	0.5	2.2	1.2	3.6	0.3	1.1	0.3	1.2	1.2	3.8	0.1	1.8	-0.3	1.3	0.4	1.2	-0.1	3.0	0.4	1.0	1.1	3.6	0.6	1.2		

700 nm

NMI *j* → / NMI *i* ↓	D_i / 10^{-2}	U_i / 10^{-2}	BNM-INM D_{ij} / 10^{-2}	BNM-INM U_{ij} / 10^{-2}	CENAM D_{ij} / 10^{-2}	CENAM U_{ij} / 10^{-2}	CSIRO D_{ij} / 10^{-2}	CSIRO U_{ij} / 10^{-2}	HUT D_{ij} / 10^{-2}	HUT U_{ij} / 10^{-2}	IFA-CSIC D_{ij} / 10^{-2}	IFA-CSIC U_{ij} / 10^{-2}	MSL-IRL D_{ij} / 10^{-2}	MSL-IRL U_{ij} / 10^{-2}	NIM D_{ij} / 10^{-2}	NIM U_{ij} / 10^{-2}	NIST D_{ij} / 10^{-2}	NIST U_{ij} / 10^{-2}	NMIJ D_{ij} / 10^{-2}	NMIJ U_{ij} / 10^{-2}	NPL D_{ij} / 10^{-2}	NPL U_{ij} / 10^{-2}	NRC D_{ij} / 10^{-2}	NRC U_{ij} / 10^{-2}	PTB D_{ij} / 10^{-2}	PTB U_{ij} / 10^{-2}	VNIIOFI D_{ij} / 10^{-2}	VNIIOFI U_{ij} / 10^{-2}
BNM-INM	-0.2	2.0			0.8	3.9	0.0	2.1	-0.1	2.1	0.7	3.9	-0.2	2.5	-1.0	2.2	0.1	2.1	0.2	3.5	-0.1	2.1	-0.3	2.8	0.2	2.2	-0.5	2.2
CENAM	-1.0	3.4	-0.8	3.9			-0.8	3.4	-1.0	3.4	-0.2	4.7	-1.0	3.6	-1.9	3.5	-0.8	3.4	-0.6	4.4	-0.9	3.4	-1.1	3.9	-0.6	3.5	-1.3	3.5
CSIRO	-0.2	0.7	0.0	2.1	0.8	3.4			-0.1	1.0	0.7	3.4	-0.2	1.6	-1.0	1.2	0.1	1.0	0.2	3.0	-0.1	0.9	-0.3	2.0	0.2	1.1	-0.5	1.1
HUT	0.0	0.7	0.1	2.1	1.0	3.4	0.1	1.0			0.8	3.4	-0.1	1.6	-0.9	1.2	0.2	1.0	0.3	3.0	0.1	0.9	-0.2	2.0	0.3	1.1	-0.4	1.1
IFA-CSIC	-0.8	3.3	-0.7	3.9	0.2	4.7	-0.7	3.4	-0.8	3.4			-0.9	3.6	-1.7	3.4	-0.6	3.4	-0.5	4.4	-0.7	3.3	-1.0	3.8	-0.5	3.4	-1.2	3.4

MSL-IRL	0.0	1.4	0.2	2.5	1.0	3.6	0.2	1.6	0.1	1.6	0.9	3.6			-0.8	1.7	0.3	1.6	0.4	3.2	0.1	1.5	-0.1	2.4	0.4	1.6	-0.3	1.6
NIM	0.8	0.9	1.0	2.2	1.9	3.5	1.0	1.2	0.9	1.2	1.7	3.4	0.8	1.7			1.1	1.2	1.2	3.0	1.0	1.1	0.7	2.1	1.2	1.3	0.5	1.3
NIST	-0.2	0.7	-0.1	2.1	0.8	3.4	-0.1	1.0	-0.2	1.0	0.6	3.4	-0.3	1.6	-1.1	1.2			0.1	3.0	-0.1	0.9	-0.4	2.0	0.1	1.1	-0.6	1.1
NMIJ	-0.4	2.9	-0.2	3.5	0.6	4.4	-0.2	3.0	-0.3	3.0	0.5	4.4	-0.4	3.2	-1.2	3.0	-0.1	3.0			-0.3	2.9	-0.5	3.4	0.0	3.0	-0.7	3.0
NPL	-0.1	0.5	0.1	2.1	0.9	3.4	0.1	0.9	-0.1	0.9	0.7	3.3	-0.1	1.5	-1.0	1.1	0.1	0.9	0.3	2.9			-0.2	2.0	0.3	1.0	-0.4	1.0
NRC	0.1	1.9	0.3	2.8	1.1	3.9	0.3	2.0	0.2	2.0	1.0	3.8	0.1	2.4	-0.7	2.1	0.4	2.0	0.5	3.4	0.2	2.0			0.5	2.1	-0.2	2.1
PTB	-0.4	0.8	-0.2	2.2	0.6	3.5	-0.2	1.1	-0.3	1.1	0.5	3.4	-0.4	1.6	-1.2	1.3	-0.1	1.1	0.0	3.0	-0.3	1.0	-0.5	2.1			-0.7	1.2
VNIIOFI	0.3	0.8	0.5	2.2	1.3	3.5	0.5	1.1	0.4	1.1	1.2	3.4	0.3	1.6	-0.5	1.3	0.6	1.1	0.7	3.0	0.4	1.0	0.2	2.1	0.7	1.2		

750 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.0	2.0			0.7	3.8	0.1	2.2	-0.2	2.1	0.8	3.7	-0.2	2.5	0.2	2.2	0.2	2.1	0.1	3.5	-0.2	2.0	0.0	2.7	0.3	2.2	-0.6	2.2
CENAM	-0.8	3.2	-0.7	3.8			-0.7	3.3	-0.9	3.3	0.1	4.5	-0.9	3.6	-0.5	3.4	-0.5	3.3	-0.7	4.3	-0.9	3.2	-0.8	3.7	-0.5	3.3	-1.3	3.3
CSIRO	-0.1	0.8	-0.1	2.2	0.7	3.3			-0.3	1.1	0.8	3.2	-0.2	1.7	0.1	1.3	0.1	1.1	0.0	3.0	-0.2	0.9	-0.1	2.0	0.2	1.2	-0.7	1.2
HUT	0.2	0.7	0.2	2.1	0.9	3.3	0.3	1.1			1.1	3.2	0.1	1.7	0.4	1.2	0.4	1.0	0.3	3.0	0.0	0.8	0.2	2.0	0.5	1.1	-0.4	1.1
IFA-CSIC	-0.9	3.1	-0.8	3.7	-0.1	4.5	-0.8	3.2	-1.1	3.2			-1.0	3.5	-0.6	3.3	-0.6	3.2	-0.8	4.3	-1.0	3.2	-0.9	3.6	-0.6	3.2	-1.4	3.2
MSL-IRL	0.1	1.5	0.2	2.5	0.9	3.6	0.2	1.7	-0.1	1.7	1.0	3.5			0.4	1.8	0.4	1.7	0.2	3.3	0.0	1.6	0.1	2.4	0.4	1.7	-0.4	1.7
NIM	-0.3	1.0	-0.2	2.2	0.5	3.4	-0.1	1.3	-0.4	1.2	0.6	3.3	-0.4	1.8			0.0	1.2	-0.2	3.1	-0.4	1.1	-0.2	2.1	0.0	1.3	-0.8	1.3
NIST	-0.3	0.7	-0.2	2.1	0.5	3.3	-0.1	1.1	-0.4	1.0	0.6	3.2	-0.4	1.7	0.0	1.2			-0.1	3.0	-0.4	0.8	-0.2	2.0	0.0	1.1	-0.8	1.1
NMIJ	-0.1	2.9	-0.1	3.5	0.7	4.3	0.0	3.0	-0.3	3.0	0.8	4.3	-0.2	3.3	0.2	3.1	0.1	3.0			-0.2	2.9	-0.1	3.4	0.2	3.0	-0.7	3.0
NPL	0.1	0.5	0.2	2.0	0.9	3.2	0.2	0.9	0.0	0.8	1.0	3.2	0.0	1.6	0.4	1.1	0.4	0.8	0.2	2.9			0.1	1.9	0.4	0.9	-0.4	0.9
NRC	0.0	1.8	0.0	2.7	0.8	3.7	0.1	2.0	-0.2	2.0	0.9	3.6	-0.1	2.4	0.2	2.1	0.2	2.0	0.1	3.4	-0.1	1.9			0.3	2.0	-0.6	2.0
PTB	-0.3	0.8	-0.3	2.2	0.5	3.3	-0.2	1.2	-0.5	1.1	0.6	3.2	-0.4	1.7	0.0	1.3	0.0	1.1	-0.2	3.0	-0.4	0.9	-0.3	2.0			-0.8	1.2
VNIIOFI	0.5	0.8	0.6	2.2	1.3	3.3	0.7	1.2	0.4	1.1	1.4	3.2	0.4	1.7	0.8	1.3	0.8	1.1	0.7	3.0	0.4	0.9	0.6	2.0	0.8	1.2		

800 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.8	2.0			0.1	4.5	-0.7	2.2	-1.0	2.1	0.0	3.7	-0.8	2.5	-0.6	2.2	-0.7	2.1	-0.7	3.5	-1.0	2.0	-0.6	2.7	-0.4	2.1	-1.4	2.1
CENAM	-0.9	4.0	-0.1	4.5			-0.7	4.1	-1.0	4.1	0.0	5.1	-0.9	4.3	-0.6	4.2	-0.8	4.1	-0.7	5.0	-1.0	4.1	-0.6	4.4	-0.4	4.1	-1.5	4.1
CSIRO	-0.1	0.8	0.7	2.2	0.7	4.1			-0.3	1.1	0.7	3.3	-0.1	1.7	0.1	1.4	-0.1	1.1	0.0	3.0	-0.3	1.0	0.1	2.1	0.3	1.2	-0.7	1.2
HUT	0.2	0.7	1.0	2.1	1.0	4.1	0.3	1.1			1.0	3.2	0.2	1.6	0.4	1.3	0.2	0.9	0.3	3.0	0.0	0.8	0.4	2.0	0.6	1.1	-0.4	1.0
IFA-CSIC	-0.8	3.1	0.0	3.7	0.0	5.1	-0.7	3.3	-1.0	3.2			-0.9	3.5	-0.6	3.3	-0.8	3.2	-0.7	4.3	-1.0	3.2	-0.6	3.7	-0.4	3.3	-1.4	3.3
MSL-IRL	0.0	1.4	0.8	2.5	0.9	4.3	0.1	1.7	-0.2	1.6	0.9	3.5			0.2	1.8	0.1	1.6	0.1	3.3	-0.1	1.5	0.3	2.4	0.5	1.7	-0.6	1.7
NIM	-0.2	1.0	0.6	2.2	0.6	4.2	-0.1	1.4	-0.4	1.3	0.6	3.3	-0.2	1.8			-0.2	1.2	-0.1	3.1	-0.4	1.1	0.0	2.1	0.2	1.3	-0.8	1.3
NIST	-0.1	0.6	0.7	2.1	0.8	4.1	0.1	1.1	-0.2	0.9	0.8	3.2	-0.1	1.6	0.2	1.2			0.1	3.0	-0.2	0.8	0.2	2.0	0.4	1.0	-0.7	1.0
NMIJ	-0.1	2.9	0.7	3.5	0.7	5.0	0.0	3.0	-0.3	3.0	0.7	4.3	-0.1	3.3	0.1	3.1	-0.1	3.0			-0.3	2.9	0.1	3.4	0.3	3.0	-0.7	3.0
NPL	0.2	0.4	1.0	2.0	1.0	4.1	0.3	1.0	0.0	0.8	1.0	3.2	0.1	1.5	0.4	1.1	0.2	0.8	0.3	2.9			0.4	1.9	0.6	0.9	-0.4	0.9
NRC	-0.2	1.8	0.6	2.7	0.6	4.4	-0.1	2.1	-0.4	2.0	0.6	3.7	-0.3	2.4	0.0	2.1	-0.2	2.0	-0.1	3.4	-0.4	1.9			0.2	2.0	-0.8	2.0
PTB	-0.4	0.8	0.4	2.1	0.4	4.1	-0.3	1.2	-0.6	1.1	0.4	3.3	-0.5	1.7	-0.2	1.3	-0.4	1.0	-0.3	3.0	-0.6	0.9	-0.2	2.0			-1.0	1.1
VNIIOFI	0.6	0.7	1.4	2.1	1.5	4.1	0.7	1.2	0.4	1.0	1.4	3.3	0.6	1.7	0.8	1.3	0.7	1.0	0.7	3.0	0.4	0.9	0.8	2.0	1.0	1.1		

850 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.4	1.9			1.1	4.4	-0.4	2.2	-0.7	2.0	0.6	4.3	-0.6	2.5	0.9	2.2	-0.3	2.0	-0.6	3.5	-0.8	2.0	-0.2	2.7	-0.1	2.0	-1.2	2.1
CENAM	-1.5	4.0	-1.1	4.4			-1.5	4.1	-1.8	4.0	-0.6	5.6	-1.7	4.3	-0.2	4.1	-1.4	4.0	-1.7	4.9	-1.9	4.0	-1.3	4.4	-1.2	4.0	-2.3	4.1
CSIRO	0.0	1.0	0.4	2.2	1.5	4.1			-0.3	1.2	1.0	4.0	-0.2	1.9	1.3	1.5	0.1	1.2	-0.2	3.1	-0.4	1.1	0.2	2.1	0.3	1.2	-0.8	1.3
HUT	0.3	0.7	0.7	2.0	1.8	4.0	0.3	1.2			1.3	4.0	0.1	1.8	1.6	1.3	0.4	1.0	0.1	3.0	-0.1	0.9	0.5	2.0	0.6	1.1	-0.5	1.1
IFA-CSIC	-1.0	3.9	-0.6	4.3	0.6	5.6	-1.0	4.0	-1.3	4.0			-1.1	4.2	0.3	4.0	-0.8	3.9	-1.1	4.9	-1.3	3.9	-0.8	4.3	-0.7	4.0	-1.8	4.0

MSL-IRL	0.2	1.6	0.6	2.5	1.7	4.3	0.2	1.9	-0.1	1.8	1.1	4.2			1.5	1.9	0.3	1.7	0.0	3.4	-0.2	1.7	0.4	2.5	0.5	1.8	-0.6	1.8
NIM	-1.3	1.0	-0.9	2.2	0.2	4.1	-1.3	1.5	-1.6	1.3	-0.3	4.0	-1.5	1.9			-1.2	1.3	-1.5	3.1	-1.7	1.2	-1.1	2.2	-1.0	1.3	-2.1	1.4
NIST	-0.2	0.7	0.3	2.0	1.4	4.0	-0.1	1.2	-0.4	1.0	0.8	3.9	-0.3	1.7	1.2	1.3			-0.3	3.0	-0.5	0.8	0.1	2.0	0.2	1.0	-0.9	1.1
NMIJ	0.1	2.9	0.6	3.5	1.7	4.9	0.2	3.1	-0.1	3.0	1.1	4.9	0.0	3.4	1.5	3.1	0.3	3.0			-0.2	3.0	0.4	3.5	0.5	3.0	-0.6	3.1
NPL	0.4	0.5	0.8	2.0	1.9	4.0	0.4	1.1	0.1	0.9	1.3	3.9	0.2	1.7	1.7	1.2	0.5	0.8	0.2	3.0			0.6	2.0	0.7	0.9	-0.4	1.0
NRC	-0.2	1.9	0.2	2.7	1.3	4.4	-0.2	2.1	-0.5	2.0	0.8	4.3	-0.4	2.5	1.1	2.2	-0.1	2.0	-0.4	3.5	-0.6	2.0			0.1	2.0	-1.0	2.1
PTB	-0.3	0.7	0.1	2.0	1.2	4.0	-0.3	1.2	-0.6	1.1	0.7	4.0	-0.5	1.8	1.0	1.3	-0.2	1.0	-0.5	3.0	-0.7	0.9	-0.1	2.0			-1.1	1.1
VNIIOFI	0.8	0.8	1.2	2.1	2.3	4.1	0.8	1.3	0.5	1.1	1.8	4.0	0.6	1.8	2.1	1.4	0.9	1.1	0.6	3.1	0.4	1.0	1.0	2.1	1.1	1.1		

900 nm NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.1	1.9			2.0	4.3	-0.1	2.1	-0.2	2.0	1.0	4.3			1.6	2.1	0.0	2.0	-0.4	3.5	-0.5	1.9	0.1	2.7	0.3	2.0	-1.0	2.1
CENAM	-2.1	3.9	-2.0	4.3			-2.1	4.0	-2.1	3.9	-1.0	5.5			-0.4	4.0	-2.0	3.9	-2.4	4.9	-2.5	3.9	-1.9	4.3	-1.7	3.9	-3.0	4.0
CSIRO	0.0	1.0	0.1	2.1	2.1	4.0			0.0	1.2	1.1	4.0			1.7	1.4	0.1	1.2	-0.3	3.1	-0.4	1.1	0.3	2.1	0.4	1.2	-0.8	1.3
HUT	0.1	0.7	0.2	2.0	2.1	3.9	0.0	1.2			1.1	3.9			1.7	1.2	0.1	0.9	-0.2	3.0	-0.4	0.8	0.3	2.0	0.5	1.0	-0.8	1.1
IFA-CSIC	-1.1	3.8	-1.0	4.3	1.0	5.5	-1.1	4.0	-1.1	3.9					0.6	4.0	-1.0	3.9	-1.4	4.8	-1.5	3.9	-0.8	4.3	-0.7	3.9	-2.0	3.9
MSL-IRL																												
NIM	-1.7	1.0	-1.6	2.1	0.4	4.0	-1.7	1.4	-1.7	1.2	-0.6	4.0					-1.6	1.2	-2.0	3.1	-2.1	1.1	-1.5	2.1	-1.3	1.2	-2.6	1.3
NIST	-0.1	0.6	0.0	2.0	2.0	3.9	-0.1	1.2	-0.1	0.9	1.0	3.9			1.6	1.2			-0.4	3.0	-0.5	0.7	0.2	2.0	0.3	0.9	-1.0	1.0
NMIJ	0.3	2.9	0.4	3.5	2.4	4.9	0.3	3.1	0.2	3.0	1.4	4.8			2.0	3.1	0.4	3.0			-0.1	3.0	0.5	3.5	0.7	3.0	-0.6	3.0
NPL	0.4	0.4	0.5	1.9	2.5	3.9	0.4	1.1	0.4	0.8	1.5	3.9			2.1	1.1	0.5	0.7	0.1	3.0			0.7	1.9	0.8	0.8	-0.5	0.9
NRC	-0.2	1.8	-0.1	2.7	1.9	4.3	-0.3	2.1	-0.3	2.0	0.8	4.3			1.5	2.1	-0.2	2.0	-0.5	3.5	-0.7	1.9			0.2	2.0	-1.1	2.0
PTB	-0.4	0.7	-0.3	2.0	1.7	3.9	-0.4	1.2	-0.5	1.0	0.7	3.9			1.3	1.2	-0.3	0.9	-0.7	3.0	-0.8	0.8	-0.2	2.0			-1.3	1.1
VNIIOFI	0.9	0.7	1.0	2.1	3.0	4.0	0.8	1.3	0.8	1.1	2.0	3.9			2.6	1.3	1.0	1.0	0.6	3.0	0.5	0.9	1.1	2.0	1.3	1.1		

950 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.0	1.9			2.5	4.3	0.0	2.2			1.3	4.3			1.2	2.2	0.1	2.0	-0.3	3.5	-0.4	1.9	0.4	2.6	0.2	2.0	-0.9	2.1
CENAM	-2.5	3.8	-2.5	4.3			-2.5	4.0			-1.2	5.4			-1.3	4.0	-2.4	3.9	-2.8	4.8	-2.9	3.8	-2.1	4.2	-2.3	3.9	-3.4	3.9
CSIRO	-0.1	1.0	0.0	2.2	2.5	4.0					1.3	4.0			1.1	1.5	0.1	1.2	-0.3	3.1	-0.4	1.2	0.4	2.1	0.2	1.3	-0.9	1.4
HUT																												
IFA-CSIC	-1.4	3.8	-1.3	4.3	1.2	5.4	-1.3	4.0							-0.2	4.0	-1.3	3.9	-1.6	4.9	-1.7	3.9	-0.9	4.3	-1.1	3.9	-2.2	4.0
MSL-IRL																												
NIM	-1.2	1.0	-1.2	2.2	1.3	4.0	-1.1	1.5			0.2	4.0					-1.1	1.2	-1.4	3.1	-1.6	1.1	-0.8	2.1	-0.9	1.3	-2.0	1.4
NIST	-0.1	0.6	-0.1	2.0	2.4	3.9	-0.1	1.2			1.3	3.9			1.1	1.2			-0.4	3.0	-0.5	0.7	0.3	1.9	0.1	0.9	-1.0	1.1
NMIJ	0.3	2.9	0.3	3.5	2.8	4.8	0.3	3.1			1.6	4.9			1.4	3.1	0.4	3.0			-0.1	3.0	0.7	3.5	0.5	3.0	-0.6	3.1
NPL	0.4	0.4	0.4	1.9	2.9	3.8	0.4	1.2			1.7	3.9			1.6	1.1	0.5	0.7	0.1	3.0			0.8	1.9	0.6	0.8	-0.5	1.0
NRC	-0.4	1.8	-0.4	2.6	2.1	4.2	-0.4	2.1			0.9	4.3			0.8	2.1	-0.3	1.9	-0.7	3.5	-0.8	1.9			-0.2	2.0	-1.3	2.0
PTB	-0.2	0.7	-0.2	2.0	2.3	3.9	-0.2	1.3			1.1	3.9			0.9	1.3	-0.1	0.9	-0.5	3.0	-0.6	0.8	0.2	2.0			-1.1	1.1
VNIIOFI	0.8	0.8	0.9	2.1	3.4	3.9	0.9	1.4			2.2	4.0			2.0	1.4	1.0	1.1	0.6	3.1	0.5	1.0	1.3	2.0	1.1	1.1		

1000 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.2	1.9			3.1	4.5	0.2	2.2			1.5	4.2			1.5	2.2	0.3	2.0	0.0	3.5	-0.3	1.9	0.6	2.6	0.5	2.0	-0.9	2.1
CENAM	-2.9	4.1	-3.1	4.5			-2.9	4.3			-1.5	5.6			-1.5	4.2	-2.8	4.1	-3.0	5.1	-3.4	4.1	-2.5	4.5	-2.6	4.2	-3.9	4.2
CSIRO	-0.1	1.1	-0.2	2.2	2.9	4.3					1.3	4.0			1.3	1.5	0.0	1.3	-0.2	3.2	-0.5	1.2	0.3	2.1	0.3	1.3	-1.1	1.4
HUT																												
IFA-CSIC	-1.4	3.8	-1.5	4.2	1.5	5.6	-1.3	4.0							0.0	3.9	-1.3	3.8	-1.5	4.8	-1.9	3.8	-1.0	4.2	-1.0	3.9	-2.4	3.9

MSL-IRL																												
NIM	-1.4	1.0	-1.5	2.2	1.5	4.2	-1.3	1.5			0.0	3.9					-1.3	1.2	-1.5	3.1	-1.8	1.1	-1.0	2.1	-1.0	1.3	-2.4	1.4
NIST	-0.1	0.6	-0.3	2.0	2.8	4.1	0.0	1.3			1.3	3.8			1.3	1.2			-0.2	3.0	-0.6	0.7	0.3	1.9	0.2	0.9	-1.1	1.1
NMIJ	0.1	2.9	0.0	3.5	3.0	5.1	0.2	3.2			1.5	4.8			1.5	3.1	0.2	3.0			-0.4	3.0	0.5	3.5	0.5	3.0	-0.9	3.1
NPL	0.5	0.4	0.3	1.9	3.4	4.1	0.5	1.2			1.9	3.8			1.8	1.1	0.6	0.7	0.4	3.0			0.9	1.9	0.8	0.8	-0.5	1.0
NRC	-0.4	1.8	-0.6	2.6	2.5	4.5	-0.3	2.1			1.0	4.2			1.0	2.1	-0.3	1.9	-0.5	3.5	-0.9	1.9			-0.1	2.0	-1.4	2.0
PTB	-0.4	0.7	-0.5	2.0	2.6	4.2	-0.3	1.3			1.0	3.9			1.0	1.3	-0.2	0.9	-0.5	3.0	-0.8	0.8	0.1	2.0			-1.4	1.1
VNIIOFI	1.0	0.8	0.9	2.1	3.9	4.2	1.1	1.4			2.4	3.9			2.4	1.4	1.1	1.1	0.9	3.1	0.5	1.0	1.4	2.0	1.4	1.1		

1100 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.4	2.2			3.2	4.6	0.0	2.6			1.0	5.2			0.8	2.5	-0.3	2.3	-0.3	3.7	-1.0	2.3	0.1	2.8	0.0	2.4	-1.8	2.4
CENAM	-3.6	4.0	-3.2	4.6			-3.2	4.2			-2.2	6.2			-2.4	4.1	-3.5	4.0	-3.5	5.0	-4.1	4.0	-3.1	4.3	-3.2	4.1	-5.0	4.1
CSIRO	-0.4	1.2	0.0	2.6	3.2	4.2					1.0	4.9			0.8	1.6	-0.3	1.4	-0.2	3.2	-0.9	1.3	0.1	2.1	0.0	1.6	-1.8	1.6
HUT																												
IFA-CSIC	-1.4	4.7	-1.0	5.2	2.2	6.2	-1.0	4.9							-0.2	4.8	-1.3	4.8	-1.3	5.6	-2.0	4.8	-0.9	5.0	-1.0	4.8	-2.8	4.8
MSL-IRL																												
NIM	-1.2	0.9	-0.8	2.5	2.4	4.1	-0.8	1.6			0.2	4.8					-1.0	1.1	-1.0	3.1	-1.7	1.1	-0.7	1.9	-0.8	1.4	-2.6	1.4
NIST	-0.2	0.5	0.3	2.3	3.5	4.0	0.3	1.4			1.3	4.8			1.0	1.1			0.0	3.0	-0.7	0.6	0.3	1.7	0.3	1.1	-1.5	1.1
NMIJ	-0.2	2.9	0.3	3.7	3.5	5.0	0.2	3.2			1.3	5.6			1.0	3.1	0.0	3.0			-0.7	3.0	0.3	3.4	0.3	3.1	-1.5	3.1
NPL	0.5	0.4	1.0	2.3	4.1	4.0	0.9	1.3			2.0	4.8			1.7	1.1	0.7	0.6	0.7	3.0			1.0	1.7	1.0	1.0	-0.8	1.0
NRC	-0.5	1.6	-0.1	2.8	3.1	4.3	-0.1	2.1			0.9	5.0			0.7	1.9	-0.3	1.7	-0.3	3.4	-1.0	1.7			-0.1	1.9	-1.9	1.9
PTB	-0.4	1.0	0.0	2.4	3.2	4.1	0.0	1.6			1.0	4.8			0.8	1.4	-0.3	1.1	-0.3	3.1	-1.0	1.0	0.1	1.9			-1.8	1.4
VNIIOFI	1.4	0.9	1.8	2.4	5.0	4.1	1.8	1.6			2.8	4.8			2.6	1.4	1.5	1.1	1.5	3.1	0.8	1.0	1.9	1.9	1.8	1.4		

1200 nm

NMI *j* → / NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
			D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.3	2.1			4.1	4.5	0.9	2.5			1.9	5.0			0.7	2.3	0.8	2.2	1.4	3.6	0.0	2.1	1.4	3.1	0.7	2.3	-1.2	2.3
CENAM	-3.9	4.0	-4.1	4.5			-3.2	4.2			-2.2	6.0			-3.4	4.1	-3.3	4.0	-2.7	4.9	-4.2	4.0	-2.7	4.6	-3.4	4.1	-5.3	4.1
CSIRO	-0.7	1.3	-0.9	2.5	3.2	4.2					1.0	4.7			-0.2	1.6	-0.1	1.4	0.5	3.2	-1.0	1.4	0.5	2.7	-0.3	1.7	-2.1	1.6
HUT																												
IFA-CSIC	-1.7	4.5	-1.9	5.0	2.2	6.0	-1.0	4.7							-1.2	4.6	-1.1	4.6	-0.5	5.4	-1.9	4.6	-0.5	5.1	-1.2	4.6	-3.1	4.6
MSL-IRL																												
NIM	-0.4	0.8	-0.7	2.3	3.4	4.1	0.2	1.6			1.2	4.6					0.1	1.0	0.7	3.1	-0.7	1.0	0.7	2.5	0.0	1.3	-1.9	1.3
NIST	-0.5	0.5	-0.8	2.2	3.3	4.0	0.1	1.4			1.1	4.6			-0.1	1.0			0.6	3.0	-0.8	0.6	0.6	2.4	-0.1	1.1	-2.0	1.1
NMIJ	-1.1	2.9	-1.4	3.6	2.7	4.9	-0.5	3.2			0.5	5.4			-0.7	3.1	-0.6	3.0			-1.4	2.9	0.0	3.7	-0.7	3.1	-2.6	3.1
NPL	0.3	0.4	0.0	2.1	4.2	4.0	1.0	1.4			1.9	4.6			0.7	1.0	0.8	0.6	1.4	2.9			1.5	2.4	0.7	1.0	-1.2	1.0
NRC	-1.2	2.3	-1.4	3.1	2.7	4.6	-0.5	2.7			0.5	5.1			-0.7	2.5	-0.6	2.4	0.0	3.7	-1.5	2.4			-0.7	2.5	-2.6	2.5
PTB	-0.4	1.0	-0.7	2.3	3.4	4.1	0.3	1.7			1.2	4.6			0.0	1.3	0.1	1.1	0.7	3.1	-0.7	1.0	0.7	2.5			-1.9	1.3
VNIIOFI	1.5	0.9	1.2	2.3	5.3	4.1	2.1	1.6			3.1	4.6			1.9	1.3	2.0	1.1	2.6	3.1	1.2	1.0	2.6	2.5	1.9	1.3		

1300 nm

NMI *j* → / NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
			D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.2	2.1			4.0	4.4	0.7	2.5			2.2	4.5			0.8	2.3	0.6	2.2	1.2	3.6	-0.3	2.1	1.2	3.2	0.9	2.3	-1.4	2.3
CENAM	-3.8	3.9	-4.0	4.4			-3.3	4.2			-1.8	5.6			-3.1	4.0	-3.4	3.9	-2.8	4.9	-4.3	3.9	-2.7	4.6	-3.0	4.0	-5.4	4.0
CSIRO	-0.5	1.4	-0.7	2.5	3.3	4.2					1.5	4.3			0.2	1.7	-0.1	1.5	0.5	3.3	-1.0	1.5	0.6	2.8	0.3	1.7	-2.1	1.7
HUT																												
IFA-CSIC	-2.0	4.0	-2.2	4.5	1.8	5.6	-1.5	4.3							-1.3	4.1	-1.6	4.0	-1.0	5.0	-2.5	4.0	-0.9	4.6	-1.3	4.1	-3.6	4.1

MSL-IRL																												
NIM	-0.6	0.8	-0.8	2.3	3.1	4.0	-0.2	1.7			1.3	4.1					-0.2	1.0	0.4	3.1	-1.2	1.0	0.4	2.5	0.1	1.3	-2.2	1.3
NIST	-0.4	0.5	-0.6	2.2	3.4	3.9	0.1	1.5			1.6	4.0			0.2	1.0			0.6	3.0	-0.9	0.6	0.6	2.4	0.3	1.1	-2.0	1.0
NMIJ	-1.0	2.9	-1.2	3.6	2.8	4.9	-0.5	3.3			1.0	5.0			-0.4	3.1	-0.6	3.0			-1.5	3.0	0.0	3.8	-0.3	3.1	-2.6	3.1
NPL	0.5	0.5	0.3	2.1	4.3	3.9	1.0	1.5			2.5	4.0			1.2	1.0	0.9	0.6	1.5	3.0			1.6	2.4	1.3	1.0	-1.1	1.0
NRC	-1.1	2.3	-1.2	3.2	2.7	4.6	-0.6	2.8			0.9	4.6			-0.4	2.5	-0.6	2.4	0.0	3.8	-1.6	2.4			-0.3	2.5	-2.6	2.5
PTB	-0.7	1.0	-0.9	2.3	3.0	4.0	-0.3	1.7			1.3	4.1			-0.1	1.3	-0.3	1.1	0.3	3.1	-1.3	1.0	0.3	2.5			-2.3	1.3
VNIIOFI	1.6	0.8	1.4	2.3	5.4	4.0	2.1	1.7			3.6	4.1			2.2	1.3	2.0	1.0	2.6	3.1	1.1	1.0	2.6	2.5	2.3	1.3		

1400 nm

NMI j			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI I	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.1	2.1			2.7	4.5	0.6	2.6			2.2	4.7			1.6	2.3	0.3	2.2	-0.6	3.6	-0.7	2.2	0.8	3.3	-0.6	3.0	-1.8	2.3
CENAM	-2.8	3.9	-2.7	4.5			-2.1	4.2			-0.5	5.7			-1.1	4.1	-2.4	4.0	-3.3	4.9	-3.4	4.0	-1.8	4.6	-3.4	4.5	-4.5	4.0
CSIRO	-0.6	1.5	-0.6	2.6	2.1	4.2					1.7	4.5			1.0	1.8	-0.3	1.6	-1.1	3.4	-1.3	1.6	0.3	2.9	-1.2	2.7	-2.4	1.8
HUT																												
IFA-CSIC	-2.3	4.2	-2.2	4.7	0.5	5.7	-1.7	4.5							-0.7	4.3	-1.9	4.2	-2.8	5.1	-2.9	4.2	-1.4	4.9	-2.9	4.7	-4.0	4.3
MSL-IRL																												
NIM	-1.6	0.9	-1.6	2.3	1.1	4.1	-1.0	1.8			0.7	4.3					-1.3	1.1	-2.1	3.1	-2.3	1.1	-0.7	2.7	-2.2	2.4	-3.4	1.3
NIST	-0.3	0.5	-0.3	2.2	2.4	4.0	0.3	1.6			1.9	4.2			1.3	1.1			-0.8	3.0	-1.0	0.7	0.6	2.5	-0.9	2.3	-2.1	1.0
NMIJ	0.5	2.9	0.6	3.6	3.3	4.9	1.1	3.4			2.8	5.1			2.1	3.1	0.8	3.0			-0.2	3.0	1.4	3.9	-0.1	3.7	-1.3	3.1
NPL	0.7	0.5	0.7	2.2	3.4	4.0	1.3	1.6			2.9	4.2			2.3	1.1	1.0	0.7	0.2	3.0			1.6	2.5	0.1	2.3	-1.1	1.0
NRC	-0.9	2.4	-0.8	3.3	1.8	4.6	-0.3	2.9			1.4	4.9			0.7	2.7	-0.6	2.5	-1.4	3.9	-1.6	2.5			-1.5	3.3	-2.7	2.6
PTB	0.6	2.2	0.6	3.0	3.4	4.5	1.2	2.7			2.9	4.7			2.2	2.4	0.9	2.3	0.1	3.7	-0.1	2.3	1.5	3.3			-1.2	2.4
VNIIOFI	1.7	0.8	1.8	2.3	4.5	4.0	2.4	1.8			4.0	4.3			3.4	1.3	2.1	1.0	1.3	3.1	1.1	1.0	2.7	2.6	1.2	2.4		

1500 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.1	2.6			2.1	4.8	0.3	3.1			2.3	5.0			0.8	2.9	0.2	2.7	1.2	4.0	-0.7	2.7	1.1	3.6	0.7	3.4	-1.6	2.8
CENAM	-2.2	3.9	-2.1	4.8			-1.8	4.3			0.3	5.7			-1.3	4.1	-1.9	4.0	-0.8	4.9	-2.8	4.0	-1.0	4.6	-1.4	4.5	-3.6	4.0
CSIRO	-0.4	1.5	-0.3	3.1	1.8	4.3					2.0	4.5			0.5	1.9	-0.1	1.7	0.9	3.3	-1.0	1.7	0.8	2.9	0.3	2.7	-1.9	1.8
HUT																												
IFA-CSIC	-2.4	4.2	-2.3	5.0	-0.3	5.7	-2.0	4.5							-1.5	4.3	-2.1	4.2	-1.1	5.1	-3.0	4.2	-1.2	4.8	-1.7	4.7	-3.9	4.3
MSL-IRL																												
NIM	-0.9	0.9	-0.8	2.9	1.3	4.1	-0.5	1.9			1.5	4.3					-0.6	1.1	0.4	3.1	-1.5	1.1	0.3	2.6	-0.2	2.4	-2.4	1.4
NIST	-0.2	0.5	-0.2	2.7	1.9	4.0	0.1	1.7			2.1	4.2			0.6	1.1			1.1	3.0	-0.9	0.6	0.9	2.4	0.5	2.2	-1.7	1.0
NMIJ	-1.3	2.9	-1.2	4.0	0.8	4.9	-0.9	3.3			1.1	5.1			-0.4	3.1	-1.1	3.0			-2.0	3.0	-0.2	3.8	-0.6	3.6	-2.8	3.1
NPL	0.6	0.5	0.7	2.7	2.8	4.0	1.0	1.7			3.0	4.2			1.5	1.1	0.9	0.6	2.0	3.0			1.8	2.4	1.4	2.2	-0.9	1.0
NRC	-1.2	2.3	-1.1	3.6	1.0	4.6	-0.8	2.9			1.2	4.8			-0.3	2.6	-0.9	2.4	0.2	3.8	-1.8	2.4			-0.4	3.2	-2.7	2.5
PTB	-0.7	2.2	-0.7	3.4	1.4	4.5	-0.3	2.7			1.7	4.7			0.2	2.4	-0.5	2.2	0.6	3.6	-1.4	2.2	0.4	3.2			-2.2	2.4
VNIIOFI	1.5	0.9	1.6	2.8	3.6	4.0	1.9	1.8			3.9	4.3			2.4	1.4	1.7	1.0	2.8	3.1	0.9	1.0	2.7	2.5	2.2	2.4		

1600 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.1	2.6			1.0	4.8	0.3	3.3			2.7	4.8			1.1	2.8	0.3	2.7	1.3	4.0	-0.7	2.7	1.5	3.6	0.6	3.4	-1.4	3.0
CENAM	-0.9	4.0	-1.0	4.8			-0.7	4.4			1.7	5.7			0.1	4.1	-0.7	4.0	0.3	4.9	-1.7	4.0	0.5	4.6	-0.4	4.5	-2.4	4.2
CSIRO	-0.2	1.9	-0.3	3.3	0.7	4.4					2.4	4.5			0.8	2.2	0.0	2.0	1.0	3.5	-1.0	2.0	1.2	3.1	0.3	2.9	-1.7	2.4
HUT																												
IFA-CSIC	-2.6	4.0	-2.7	4.8	-1.7	5.7	-2.4	4.5							-1.6	4.2	-2.3	4.0	-1.4	5.0	-3.4	4.1	-1.2	4.7	-2.1	4.6	-4.1	4.2

NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	BNM-INM D_{ij}	BNM-INM U_{ij}	CENAM D_{ij}	CENAM U_{ij}	CSIRO D_{ij}	CSIRO U_{ij}	HUT D_{ij}	HUT U_{ij}	IFA-CSIC D_{ij}	IFA-CSIC U_{ij}	MSL-IRL D_{ij}	MSL-IRL U_{ij}	NIM D_{ij}	NIM U_{ij}	NIST D_{ij}	NIST U_{ij}	NMIJ D_{ij}	NMIJ U_{ij}	NPL D_{ij}	NPL U_{ij}	NRC D_{ij}	NRC U_{ij}	PTB D_{ij}	PTB U_{ij}	VNIIOFI D_{ij}	VNIIOFI U_{ij}
MSL-IRL																												
NIM	-1.0	0.9	-1.1	2.8	-0.1	4.1	-0.8	2.2			1.6	4.2					-0.8	1.1	0.2	3.1	-1.8	1.1	0.4	2.6	-0.5	2.4	-2.5	1.6
NIST	-0.2	0.5	-0.3	2.7	0.7	4.0	0.0	2.0			2.3	4.0			0.8	1.1			1.0	3.0	-1.0	0.6	1.2	2.4	0.3	2.2	-1.7	1.4
NMIJ	-1.2	2.9	-1.3	4.0	-0.3	4.9	-1.0	3.5			1.4	5.0			-0.2	3.1	-1.0	3.0			-2.0	3.0	0.2	3.8	-0.7	3.7	-2.7	3.2
NPL	0.8	0.5	0.7	2.7	1.7	4.0	1.0	2.0			3.4	4.1			1.8	1.1	1.0	0.6	2.0	3.0			2.2	2.4	1.3	2.2	-0.7	1.4
NRC	-1.4	2.3	-1.5	3.6	-0.5	4.6	-1.2	3.1			1.2	4.7			-0.4	2.6	-1.2	2.4	-0.2	3.8	-2.2	2.4			-0.9	3.2	-2.9	2.7
PTB	-0.5	2.2	-0.6	3.4	0.4	4.5	-0.3	2.9			2.1	4.6			0.5	2.4	-0.3	2.2	0.7	3.7	-1.3	2.2	0.9	3.2			-2.0	2.5
VNIIOFI	1.5	1.2	1.4	3.0	2.4	4.2	1.7	2.4			4.1	4.2			2.5	1.6	1.7	1.4	2.7	3.2	0.7	1.4	2.9	2.7	2.0	2.5		

1700 nm

NMI *i* \ NMI *j*	D_i / 10^{-2}	U_i / 10^{-2}	BNM-INM D_{ij} / 10^{-2}	BNM-INM U_{ij} / 10^{-2}	CENAM D_{ij} / 10^{-2}	CENAM U_{ij} / 10^{-2}	CSIRO D_{ij} / 10^{-2}	CSIRO U_{ij} / 10^{-2}	HUT D_{ij} / 10^{-2}	HUT U_{ij} / 10^{-2}	IFA-CSIC D_{ij} / 10^{-2}	IFA-CSIC U_{ij} / 10^{-2}	MSL-IRL D_{ij} / 10^{-2}	MSL-IRL U_{ij} / 10^{-2}	NIM D_{ij} / 10^{-2}	NIM U_{ij} / 10^{-2}	NIST D_{ij} / 10^{-2}	NIST U_{ij} / 10^{-2}	NMIJ D_{ij} / 10^{-2}	NMIJ U_{ij} / 10^{-2}	NPL D_{ij} / 10^{-2}	NPL U_{ij} / 10^{-2}	NRC D_{ij} / 10^{-2}	NRC U_{ij} / 10^{-2}	PTB D_{ij} / 10^{-2}	PTB U_{ij} / 10^{-2}	VNIIOFI D_{ij} / 10^{-2}	VNIIOFI U_{ij} / 10^{-2}
BNM-INM	0.1	2.6			0.6	4.8	0.7	3.4			4.5	5.3			1.2	2.8	0.2	2.7	1.3	3.9	-0.8	2.7	2.0	4.0	0.7	3.4	-1.5	3.0
CENAM	-0.5	4.0	-0.6	4.8			0.1	4.5			4.0	6.0			0.6	4.1	-0.3	4.0	0.7	4.9	-1.3	4.0	1.4	4.9	0.1	4.5	-2.1	4.2
CSIRO	-0.6	2.1	-0.7	3.4	-0.1	4.5					3.9	5.0			0.5	2.4	-0.5	2.2	0.6	3.6	-1.4	2.2	1.3	3.6	0.0	3.1	-2.2	2.5
HUT																												
IFA-CSIC	-4.5	4.5	-4.5	5.3	-4.0	6.0	-3.9	5.0							-3.4	4.7	-4.3	4.6	-3.2	5.4	-5.3	4.6	-2.5	5.4	-3.9	5.0	-6.1	4.7
MSL-IRL																												
NIM	-1.1	0.9	-1.2	2.8	-0.6	4.1	-0.5	2.4			3.4	4.7					-0.9	1.1	0.1	3.1	-1.9	1.1	0.8	3.1	-0.5	2.4	-2.7	1.7
NIST	-0.1	0.5	-0.2	2.7	0.3	4.0	0.5	2.2			4.3	4.6			0.9	1.1			1.1	2.9	-1.0	0.6	1.8	3.0	0.4	2.2	-1.8	1.4
NMIJ	-1.2	2.8	-1.3	3.9	-0.7	4.9	-0.6	3.6			3.2	5.4			-0.1	3.1	-1.1	2.9			-2.0	3.0	0.7	4.1	-0.6	3.6	-2.8	3.2
NPL	0.8	0.6	0.8	2.7	1.3	4.0	1.4	2.2			5.3	4.6			1.9	1.1	1.0	0.6	2.0	3.0			2.8	3.0	1.4	2.2	-0.8	1.4
NRC	-1.9	2.9	-2.0	4.0	-1.4	4.9	-1.3	3.6			2.5	5.4			-0.8	3.1	-1.8	3.0	-0.7	4.1	-2.8	3.0			-1.3	3.7	-3.5	3.2
PTB	-0.6	2.2	-0.7	3.4	-0.1	4.5	0.0	3.1			3.9	5.0			0.5	2.4	-0.4	2.2	0.6	3.6	-1.4	2.2	1.3	3.7			-2.2	2.6
VNIIOFI	1.6	1.3	1.5	3.0	2.1	4.2	2.2	2.5			6.1	4.7			2.7	1.7	1.8	1.4	2.8	3.2	0.8	1.4	3.5	3.2	2.2	2.6		

1800 nm

NMI j			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI I	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.1	3.0			-0.1	5.0	0.5	4.2			3.6	5.4			1.4	3.2	0.0	3.0	0.8	4.2	-1.1	3.1	1.8	4.1	-0.1	3.7	-1.7	3.4
CENAM	0.0	4.0	0.1	5.0			0.6	4.9			3.8	6.0			1.5	4.1	0.1	4.0	0.9	5.0	-1.0	4.1	1.9	4.9	0.0	4.6	-1.6	4.3
CSIRO	-0.6	2.8	-0.5	4.2	-0.6	4.9					3.2	5.3			0.9	3.1	-0.5	2.9	0.3	4.1	-1.6	3.0	1.3	4.1	-0.6	3.6	-2.2	3.3
HUT																												
IFA-CSIC	-3.7	4.4	-3.6	5.4	-3.8	6.0	-3.2	5.3							-2.3	4.6	-3.7	4.5	-2.9	5.4	-4.7	4.6	-1.9	5.3	-3.7	5.0	-5.3	4.7
MSL-IRL																												
NIM	-1.5	0.9	-1.4	3.2	-1.5	4.1	-0.9	3.1			2.3	4.6					-1.4	1.1	-0.6	3.1	-2.5	1.3	0.4	3.0	-1.5	2.4	-3.1	1.8
NIST	-0.1	0.5	0.0	3.0	-0.1	4.0	0.5	2.9			3.7	4.5			1.4	1.1			0.8	3.0	-1.1	0.9	1.8	2.9	-0.1	2.2	-1.7	1.6
NMIJ	-0.9	2.9	-0.8	4.2	-0.9	5.0	-0.3	4.1			2.9	5.4			0.6	3.1	-0.8	3.0			-1.9	3.0	1.0	4.1	-0.8	3.7	-2.5	3.3
NPL	1.0	0.9	1.1	3.1	1.0	4.1	1.6	3.0			4.7	4.6			2.5	1.3	1.1	0.9	1.9	3.0			2.9	3.0	1.0	2.4	-0.6	1.7
NRC	-1.9	2.8	-1.8	4.1	-1.9	4.9	-1.3	4.1			1.9	5.3			-0.4	3.0	-1.8	2.9	-1.0	4.1	-2.9	3.0			-1.8	3.6	-3.5	3.2
PTB	0.0	2.2	0.1	3.7	0.0	4.6	0.6	3.6			3.7	5.0			1.5	2.4	0.1	2.2	0.8	3.7	-1.0	2.4	1.8	3.6			-1.6	2.7
VNIIOFI	1.6	1.4	1.7	3.4	1.6	4.3	2.2	3.3			5.3	4.7			3.1	1.8	1.7	1.6	2.5	3.3	0.6	1.7	3.5	3.2	1.6	2.7		

1900 nm

NMI j			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI i	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.7	2.9			-1.2	5.0	-0.5	4.0			2.7	5.2			0.6	3.2	-0.6	3.1	-1.5	4.3	-1.5	3.3	2.1	5.2	-1.4	3.8	-1.8	3.4
CENAM	0.5	4.0	1.2	5.0			0.6	4.8			3.9	5.8			1.8	4.2	0.6	4.1	-0.4	5.0	-0.3	4.2	3.3	5.8	-0.2	4.6	-0.6	4.3
CSIRO	-0.2	2.5	0.5	4.0	-0.6	4.8					3.2	5.0			1.2	2.8	0.0	2.7	-1.0	4.0	-0.9	2.9	2.6	5.0	-0.9	3.5	-1.3	3.1
HUT																												
IFA-CSIC	-3.4	4.2	-2.7	5.2	-3.9	5.8	-3.2	5.0							-2.1	4.4	-3.2	4.3	-4.2	5.2	-4.1	4.4	-0.6	6.0	-4.1	4.8	-4.5	4.5

MSL-IRL																												
NIM	-1.3	1.0	-0.6	3.2	-1.8	4.2	-1.2	2.8			2.1	4.4					-1.2	1.2	-2.2	3.2	-2.1	1.6	1.5	4.4	-2.0	2.5	-2.5	1.9
NIST	-0.1	0.6	0.6	3.1	-0.6	4.1	0.0	2.7			3.2	4.3			1.2	1.2			-1.0	3.1	-0.9	1.3	2.7	4.3	-0.8	2.4	-1.3	1.7
NMIJ	0.9	2.9	1.5	4.3	0.4	5.0	1.0	4.0			4.2	5.2			2.2	3.2	1.0	3.1			0.1	3.3	3.6	5.2	0.2	3.8	-0.3	3.4
NPL	0.8	1.3	1.5	3.3	0.3	4.2	0.9	2.9			4.1	4.4			2.1	1.6	0.9	1.3	-0.1	3.3			3.6	4.4	0.1	2.6	-0.4	2.0
NRC	-2.8	4.2	-2.1	5.2	-3.3	5.8	-2.6	5.0			0.6	6.0			-1.5	4.4	-2.7	4.3	-3.6	5.2	-3.6	4.4			-3.5	4.8	-3.9	4.5
PTB	0.7	2.3	1.4	3.8	0.2	4.6	0.9	3.5			4.1	4.8			2.0	2.5	0.8	2.4	-0.2	3.8	-0.1	2.6	3.5	4.8			-0.4	2.8
VNIIOFI	1.1	1.5	1.8	3.4	0.6	4.3	1.3	3.1			4.5	4.5			2.5	1.9	1.3	1.7	0.3	3.4	0.4	2.0	3.9	4.5	0.4	2.8		

2000 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.4	2.1			-0.9	6.0	-0.8	3.6			2.6	4.8			0.8	2.4	-0.3	2.2	-0.7	3.7	-1.2	2.6	1.9	4.1	0.3	3.1	-1.8	2.7
CENAM	0.5	5.6	0.9	6.0			0.0	6.3			3.5	7.0			1.6	5.7	0.6	5.6	0.2	6.4	-0.3	5.7	2.8	6.5	1.1	6.0	-0.9	5.8
CSIRO	0.5	2.8	0.8	3.6	0.0	6.3					3.5	5.1			1.6	3.1	0.6	2.9	0.2	4.2	-0.4	3.2	2.7	4.5	1.1	3.7	-0.9	3.3
HUT																												
IFA-CSIC	-3.0	4.2	-2.6	4.8	-3.5	7.0	-3.5	5.1							-1.9	4.4	-2.9	4.3	-3.3	5.2	-3.8	4.5	-0.8	5.5	-2.4	4.8	-4.4	4.6
MSL-IRL																												
NIM	-1.2	1.0	-0.8	2.4	-1.6	5.7	-1.6	3.1			1.9	4.4					-1.0	1.2	-1.5	3.2	-2.0	1.8	1.1	3.6	-0.5	2.5	-2.5	2.0
NIST	-0.1	0.6	0.3	2.2	-0.6	5.6	-0.6	2.9			2.9	4.3			1.0	1.2			-0.4	3.1	-0.9	1.5	2.2	3.5	0.5	2.3	-1.5	1.8
NMIJ	0.3	3.0	0.7	3.7	-0.2	6.4	-0.2	4.2			3.3	5.2			1.5	3.2	0.4	3.1			-0.5	3.4	2.6	4.6	0.9	3.8	-1.1	3.5
NPL	0.8	1.5	1.2	2.6	0.3	5.7	0.4	3.2			3.8	4.5			2.0	1.8	0.9	1.5	0.5	3.4			3.1	3.7	1.5	2.7	-0.6	2.2
NRC	-2.3	3.4	-1.9	4.1	-2.8	6.5	-2.7	4.5			0.8	5.5			-1.1	3.6	-2.2	3.5	-2.6	4.6	-3.1	3.7			-1.6	4.1	-3.6	3.8
PTB	-0.6	2.3	-0.3	3.1	-1.1	6.0	-1.1	3.7			2.4	4.8			0.5	2.5	-0.5	2.3	-0.9	3.8	-1.5	2.7	1.6	4.1			-2.0	2.8
VNIIOFI	1.4	1.5	1.8	2.7	0.9	5.8	0.9	3.3			4.4	4.6			2.5	2.0	1.5	1.8	1.1	3.5	0.6	2.2	3.6	3.8	2.0	2.8		

2100 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-1.1	2.0			-0.9	5.9	-1.4	3.6			2.0	4.8			-0.4	2.4	-0.7	2.2	-0.8	3.8	-1.8	2.6	1.4	4.4	-0.5	3.4	-2.7	2.7
CENAM	-0.1	5.6	0.9	5.9			-0.4	6.3			3.0	7.0			0.5	5.6	0.3	5.6	0.1	6.4	-0.8	5.7	2.3	6.8	0.4	6.2	-1.7	5.8
CSIRO	0.3	2.8	1.4	3.6	0.4	6.3					3.4	5.2			1.0	3.1	0.7	3.0	0.5	4.3	-0.4	3.3	2.7	4.9	0.9	4.0	-1.3	3.4
HUT																												
IFA-CSIC	-3.1	4.3	-2.0	4.8	-3.0	7.0	-3.4	5.2							-2.4	4.5	-2.7	4.4	-2.9	5.4	-3.8	4.6	-0.7	5.9	-2.5	5.1	-4.7	4.7
MSL-IRL																												
NIM	-0.7	1.0	0.4	2.4	-0.5	5.6	-1.0	3.1			2.4	4.5					-0.3	1.2	-0.4	3.3	-1.4	1.9	1.8	4.1	-0.1	2.9	-2.3	2.0
NIST	-0.4	0.6	0.7	2.2	-0.3	5.6	-0.7	3.0			2.7	4.4			0.3	1.2			-0.1	3.2	-1.1	1.6	2.0	4.0	0.2	2.7	-2.0	1.8
NMIJ	-0.2	3.1	0.8	3.8	-0.1	6.4	-0.5	4.3			2.9	5.4			0.4	3.3	0.1	3.2			-1.0	3.5	2.2	5.0	0.3	4.1	-1.8	3.5
NPL	0.7	1.6	1.8	2.6	0.8	5.7	0.4	3.3			3.8	4.6			1.4	1.9	1.1	1.6	1.0	3.5			3.1	4.2	1.3	3.1	-0.9	2.3
NRC	-2.4	3.9	-1.4	4.4	-2.3	6.8	-2.7	4.9			0.7	5.9			-1.8	4.1	-2.0	4.0	-2.2	5.0	-3.1	4.2			-1.9	4.7	-4.0	4.3
PTB	-0.6	2.7	0.5	3.4	-0.4	6.2	-0.9	4.0			2.5	5.1			0.1	2.9	-0.2	2.7	-0.3	4.1	-1.3	3.1	1.9	4.7			-2.2	3.2
VNIIOFI	1.6	1.5	2.7	2.7	1.7	5.8	1.3	3.4			4.7	4.7			2.3	2.0	2.0	1.8	1.8	3.5	0.9	2.3	4.0	4.3	2.2	3.2		

2200 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.6	2.0			0.4	5.8	0.1	3.5			3.8	5.8			-0.4	2.3	-0.9	2.2	0.6	3.6	-1.2	2.7	1.5	4.8	0.9	3.4	-1.8	2.7
CENAM	-1.1	5.5	-0.4	5.8			-0.4	6.1			3.4	7.7			-0.9	5.6	-1.3	5.5	0.2	6.2	-1.7	5.7	1.0	7.0	0.4	6.1	-2.3	5.7
CSIRO	-0.7	2.7	-0.1	3.5	0.4	6.1					3.8	6.1			-0.5	3.0	-1.0	2.9	0.5	4.1	-1.3	3.3	1.4	5.2	0.8	3.9	-1.9	3.3
HUT																												
IFA-CSIC	-4.5	5.4	-3.8	5.8	-3.4	7.7	-3.8	6.1							-4.3	5.5	-4.7	5.4	-3.3	6.2	-5.1	5.7	-2.4	6.9	-3.0	6.0	-5.7	5.7

MSL-IRL																												
NIM	-0.2	1.0	0.4	2.3	0.9	5.6	0.5	3.0			4.3	5.5					-0.5	1.2	1.0	3.2	-0.8	2.0	1.9	4.5	1.3	2.8	-1.4	2.0
NIST	0.2	0.6	0.9	2.2	1.3	5.5	1.0	2.9			4.7	5.4			0.5	1.2			1.5	3.0	-0.3	1.8	2.3	4.4	1.7	2.7	-0.9	1.8
NMIJ	-1.2	2.9	-0.6	3.6	-0.2	6.2	-0.5	4.1			3.3	6.2			-1.0	3.2	-1.5	3.0			-1.8	3.5	0.9	5.3	0.3	4.0	-2.4	3.5
NPL	0.6	1.8	1.2	2.7	1.7	5.7	1.3	3.3			5.1	5.7			0.8	2.0	0.3	1.8	1.8	3.5			2.7	4.7	2.1	3.2	-0.6	2.5
NRC	-2.1	4.3	-1.5	4.8	-1.0	7.0	-1.4	5.2			2.4	6.9			-1.9	4.5	-2.3	4.4	-0.9	5.3	-2.7	4.7			-0.6	5.1	-3.3	4.7
PTB	-1.5	2.6	-0.9	3.4	-0.4	6.1	-0.8	3.9			3.0	6.0			-1.3	2.8	-1.7	2.7	-0.3	4.0	-2.1	3.2	0.6	5.1			-2.7	3.2
VNIIOFI	1.2	1.6	1.8	2.7	2.3	5.7	1.9	3.3			5.7	5.7			1.4	2.0	0.9	1.8	2.4	3.5	0.6	2.5	3.3	4.7	2.7	3.2		

2300 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.6	2.1			-0.1	5.9	-0.5	3.8							0.5	2.4	-0.9	2.2	-0.6	3.8	-1.6	3.1	1.3	5.4	0.4	3.4	-1.5	2.7
CENAM	-0.5	5.5	0.1	5.9			-0.5	6.4							0.6	5.6	-0.9	5.6	-0.5	6.3	-1.6	6.0	1.4	7.4	0.5	6.1	-1.4	5.8
CSIRO	-0.1	3.1	0.5	3.8	0.5	6.4									1.0	3.3	-0.4	3.2	-0.1	4.4	-1.1	3.9	1.9	5.8	0.9	4.1	-1.0	3.6
HUT																												
IFA-CSIC																												
MSL-IRL																												
NIM	-1.1	0.9	-0.5	2.4	-0.6	5.6	-1.0	3.3									-1.5	1.2	-1.1	3.3	-2.1	2.5	0.8	5.0	-0.1	2.8	-2.0	2.0
NIST	0.3	0.7	0.9	2.2	0.9	5.6	0.4	3.2							1.5	1.2			0.4	3.1	-0.7	2.4	2.3	4.9	1.4	2.7	-0.5	1.8
NMIJ	0.0	3.0	0.6	3.8	0.5	6.3	0.1	4.4							1.1	3.3	-0.4	3.1			-1.0	3.9	1.9	5.8	1.0	4.1	-0.9	3.6
NPL	1.0	2.3	1.6	3.1	1.6	6.0	1.1	3.9							2.1	2.5	0.7	2.4	1.0	3.9			3.0	5.4	2.0	3.5	0.1	2.9
NRC	-1.9	4.9	-1.3	5.4	-1.4	7.4	-1.9	5.8							-0.8	5.0	-2.3	4.9	-1.9	5.8	-3.0	5.4			-0.9	5.6	-2.8	5.2
PTB	-1.0	2.7	-0.4	3.4	-0.5	6.1	-0.9	4.1							0.1	2.8	-1.4	2.7	-1.0	4.1	-2.0	3.5	0.9	5.6			-1.9	3.2
VNIIOFI	0.9	1.6	1.5	2.7	1.4	5.8	1.0	3.6							2.0	2.0	0.5	1.8	0.9	3.6	-0.1	2.9	2.8	5.2	1.9	3.2		

2400 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *I*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	-0.5	2.1			-0.6	6.0	-1.4	4.4							0.9	2.4	-0.6	2.2	-1.2	4.1	-2.1	3.6	0.4	6.0	-0.4	3.4	-1.7	3.5
CENAM	0.1	5.7	0.6	6.0			-0.8	6.8							1.5	5.8	0.0	5.7	-0.6	6.6	-1.5	6.3	1.0	7.9	0.2	6.2	-1.1	6.3
CSIRO	0.9	3.7	1.4	4.4	0.8	6.8									2.3	4.0	0.8	3.9	0.2	5.2	-0.7	4.8	1.8	6.7	1.0	4.6	-0.3	4.7
HUT																												
IFA-CSIC																												
MSL-IRL																												
NIM	-1.4	1.1	-0.9	2.4	-1.5	5.8	-2.3	4.0									-1.5	1.4	-2.1	3.7	-3.0	3.2	-0.5	5.7	-1.3	2.9	-2.6	3.0
NIST	0.1	0.8	0.6	2.2	0.0	5.7	-0.8	3.9							1.5	1.4			-0.6	3.5	-1.5	3.0	1.0	5.6	0.2	2.7	-1.1	2.8
NMIJ	0.7	3.4	1.2	4.1	0.6	6.6	-0.2	5.2							2.1	3.7	0.6	3.5			-0.9	4.5	1.6	6.5	0.8	4.4	-0.5	4.4
NPL	1.6	2.9	2.1	3.6	1.5	6.3	0.7	4.8							3.0	3.2	1.5	3.0	0.9	4.5			2.5	6.3	1.7	4.0	0.4	4.0
NRC	-0.9	5.5	-0.4	6.0	-1.0	7.9	-1.8	6.7							0.5	5.7	-1.0	5.6	-1.6	6.5	-2.5	6.3			-0.8	6.2	-2.1	6.2
PTB	-0.1	2.6	0.4	3.4	-0.2	6.2	-1.0	4.6							1.3	2.9	-0.2	2.7	-0.8	4.4	-1.7	4.0	0.8	6.2			-1.3	3.8
VNIIOFI	1.2	2.6	1.7	3.5	1.1	6.3	0.3	4.7							2.6	3.0	1.1	2.8	0.5	4.4	-0.4	4.0	2.1	6.2	1.3	3.8		

2500 nm

NMI *j*			BNM-INM		CENAM		CSIRO		HUT		IFA-CSIC		MSL-IRL		NIM		NIST		NMIJ		NPL		NRC		PTB		VNIIOFI	
NMI *i*	D_i / 10^{-2}	U_i / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}	D_{ij} / 10^{-2}	U_{ij} / 10^{-2}
BNM-INM	0.1	2.2			-0.3	6.2	-0.9	4.3							2.2	2.9	0.6	2.7	-5.7	6.4	-1.5	4.3	1.3	9.2	0.2	3.6	-1.2	3.6
CENAM	0.4	5.7	0.3	6.2			-0.5	6.8							2.6	6.0	0.9	5.9	-5.3	8.3	-1.2	6.7	1.6	10.6	0.5	6.4	-0.9	6.4
CSIRO	1.0	3.5	0.9	4.3	0.5	6.8									3.1	4.0	1.4	3.9	-4.8	7.0	-0.7	5.1	2.1	9.6	1.1	4.6	-0.4	4.6
HUT																												
IFA-CSIC																												

MSL-IRL																												
NIM	-2.1	1.6	-2.2	2.9	-2.6	6.0	-3.1	4.0									-1.7	2.2	-7.9	6.2	-3.8	4.0	-1.0	9.1	-2.0	3.2	-3.5	3.3
NIST	-0.5	1.4	-0.6	2.7	-0.9	5.9	-1.4	3.9							1.7	2.2			-6.2	6.1	-2.1	3.9	0.7	9.0	-0.4	3.1	-1.8	3.1
NMIJ	5.8	5.9	5.7	6.4	5.3	8.3	4.8	7.0							7.9	6.2	6.2	6.1			4.1	7.0	6.9	10.7	5.9	6.6	4.4	6.6
NPL	1.6	3.6	1.5	4.3	1.2	6.7	0.7	5.1							3.8	4.0	2.1	3.9	-4.1	7.0			2.8	9.6	1.7	4.5	0.3	4.6
NRC	-1.1	8.9	-1.3	9.2	-1.6	10.6	-2.1	9.6							1.0	9.1	-0.7	9.0	-6.9	10.7	-2.8	9.6			-1.1	9.3	-2.5	9.3
PTB	-0.1	2.8	-0.2	3.6	-0.5	6.4	-1.1	4.6							2.0	3.2	0.4	3.1	-5.9	6.6	-1.7	4.5	1.1	9.3			-1.4	4.0
VNIIOFI	1.4	2.7	1.2	3.6	0.9	6.4	0.4	4.6							3.5	3.3	1.8	3.1	-4.4	6.6	-0.3	4.6	2.5	9.3	1.4	4.0		

Appendix B: A guide to the analysis approach

This appendix has been written to assist readers of this report in understanding the analysis methodology for the CCPR K1-a Key Comparison. This comparison involved 120 measurements made over a 3-year period by 13 participants and thus the analysis had to deal with a certain degree of complexity. However, the model used in this analysis can more easily be understood by working through some simpler examples increasing in complexity.

There are five simple examples described in this appendix and then the actual comparison is discussed. The first example considers a comparison consisting of a single lamp measured by two participants and the pilot. The second considers a comparison consisting of two lamps, two participants and the pilot. The pilot measures both lamps, participant A measures lamp 1 and participant B measures lamp 2.

The third example considers a comparison consisting of four lamps, two participants and the pilot. The pilot measures all four lamps, participant A measures lamps 1 and 2 and participant B measures lamps 3 and 4.

The fourth example considers a comparison consisting of four lamps, two participants and the pilot. The pilot measures all four lamps on two occasions, participant A measures lamps 1 and 2 on two occasions each and participant B measures lamps 3 and 4 on two occasions each.

The first four examples consider an ‘additive’ model – that is the systematic effect that the participants associated with their measurements is a certain value in mW m^2 nm^{-1} and is independent of the absolute irradiance of the lamp. This is not totally realistic, but easy to understand. In the fifth example the same measurements as in the fourth example are considered, but in this case the model is ‘multiplicative’ – that is the systematic effect that the participants associated with their measurements is a certain proportion of the spectral irradiance of the lamp.

Finally the actual comparison is discussed. It should be noted that there is still some debate at the CCPR about the methodologies used in this analysis, in particular concerning analysis that includes effects due to correlation associated with measurements by the same participant and correlation associated with measurements by different participants. The method proposed here has been accepted by the participants of this comparison, for this comparison, but should not be considered a recommendation of the CCPR or set any precedent for future comparisons. This appendix has been written to assist in this debate by describing the analysis in, perhaps, a more straightforward manner.

B.1 First example – one lamp

Imagine a simple comparison consisting of just one lamp measured by the pilot and then sent sequentially to participant A and participant B. We assume that each participant measures a value slightly higher or lower than the lamp’s spectral irradiance because the participant has some systematic offset associated with all its measurements.

We write this model as three equations:

$$\begin{aligned} e_{\mathrm{A}1} &= E_1 + S_{\mathrm{A}} \\ e_{\mathrm{B}1} &= E_1 + S_{\mathrm{B}} \, , \\ e_{\mathrm{p}1} &= E_1 + S_{\mathrm{p}} \end{aligned} \qquad (1)$$

where E_1 is the irradiance of the lamp, S_{A}, S_{B} and S_{p} are the systematic offsets associated with the measurements made by participants A, B and the pilot, respectively, and the measurement values are represented by e_{A1}, e_{B1} and e_{p1} for participant A, participant B and the pilot, respectively.

We are interested in the differences between measurements made by each participant and some reference value and the differences between the measurements made by each pair of participants. Together with the associated uncertainties at a 95 % level of confidence, these differences are, respectively, the required unilateral and bilateral degrees of equivalence. In this simple comparison, it would be appropriate to use the spectral irradiance of the lamp as the reference value, and thus we need to determine the difference between each participant's measurement and the lamp's irradiance – i.e., we need to determine the systematic offsets, S_A, S_B and S_p. The bilateral degrees of equivalence can then be determined as the differences between these systematic offsets, e.g., the value component of the bilateral degree of equivalence for participant A and participant B is $S_A - S_B$.

In the set of equations (1) we have four unknowns S_A, S_B, S_p and E_1. There are an infinite number of solutions for this set – given any solution, any constant could be added to E_1 and subtracted from S_A, S_B and S_p to provide another solution. We must define a *constraint equation* to ensure that the set of equations can be solved uniquely. Mathematically the choice of constraint is arbitrary and will not affect the bilateral degrees of equivalence, but the choice will provide a metrological meaning to the unilateral degrees of equivalence.

In particular we choose the constraint that the systematic factors of the different participants are 'on average' zero, viz.,-

$$w_A S_A + w_B S_B + w_p S_p = 0, \tag{2}$$

where w_A, w_B and w_p are weights assigned in an appropriate manner and which sum to unity. Combining equation set (1) with the constraint equation (2) we obtain

$$\begin{aligned} \left(w_A + w_B + w_p\right) E_1 &= w_A e_{A1} + w_B e_{B1} + w_p e_{p1} \\ 1 \times E_1 &= w_A e_{A1} + w_B e_{B1} + w_p e_{p1} \end{aligned}. \tag{3}$$

Therefore the constraint equation (2) is the equivalent of saying that although each participant individually will have some systematic offset associated with all its measurements, the weighted mean of the measurements made by the participants is the best estimate of the irradiance of the lamp.

The choice of the weights for the constraint equation must make metrological sense. One approach is to make each weight inversely proportional to the square of the standard uncertainty associated with the participant's measurement – this is the weighted mean. In accordance with the rules of the CCPR on the analysis of key comparisons, each weight has been chosen to be inversely proportional to the square of the combined standard uncertainty associated with the measurement by the corresponding participant of a 'typical lamp', or inversely proportional to the square of a cut-off uncertainty, whichever gives the smaller weight.

B.2 Second example – two lamps

The comparison described above could not be carried out with many participants and a single lamp, as lamps are fragile. Therefore it was necessary in K1-a to transport a different lamp to each participant. Keeping with the spirit of building complexity slowly into this analysis, we next consider a simple comparison consisting of just two lamps. Lamp 1 is measured by participant A and the pilot, and Lamp 2 by participant B and the pilot. As above, we assume each participant measures a value slightly higher or lower than the lamp's spectral irradiance, because the participant has some systematic offset associated with all its measurements.

We write this model as four equations, viz.,

$$\begin{aligned} e_{A1} &= E_1 + S_A \\ e_{B2} &= E_2 + S_B \\ e_{p1} &= E_1 + S_p \\ e_{p2} &= E_2 + S_p \end{aligned}, \tag{4}$$

where e_{A1} is the measurement by participant A of lamp 1, E_1 is the spectral irradiance of lamp 1, S_A is the systematic offset applied associated with participant A's measurement and so on (B representing participant B and p the pilot).

Again, although we have insufficient information in these equations to solve the problem, we want the systematic offsets associated with the participants' measurements to be, on average, zero. We use the same arguments as above to introduce the same constraint equation, viz.,

$$w_A S_A + w_B S_B + w_p S_p = 0\,. \tag{5}$$

As each participant has measured a different lamp, the weighted mean of the measurements no longer makes metrological sense; however, the constraint equation still implies that had the participants all measured the same lamp, we would consider the weighted mean of those measurements to be the best estimate of the irradiance of that lamp. Again, in accordance with the rules of the CCPR on the analysis of key comparisons we determine the weights from the uncertainties declared by the participants, limited by a cut-off.

Thus we have the simultaneous equations

$$\begin{aligned} e_{A1} &= E_1 + 0 + S_A + 0 + 0 \\ e_{B2} &= 0 + E_2 + 0 + S_B + 0 \\ e_{p1} &= E_1 + 0 + 0 + 0 + S_p \\ e_{p2} &= 0 + E_2 + 0 + 0 + S_p \\ 0 &= 0 + 0 + w_A S_A + w_B S_B + w_p S_p \end{aligned} \tag{6}$$

or, in matrix notation,

$$\begin{pmatrix} e_{A1} \\ e_{B2} \\ e_{p1} \\ e_{p2} \\ 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & w_A & w_B & w_p \end{pmatrix} \begin{pmatrix} E_1 \\ E_2 \\ S_A \\ S_B \\ S_p \end{pmatrix}. \tag{7}$$

$$\mathbf{y} = \mathbf{A}\mathbf{x}$$

Hence

$$\mathbf{x} = \mathbf{A}^{-1}\mathbf{y}\,. \tag{8}$$

Once we introduce the additional complication of multiple lamps, this solution will be easier if we write equations (6) and (7) a little differently. Rather than adding another row to matrix **A** to account for the constraint equation, we eliminate one of the variables. For example we can eliminate the systematic offset of participant A using the constraint equation (5),

$$S_A = \tfrac{-w_B}{w_A} S_B + \tfrac{-w_p}{w_A} S_p \tag{9}$$

and thus rewrite equation (7) (gaps emphasised here to aid understanding; they are not there) to become

$$\begin{pmatrix} e_{\mathrm{A1}} \\ e_{\mathrm{B2}} \\ \\ e_{\mathrm{p1}} \\ e_{\mathrm{p2}} \end{pmatrix} = \begin{pmatrix} 1 & 0 & \frac{-w_{\mathrm{B}}}{w_{\mathrm{A}}} & \frac{-w_{\mathrm{p}}}{w_{\mathrm{A}}} \\ 0 & 1 & 1 & 0 \\ \\ 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 \end{pmatrix} \begin{pmatrix} E_1 \\ E_2 \\ \\ S_{\mathrm{B}} \\ S_{\mathrm{p}} \end{pmatrix}. \tag{10}$$

The solution of this equation supplies S_{B} and S_{p}, and then S_{A} is determined using expression (9). In practice this method is not the most elegant method for solving the problem. However, the method that is used is mathematically equivalent to this step.

B.3 Third example – four lamps

This example is similar to the previous one except that now there are eight measurement equations rather than four. Therefore the problem is overstated – there is more information than required to solve the equations. This means some form of 'best' answer is required.

Least squares analysis is a standard method for dealing with the 'best fit' to experimental data. The standard least squares analysis equation.

$$\left(\mathbf{A}^{\mathrm{T}}\mathbf{V}^{-1}\mathbf{A}\right)\mathbf{x} = \mathbf{A}^{\mathrm{T}}\mathbf{V}^{-1}\mathbf{y} \tag{11}$$

is used in place of equation (8). **A** is the 'design matrix' for the problem. It describes which laboratory measured which lamps.

For the case where we have 2 participants and 4 lamps, lamps 1 and 2 are measured by A and the pilot, and lamps 2 and 3 are measured by B and the pilot, we can write these equations as

$$\begin{array}{lllllllll} e_{\mathrm{A1}} & = E_1 & + 0 & + 0 & + 0 & + S_{\mathrm{A}} & + 0 & + 0 \\ e_{\mathrm{A2}} & = 0 & + E_2 & + 0 & + 0 & + S_{\mathrm{A}} & + 0 & + 0 \\ e_{\mathrm{B3}} & = 0 & + 0 & + E_3 & + 0 & + 0 & + S_{\mathrm{B}} & + 0 \\ e_{\mathrm{B4}} & = 0 & + 0 & + 0 & + E_4 & + 0 & + S_{\mathrm{B}} & + 0 \\ e_{\mathrm{p1}} & = E_1 & + 0 & + 0 & + 0 & + 0 & + 0 & + S_{\mathrm{p}} \\ e_{\mathrm{p2}} & = 0 & + E_2 & + 0 & + 0 & + 0 & + 0 & + S_{\mathrm{p}} \\ e_{\mathrm{p3}} & = 0 & + 0 & + E_3 & + 0 & + 0 & + 0 & + S_{\mathrm{p}} \\ e_{\mathrm{p4}} & = 0 & + 0 & + 0 & + E_4 & + 0 & + 0 & + S_{\mathrm{p}} \end{array}. \tag{12}$$

Despite the fact that we have eight equations and seven unknowns, these equations still have no unique solution. This is because, for any chosen solution, it is still possible to add a constant to each of the S-values and subtract that constant from each of the E-values to determine a new solution. Thus we still require a constraint equation and, as before, we use the constraint equation given as equation (2) and again determine the weights according to the rules of the CCPR.

The additional information from the measurements of the second and fourth lamps provides us with further information about the systematic factors. The 'best' estimate for the systematic factors is obtained by using the least squares analysis equation (11). To use this method we need to define the necessary matrices. Eliminating, say S_{A}, using the constraint equation (5)

$$S_{\mathrm{A}} = \tfrac{-w_{\mathrm{B}}}{w_{\mathrm{A}}} S_{\mathrm{B}} + \tfrac{-w_{\mathrm{p}}}{w_{\mathrm{A}}} S_{\mathrm{p}} \tag{13}$$

we obtain,

$$\begin{array}{lcccccccccccccc}
e_{\mathrm{A1}} & = & E_1 & + & 0 & + & 0 & + & 0 & + & \tfrac{-w_{\mathrm{B}}}{w_{\mathrm{A}}} S_{\mathrm{B}} & + & \tfrac{-w_{\mathrm{p}}}{w_{\mathrm{A}}} S_{\mathrm{p}} \\
e_{\mathrm{A2}} & = & 0 & + & E_2 & + & 0 & + & 0 & + & \tfrac{-w_{\mathrm{B}}}{w_{\mathrm{A}}} S_{\mathrm{B}} & + & \tfrac{-w_{\mathrm{p}}}{w_{\mathrm{A}}} S_{\mathrm{p}} \\
e_{\mathrm{B3}} & = & 0 & + & 0 & + & E_3 & + & 0 & + & S_{\mathrm{B}} & + & 0 \\
e_{\mathrm{B4}} & = & 0 & + & 0 & + & 0 & + & E_4 & + & S_{\mathrm{B}} & + & 0 \\
e_{\mathrm{p1}} & = & E_1 & + & 0 & + & 0 & + & 0 & + & 0 & + & S_{\mathrm{p}} \\
e_{\mathrm{p2}} & = & 0 & + & E_2 & + & 0 & + & 0 & + & 0 & + & S_{\mathrm{p}} \\
e_{\mathrm{p3}} & = & 0 & + & 0 & + & E_3 & + & 0 & + & 0 & + & S_{\mathrm{p}} \\
e_{\mathrm{p4}} & = & 0 & + & 0 & + & 0 & + & E_4 & + & 0 & + & S_{\mathrm{p}}
\end{array} . \tag{14}$$

Thus, we obtain the matrices for Equation (11) from

$$\mathbf{A} = \begin{pmatrix}
1 & 0 & 0 & 0 & \frac{-w_{\mathrm{B}}}{w_{\mathrm{A}}} & \frac{-w_{\mathrm{p}}}{w_{\mathrm{A}}} \\
0 & 1 & 0 & 0 & \frac{-w_{\mathrm{B}}}{w_{\mathrm{A}}} & \frac{-w_{\mathrm{p}}}{w_{\mathrm{A}}} \\
0 & 0 & 1 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 & 1 & 0 \\
1 & 0 & 0 & 0 & 0 & 1 \\
0 & 1 & 0 & 0 & 0 & 1 \\
0 & 0 & 1 & 0 & 0 & 1 \\
0 & 0 & 0 & 1 & 0 & 1
\end{pmatrix},$$

$$\mathbf{x} = \begin{pmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ S_{\mathrm{B}} \\ S_{\mathrm{p}} \end{pmatrix}, \qquad \mathbf{y} = \begin{pmatrix} e_{\mathrm{A1}} \\ e_{\mathrm{A2}} \\ e_{\mathrm{B3}} \\ e_{\mathrm{B4}} \\ e_{\mathrm{p1}} \\ e_{\mathrm{p2}} \\ e_{\mathrm{p3}} \\ e_{\mathrm{p4}} \end{pmatrix}. \tag{15}$$

Note that the rows of **A** correspond to the eight different measurements, in the order of vector **y**, and the columns to the model parameters in the order given by $\mathbf{x}^{\mathrm{T}}$. The number one represents the measurement of a particular lamp (first four columns) by a particular participant (remaining columns). In this interpretation the matrix is changed slightly for the elimination of one of the variables in the constraint equation.

V is the covariance matrix for the measurements. This describes the uncertainties associated with the measurements. It is used to weight the 'best fit' in a manner that respects the declared uncertainties. It is important to understand at this point that we are determining best estimates for the values of E_1, E_2, E_3, E_4, S_{A}, S_{B} and S_{p} given the measurement data. Since the systematic effects are being modelled, any uncertainty associated with these systematic effects is irrelevant for this purpose. Hence **V** contains the uncertainties associated with random effects only.

The covariance matrix **V** is defined by Equation (16) (note the use of red, and the corner lines are there to help see the pattern – they have no mathematical meaning, but indicate the rows and columns corresponding to participant A (top left), participant B and the pilot (bottom right).)

$$\mathbf{V}=\begin{pmatrix} u^2(e_{A1}) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & u^2(e_{A2}) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & u^2(e_{B3}) & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & u^2(e_{B4}) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & u^2(e_{p1}) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & u^2(e_{p2}) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & u^2(e_{p3}) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & u^2(e_{p4}) \end{pmatrix}, \quad (16)$$

where $u(e_{A1})$ is the standard uncertainty associated with random effects in the measurement e_{A1} – i.e., the standard uncertainty associated with effects that are not correlated between the measurement of lamp 1 and that of lamp 2.

B.4 Fourth example – 4 lamps and 2 rounds

The next example considers two lamps measured by participant A and the pilot and two lamps measured by participant B and the pilot, as before, but now with each participant (and the pilot) measuring each lamp on two occasions (rounds). This means that there are now 16 measurement equations rather than eight.

The least squares solution is still obtained using equation (11). The design equation **A** now has extra rows to consider all 16 measurements. Each row is in fact repeated once. Thus,

$$\mathbf{A}=\begin{pmatrix} 1 & 0 & 0 & 0 & \frac{-w_B}{w_A} & \frac{-w_p}{w_A} \\ 1 & 0 & 0 & 0 & \frac{-w_B}{w_A} & \frac{-w_p}{w_A} \\ 0 & 1 & 0 & 0 & \frac{-w_B}{w_A} & \frac{-w_p}{w_A} \\ 0 & 1 & 0 & 0 & \frac{-w_B}{w_A} & \frac{-w_p}{w_A} \\ 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 \end{pmatrix}, \quad \mathbf{y}=\begin{pmatrix} e_{A1,1} \\ e_{A1,2} \\ e_{A2,1} \\ e_{A2,2} \\ e_{B3,1} \\ e_{B3,2} \\ e_{B4,1} \\ e_{B4,2} \\ e_{p1,1} \\ e_{p1,2} \\ e_{p2,1} \\ e_{p2,2} \\ e_{p3,1} \\ e_{p3,2} \\ e_{p4,1} \\ e_{p4,2} \end{pmatrix}, \quad \mathbf{x}=\begin{pmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ S_B \\ S_p \end{pmatrix}. \quad (17)$$

The covariance matrix now needs to account for the uncertainties associated with round effects. For example the effects that were common to all lamps measured by a participant within one round may be different for the second round (for example, if a key instrument was replaced or recalibrated between rounds 1 and 2). These effects create a correlation associated with the measurements of lamp 1 and lamp 2 by participant A in round 1, etc. The covariance matrix **V** can deal with this correlation by introducing appropriate off-diagonal terms. Remember, each row and the corresponding column of the covariance matrix correspond to a measurement of the lamp – in the order that the measurements are listed in **y**. The diagonal terms contain the square of the standard uncertainty associated with each measurement and the off-diagonal terms contain the square of that part of the standard uncertainty associated with effects that are common to the two measurements. We have

$$\mathbf{V}=\begin{pmatrix}
u_{eA1,1}^2 & 0 & u_{Ar1}^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & u_{eA1,2}^2 & 0 & u_{Ar2}^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
u_{Ar1}^2 & 0 & u_{eA2,1}^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & u_{Ar2}^2 & 0 & u_{eA2,2}^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & u_{eB3,1}^2 & 0 & u_{Br1}^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & u_{eB3,2}^2 & 0 & u_{Br2}^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & u_{Br1}^2 & 0 & u_{eB4,1}^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & u_{Br2}^2 & 0 & u_{eB4,2}^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & u_{ep1,1}^2 & 0 & u_{pr1}^2 & 0 & u_{pr1}^2 & 0 & u_{pr1}^2 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & u_{ep1,2}^2 & 0 & u_{pr2}^2 & 0 & u_{pr2}^2 & 0 & u_{pr2}^2\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & u_{pr1}^2 & 0 & u_{ep2,1}^2 & 0 & u_{pr1}^2 & 0 & u_{pr1}^2 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & u_{pr2}^2 & 0 & u_{ep2,2}^2 & 0 & u_{pr2}^2 & 0 & u_{pr2}^2\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & u_{pr1}^2 & 0 & u_{pr1}^2 & 0 & u_{ep3,1}^2 & 0 & u_{pr1}^2 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & u_{pr2}^2 & 0 & u_{pr2}^2 & 0 & u_{ep3,2}^2 & 0 & u_{pr2}^2\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & u_{pr1}^2 & 0 & u_{pr1}^2 & 0 & u_{pr1}^2 & 0 & u_{ep4,1}^2 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & u_{pr2}^2 & 0 & u_{pr2}^2 & 0 & u_{pr2}^2 & 0 & u_{ep4,2}^2
\end{pmatrix},\tag{18}$$

where $u_{eA1,1}$ is the standard uncertainty associated with the measurement of lamp 1 in round 1 by participant A. This is a combination of the "random" uncertainty and the "round" uncertainty. u_{Ar1} is the uncertainty associated with the measurement of lamps in round 1 by participant A – i.e. it is the uncertainty associated with A's measurements of different lamps in round 1. Note there is no uncertainty term associated with effects corresponding to all the measurements made by one participant. Such effects are included in the model as the S associated with that participant.

With the matrices defined (Equations (17) and(18)), the least squares analysis problem is solved, as before with Equation (11).

B.5 Fifth example – multiplicative model

The examples so far have considered the random and systematic effects as additive effects. More realistically, the systematic effects should be considered as a multiplicative effect. Similarly the random effects are treated multiplicatively. Thus the measurement equations are of the form

$$\begin{aligned} e_{A1,1} &= E_1 S_A \\ e_{p1,1} &= E_1 S_p \end{aligned}, \tag{19}$$

etc.

The model method described above uses linear least squares analysis. Such an analysis does not apply to multiplicative models. However, by transforming the variables logarithmically using the definitions

$$f_{A1,1} = \ln e_{A1,1}$$
$$F_i = \ln E_i \quad , \qquad (20)$$
$$T_n = \ln S_n$$

we can transform our multiplicative model (e.g., Equation (19)) into an additive model

$$f_{A1,1} = F_1 + T_A \qquad (21)$$

and solve that exactly as before, except that in the covariance matrix **V** (Equation (18)) the uncertainties are relative uncertainties rather than absolute uncertainties. The constraint equation (5) becomes

$$w_A T_A + w_B T_B + w_p T_p = 0 \qquad (22)$$

where the weights are now calculated from the relative uncertainties, rather than from the absolute uncertainties.

The final results can be converted back to the desired systematic effects by taking exponentials:

$$E_i = \exp F_i$$
$$S_n = \exp T_n \quad . \qquad (23)$$

B.6 The CCPR K1-a Key Comparison

The CCPR K1-a Key Comparison was analysed using this form of model. The measurements were described by equations of the form

$$e_{A1,1} = E_1 S_A$$
$$e_{p1,1} = E_1 S_p \quad , \qquad (24)$$

where each *S*-value represents the systematic factor associated with the measurements made by a particular participant. This factor is determined for each participant – and the value component of the unilateral degree of equivalence for each participant is the difference between this systematic factor and unity.

To determine the systematic factors the set of measurement equations are solved using linear least squares analysis, having transformed this multiplicative model into an additive model through the transformations

$$f_{A1,1} = \ln e_{A1,1}$$
$$F_i = \ln E_i \quad . \qquad (25)$$
$$T_n = \ln S_n$$

The equations are solved subject to a constraint equation. The constraint equation used takes the form

$$\sum w_i T_i = 0 \, , \qquad (26)$$

where the sum is over all participants, including the pilot. Each weight is determined from the relative standard uncertainty associated with a measurement by the corresponding participant of a single 'typical' lamp. This uncertainty is defined as the simple mean of the standard uncertainties quoted by that participant for all measurements it made. These uncertainties are 'cut-off' according to the policy of the CCPR Key Comparison Working Group, in order to ensure that no participant has an excessively large weight associated with its measurements. (Note that the weighted mean corresponding to the left-hand side of expression (26) becomes a generalised weighted mean to account for the (small) correlation between NIST and MSL-IRL.)

The set of equations are described by matrices and solved using the standard least squares analysis equation

$$\left(\mathbf{A}^{\mathrm{T}}\mathbf{V}^{-1}\mathbf{A}\right)\mathbf{x} = \mathbf{A}^{\mathrm{T}}\mathbf{V}^{-1}\mathbf{y}\,. \qquad (27)$$

A is the 'design matrix' for the problem. It describes which laboratory measured which lamps. **V** is the covariance matrix, which describes the uncertainties associated with all the measurements. It is used to weight the 'best fit' in a manner that respects the declared uncertainties. It is important to understand at this point that we are determining best estimates of the values of the lamp spectral irradiances and the laboratory systematic effects given the measurement data. Since the systematic effects are being modelled, any uncertainty associated with these systematic effects is irrelevant for this purpose. Hence **V** contains the uncertainties associated with effects that are not common to all measurements by a participant. Along the diagonal it contains (squared) standard uncertainties associated with random and round-dependent effects. Off the diagonal it contains (squared) standard uncertainties associated with round-dependent effects (within the coloured regions of Equation (18)).

B.7 Consistency and solution uncertainties

In order to draw valid conclusions from the results of modelling measurement data it is necessary that the model is consistent with the data. Consistency can be assessed by performing a chi-squared test on the results of the least squares analysis. This test describes how well the model actually fits the data compared with how well it can be expected to fit the data, given the uncertainties associated with the (random and round effects on the) measurements. Inconsistency with the model may be because the declared uncertainties associated with random effects are too small, or because the round-dependent uncertainties overestimate the correlation within a round, or underestimate the variation between rounds. Alternatively, the model may not an adequate representation of the physical situation. For this comparison there was a significant discrepancy between the model and the data.

This inadequacy was addressed by introducing an effect in the model corresponding to random drift in the lamps due to transportation (known as the 'artefact factor'). Because there was no relevant information available, the best prior estimate of this effect was taken as zero, but the standard uncertainty associated with it was regarded as unknown. This uncertainty was in turn associated with each measurement of a lamp and hence added algebraically in quadrature to *all* diagonal elements of the covariance matrix **V** . The smallest possible numerical value for the artefact uncertainty was determined such that the model was consistent with the data. This artefact factor standard uncertainty was approximately 0.3 % at UV wavelengths, dropping to 0.1 % for visible and IR wavelengths – its spectral shape and small value were consistent with what might be expected of lamp changes during transportation.

In addition to providing best estimates of the required quantities, least squares analysis generally provides the uncertainties associated with these estimates in the form of a covariance matrix. In this case the required quantities are the lamp spectral irradiances and , the systematic factors for the participants' measurements. However, the uncertainty associated with the estimated systematic effect for the participants' measurements determined by this means is not wholly appropriate for the comparison. The reason is that this uncertainty depends only on the random and round uncertainties of the participants' measurements. In order to determine a systematic factor (and hence degree of equivalence) for each participant that relates to the measurement of a single lamp as required by the MRA, a different approach is required. The solution calculated using least squares analysis is

$$\mathbf{x} = \left(\mathbf{A}^{\mathrm{T}}\mathbf{V}^{-1}\mathbf{A}\right)^{-1}\mathbf{A}^{\mathrm{T}}\mathbf{V}^{-1}\mathbf{y}\,. \qquad (28)$$

This expression can be considered a GUM input-output model. Using the standard GUM principles the uncertainty associated with **x** can be determined by applying the law of propagation of uncertainty given the uncertainty associated with **y**. The uncertainty associated with **y** takes the form of a new covariance matrix $\mathbf{V}_y$. This covariance matrix is similar to **V**, but additionally contains the uncertainties associated with systematic effects. The uncertainties associated with the systematic effect for each measurement by a participant are added in quadrature to the uncertainties already in **V** for all matrix elements relating to that participant (i.e., in Equation (18) all the blue values include the uncertainty associated with systematic effects for participant A as well as the uncertainties already described). In addition off-diagonal terms are introduced to account for the correlation between NIST and MSL-IRL*.

By using equation (28) as a GUM model (**V** within equation (28) is still that of (18)) we can determine the uncertainties associated with the best estimates of the systematic factors S_i, which are contained within **x**, given the uncertainty (and correlation) associated with the input data (the uncertainty associated with **y** described in the covariance matrix $\mathbf{V}_y$). This gives us the uncertainty associated with the systematic factor for each participant. The standard uncertainty associated with the value component of the corresponding degree of equivalence is somewhat larger.

B.8 Degrees of equivalence

The MRA requires the definition of a KCRV and unilateral degrees of equivalence. In a comparison consisting of a single stable artefact measured by all participants the KCRV can be considered as a best estimate of the relevant property value of that artefact. In a comparison involving multiple artefacts its definition is less clear. In this comparison the KCRV is defined as unity for the multiplicative model or zero for the additive model, from the systematic factors

$$\begin{aligned} \sum w_i T_i &= 0 \\ \prod S_i^{\omega_i} &= 1 \end{aligned} , \qquad (29)$$

where w_i is defined from relative standard uncertainties or ω_i from absolute standard uncertainties. This definition results from an interpretation of the guidelines of the CCPR Key Comparison Working Group. For this purpose the standard uncertainty associated with any participant's measurements is taken as either the arithmetic mean of the combined standard uncertainties reported by that participant for the measurements it made or as a cut-off uncertainty, whichever is the greater. The cut-off uncertainty is determined as the arithmetic mean of those combined standard uncertainties reported by the set of participants that are less than or equal to the median of those uncertainties.

The value components of the unilateral DoEs are determined by subtracting unity from the systematic factor for that participant. The uncertainty component of this DoE should be the uncertainty associated with a single "typical" measurement of a lamp at the 95 % level of confidence. This means that the uncertainty associated with the systematic factor is not sufficient to describe the uncertainty associated with the unilateral DoE because the uncertainty associated with the systematic factor depends on the number of measurements made by the participant. If a participant made a large number of measurements, then the

* Because there is a correlation between the measurements of MSL-IRL and NIST, additional (squared) uncertainty terms are added in the off-diagonal positions that describe the covariance between NIST and MSL-IRL. These terms are calculated from that uncertainty that is common to both NIST and MSL-IRL – the uncertainty due to systematic effects in NIST's measurement process. Note that the correlation between NIST and MSL-IRL is included in two places in this analysis: in the weights of the constraint equation and in the determination of the uncertainties (in matrix $\mathbf{V}_y$.)

averaging of the least squares analysis would provide a systematic factor uncertainty that is extremely small. This effect is particularly significant for the pilot, which made more than 65 measurements. In order to treat each participant equitably, the uncertainty component of the degree of equivalence was based on a quadrature sum of the uncertainty associated with the systematic factor (calculated as described in B.6) and that associated with the random effects in a 'typical' measurement of that participant – in practice the simple mean of the uncertainties associated with random effects stated by that participant for all the measurements it made.

The unilateral DoEs depend on the choice of weights in the constraint equation. The bilateral DoEs are determined by differencing unilateral DoEs. The bilateral DoEs do not depend on the choice of weights in the constraint equation*.

B.9 Model suitability

The model provides the ability to cope with the complexity of this Key Comparison in a straightforward manner. The solution is performed using standard mathematical methods for least squares analysis. Therefore, advantage can be taken of developments in numerical analysis that allow such calculations to be performed in a mathematically robust manner. The use of matrices readily allows correlations to be included and also facilitates the use of available mathematical algorithms.

Because the model accounts for knowledge of correlations associated with measurements made by a participant within one round and for all measurements, as well as correlations associated with measurements made by different participants, it was very important that the participants were able to describe those correlations and uncertainties adequately. For this reason the uncertainty statements of each participant were discussed amongst the participants, and in some cases challenged and changed, prior to the analysis of the results. This process ensured that the uncertainty and correlation information submitted by the participants was more reliable than it otherwise would have been.

* In practice there is a very small dependence – of the order of 0.05 % – resulting from the transformation of the multiplicative model to an additive model.

Appendix C: An Alternative Analysis of Comparison Results using a Simple Method

C.1 Introduction

The model described in this report was used in this comparison following agreement by all participants. This model accounts for the knowledge of the key comparison, including (a) systematic effects associated with the participants' results, (b) correlations associated with results from any one participant, (c) correlations associated with results from more than one participant when traceability is taken, and (d) random instability of the lamps used. As a consequence the model is considerably more complicated than that used when, say, evaluating the data from a key comparison involving the circulation of a single stable artefact around participants.

The use of such a model for key comparison data evaluation has not been agreed by CCPR. Moreover, there were views from some members of CCPR WG-KC that the complication of the model is such that it would be difficult to reproduce the results it provides. The views suggest the use of an alternative method of analysis with simple averaging of results at intermediate steps, and the application of the weighted mean with cut-off at the final stage, as agreed by CCPR.

This Appendix has been written by NIST and NPL, to describe the application of such a simple analysis to this K1.a comparison. This appendix allows the results of this approach to be compared with the results provided by the model. The model approach makes separate use of uncertainties associated with random and round effects in order to provide best estimates of the values of the various quantities required, and combined standard uncertainties to evaluate the associated uncertainties. In contrast, the simple method described here uses only the combined standard uncertainties. Further, the model approach considers correlations associated with measurements made by a single participant, and those associated with measurements made by different participants when traceability is taken, while such correlations are not considered here.

As for the model approach, the description applies to measurements at any one of the wavelengths considered.

C.2 The simple approach

The data of K1.a comparison are analyzed below to calculate the KCRV, using a simple method that was used in some of the past CCPR Key Comparisons. In this method, simple arithmetic means are taken in all the intermediate steps for the results from three lamps and two rounds within each NMI (relative to the Pilot lab measurements), then the weighted mean with cut-off is applied at the last step as agreed by CCPR. Only the total uncertainty values reported by NMIs are used. Breakdowns of uncertainty (random, correlated, uncorrelated) of each NMI (other than the pilot lab) are not used.

The following notations are used:

N	Number of participant NMIs, not counting the Pilot laboratory.
$E_{i,j,r}$	Spectral irradiance of lamp j (= 1 to 3) of NMI i (= 1 to 11), measured by the NMI at round r (= 1 to 2).
$u_{\mathrm{rel}}(E_{i,j,r})$	Relative standard uncertainty associated with $E_{i,j,r}$.
$E^{\mathrm{P}}_{i,j,r}$	Spectral irradiance of lamp j (= 1 to 3) of NMI i (= 1 to 11), measured by the Pilot at round r (= 1 to 2).
$u_{\mathrm{rel}}(E^{\mathrm{P}}_{i,j,r})$	Relative standard uncertainty associated with $E^{\mathrm{P}}_{i,j,r}$.

$u_{\mathrm{rel}}(E^{\mathrm{PR}}_{i,j,r})$ The reproducibility (random + yearly) component of the Pilot laboratory's standard uncertainty for lamp *j* of NMI *i* at round *r*.

1. For each NMI *i* and each lamp *j* it measures, the NMI measurements of the two rounds are averaged:

$$\overline{E}_{i,j} = \frac{1}{2}\sum_{r=1}^{2} E_{i,j,r} \quad \text{and} \quad u_{\mathrm{rel}}(\overline{E}_{i,j}) = \frac{1}{2}\sum_{r=1}^{2} u_{\mathrm{rel}}(E_{i,j,r}). \tag{1}$$

Note: This uncertainty calculation is an approximation, assuming that the results of the two measurements of the same lamp measurement by the same NMI are nearly fully correlated. This is normally the case when the uncertainty of transfer measurements (random components) is much smaller than the uncertainty of the scale.

For the Pilot,

$$\overline{E}^{\mathrm{P}}_{i,j} = \frac{1}{2}\sum_{r=1}^{2} E^{\mathrm{P}}_{i,j,r} \quad \text{and} \quad u_{\mathrm{rel}}(\overline{E}^{\mathrm{P}}_{i,j}) = \frac{1}{2}\sum_{r=1}^{2} u_{\mathrm{rel}}(E^{\mathrm{P}}_{i,j,r}). \tag{2}$$

The reproducibility of the Pilot measurements as the average of two rounds is

$$u_{\mathrm{rel}}(\overline{E}^{\mathrm{PR}}_{i,j}) = \sqrt{1/\{u_{\mathrm{rel}}^{-2}(E^{\mathrm{PR}}_{i,j,1}) + u_{\mathrm{rel}}^{-2}(E^{\mathrm{PR}}_{i,j,2})\}}\,. \tag{3}$$

2. For each NMI *i* and each lamp *j* it measures, the relative difference $\Delta_{i,j}$ between the NMI measurement and the Pilot measurement (as an average of two rounds) is given by

$$\Delta_{i,j} = \frac{\overline{E}_{i,j}}{\overline{E}^{\mathrm{P}}_{i,j}} - 1 \tag{4}$$

and the associated standard uncertainty by

$$u(\Delta_{i,j}) = \sqrt{u_{\mathrm{rel}}^{2}(\overline{E}_{i,j}) + u_{\mathrm{rel}}^{2}(\overline{E}^{\mathrm{PR}}_{i,j})}\,. \tag{5}$$

3. For each NMI *i*, the relative differences Δ_i (average of the three lamps) is obtained by

$$\Delta_i = \frac{1}{3}\sum_{j=1}^{3}\Delta_{i,j} \quad \text{and} \quad u(\Delta_i) = \frac{1}{3}\sum_{j=1}^{3} u(\Delta_{i,j}). \tag{6}$$

Note: This uncertainty calculation is an approximation, assuming that the results from the three lamps measured by the same NMI are nearly fully correlated.

For Pilot lab (*i* = 0 is used hereinafter),

$$\Delta_0 = 0 \quad \text{and} \quad u(\Delta_0) = \sqrt{u_{\mathrm{rel}}^{2}(\overline{E}^{\mathrm{P}}) + u_{\mathrm{rel}}^{2}(\overline{E}^{\mathrm{PR}})}\,, \tag{7}$$

where $u_{\mathrm{rel}}(\overline{E}^{\mathrm{P}})$ is the average combined standard uncertainty of all measurements made by the Pilot laboratory:

$$u_{\mathrm{rel}}(\overline{E}^{\mathrm{P}}) = \frac{1}{3N}\sum_{i=1}^{N}\sum_{j=1}^{3} u_{\mathrm{rel}}(\overline{E}^{\mathrm{P}}_{i,j}) \tag{8}$$

and $u_{\mathrm{rel}}(\overline{E}^{\mathrm{PR}}_{i,j})$ is the average reproducibility standard uncertainty of all measurements made by the Pilot laboratory:

$$u_{\mathrm{rel}}(\overline{E}^{\mathrm{PR}}) = \frac{1}{3N}\sum_{i=1}^{N}\sum_{j=1}^{3} u_{\mathrm{rel}}(\overline{E}_{i,j}^{\mathrm{PR}}) \ . \tag{9}$$

Note: Δ_0 is taken as a comparison of the Pilot measurement (with its stated uncertainty $u_{\mathrm{rel}}(\overline{E}^{\mathrm{P}})$) and the comparison scale (with an uncertainty of $u_{\mathrm{rel}}(\overline{E}^{\mathrm{PR}})$). Eqs. (7)-(9) may not follow statistical theory accurately, but they treat the uncertainties (weights) equally for Pilot and other participants.

4. The relative standard uncertainty of measurements of NMI i (averaged for all lamps and all rounds) is determined by

$$u_{\mathrm{rel}}(\overline{E}_i) = \frac{1}{3}\sum_{l=1}^{3} u_{\mathrm{rel}}(\overline{E}_{i,j}) . \tag{10}$$

For convenience of calculation hereinafter,

$$u_{\mathrm{rel}}(\overline{E}_0) = u_{\mathrm{rel}}(\overline{E}^{\mathrm{P}}) . \tag{11}$$

Note: These are required to determine the weights when determining KCRV.

5. The KCRV is calculated using the weighted mean with cut-off as agreed by CCPR. The cut-off value $u_{\mathrm{cut-off}}$ is calculated by

$$u_{\mathrm{cut-off}} = \mathrm{average}\{u_{\mathrm{rel}}(\overline{E}_i)\} \ \text{ for } u_{\mathrm{rel}}(\overline{E}_i) \le \mathrm{median}\{u_{\mathrm{rel}}(\overline{E}_i)\}; \quad i = 0 \text{ to } N. \tag{12}$$

The uncertainty $u(\Delta_i)$ for each NMI i is adjusted by the cut-off,

$$\begin{aligned} u_{\mathrm{adj}}(\Delta_i) &= u(\Delta_i) \quad \text{for } \ u(\Delta_i) \ge u_{\mathrm{cut-off}} \\ u_{\mathrm{adj}}(\Delta_i) &= u_{\mathrm{cut-off}} \quad \text{for } \ u(\Delta_i) < u_{\mathrm{cut-off}} \end{aligned} \ ; \ i = 0 \text{ to } N. \tag{13}$$

The weight w_i for NMI i is determined by

$$w_i = u_{\mathrm{adj}}^{-2}(\Delta_i) / \sum_{i=0}^{N} u_{\mathrm{adj}}^{-2}(\Delta_i). \tag{14}$$

The KCRV, Δ_{KCRV}, is determined by

$$\Delta_{\mathrm{KCRV}} = \sum_{i=0}^{N} w_i \Delta_i . \tag{15}$$

The uncertainty associated with the KCRV (with cut-off applied) is given by

$$u(\Delta_{\mathrm{KCRV}}) = \sqrt{\frac{1}{\sum_{i=0}^{N} u_{\mathrm{adj}}^{-2}(\Delta_i)}} . \tag{16}$$

6. The unilateral DoE of NMI i is given by

$$D_i = \Delta_i - \Delta_{\mathrm{KCRV}} \tag{17}$$

$$U_i = k\sqrt{u_{\mathrm{rel}}^{2}(\overline{E}_i) + u^2(\Delta_{\mathrm{KCRV}})} \qquad ; k = 2. \tag{18}$$

Note: A small correlation exists between $u_{\mathrm{rel}}(\overline{E}_i)$ and $u(\Delta_{\mathrm{KCRV}})$, but it is not considered in this calculation as the effects are insignificant in this comparison.

The results are given in the tables and figures below. The figures show comparison of the results by the NPL model (found in the main report) and the results by the simple method given in this Appendix (labelled “Recipe method” in the figures). Note that differences between the two methods are mostly insignificant, and are largely caused by the differences in the weights in the determination of the KCRV in this approach and the equivalent constraint equation in the model. The model’s constraint equation was based on weights determined only from the standard uncertainties reported by the NMIs (average of all lamps and rounds, subject to cut-off), while the “Recipe method” determined the weights from the quadrature sums of the standard uncertainties reported by the NMIs (as described above) and the transfer uncertainty of the Pilot laboratory (eqs. (5), (6), (14)). If the same weights were used, the differences between the two methods would be even smaller. In the simple method described above, correlations associated with the measurements of two different NMIs were not considered because we do not have a general consensus yet in CCPR. If we had an agreement, it would be possible to implement such a correlation in the simple method.

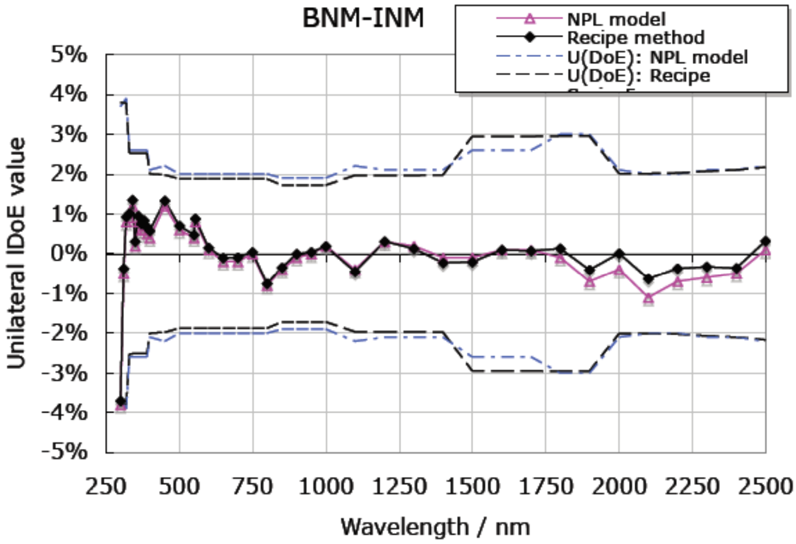
It is concluded that the simple approach described here gives results for the CCPR K1.a key comparison that are very close to those provided by the model approach. Such closeness could not be guaranteed for other key comparisons that have different characteristics in results. The main difference between the model approach and the simple method arises from the averaging of intermediate results of each NMI’s measurements. If all transfer standards measured by one NMI in different rounds were measured with the same or similar transfer (random) uncertainties, the model approach would agree even more closely with this simple method.

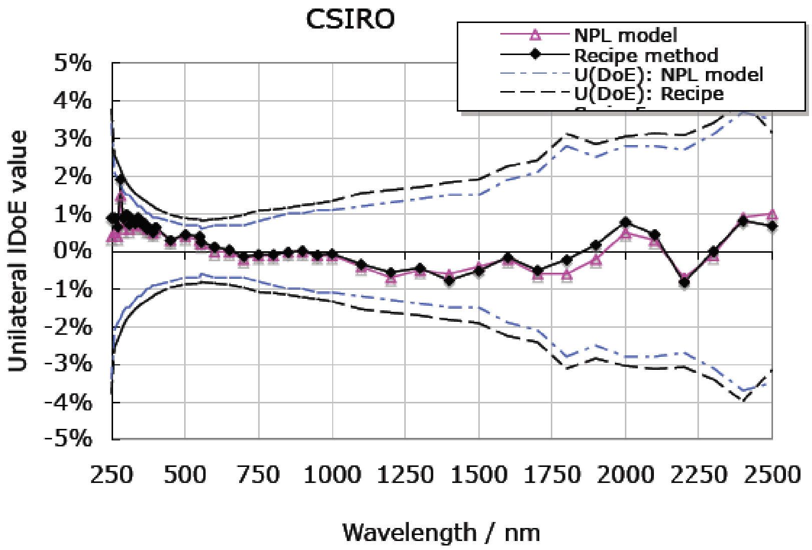
Table C-1. Value components of the Unilateral Degrees of Equivalence (values in %)

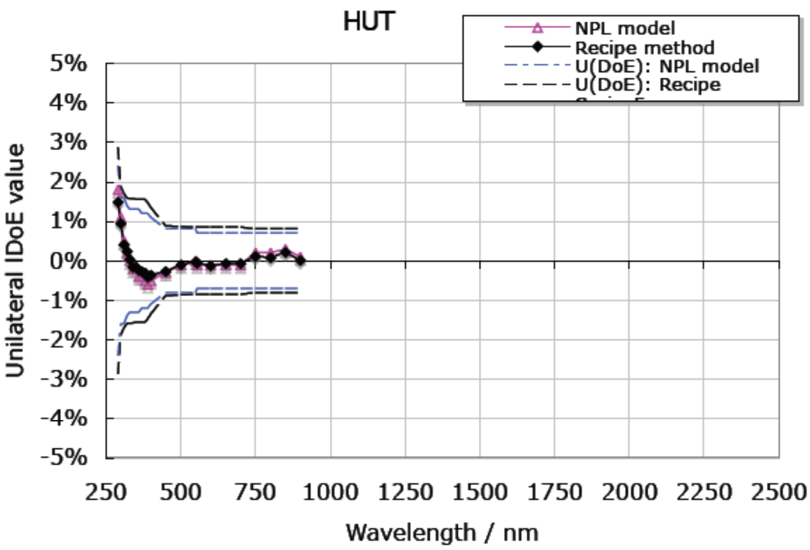
wave-length / nm	BNM-INM	CSIRO	HUT	IFA-SCIC	MSL-IRL	NIM	NIST	NMIJ	NRC	PTB	VNIIOFI	NPL
250		0.9			0.0	1.0	-0.5	2.7	-0.9	-0.5	-1.4	0.7
260		0.9			0.3	-1.6	-0.1	1.8	-3.9	0.0	1.1	-0.1
270		0.7			0.3	-1.1	0.0	1.2	-2.8	-0.1	1.0	-1.0
280		1.9			0.3	-0.8	-0.2	1.5	-3.5	-0.5	1.1	-0.6
290		0.9	1.5		0.0	-0.8	0.0	1.2	-2.7	-0.2	0.6	-0.8
300	-3.7	1.0	0.9	0.0	0.1	-1.0	0.0	1.3	-1.8	-0.1	0.5	-0.4
310	-0.4	0.7	0.4	-0.8	0.0	-0.9	0.2	1.2	-2.4	0.0	0.1	-0.3
320	0.9	0.9	0.2	0.0	0.1	-1.1	-0.1	1.2	-3.6	-0.2	0.2	0.0
330	1.0	0.7	0.0	-0.3	0.2	-0.9	-0.2	1.2	-5.0	-0.2	0.3	0.1
340	1.4	0.9	-0.2	-0.5	0.0	-0.9	-0.2	1.1	-5.2	-0.2	0.3	0.2
350	0.3	0.7	-0.2	-0.5	0.1	-0.9	-0.3	1.2	-0.6	-0.1	0.5	0.3
360	1.0	0.8	-0.2	-0.8	0.1	-0.9	-0.4	1.2	-0.9	-0.1	0.5	0.3
370	0.8	0.6	-0.3	-0.8	0.0	-0.9	-0.2	1.3	-0.2	-0.1	0.6	0.3
380	0.8	0.6	-0.3	-0.9	0.4	-0.9	-0.4	1.5	1.2	0.0	0.6	0.3
390	0.7	0.5	-0.4	-0.9	0.4	-0.7	-0.2	1.8	0.0	-0.1	0.4	0.2
400	0.6	0.6	-0.4	-0.8	0.1	-0.8	-0.1	1.3	0.1	-0.1	0.3	0.2
450	1.3	0.3	-0.3	-0.8	0.0	0.5	-0.3	0.8	1.2	-0.4	0.2	-0.1
500	0.7	0.5	-0.1	-0.6	-0.3	0.2	-0.1	0.8	0.6	-0.4	0.3	-0.2
550	0.5	0.4	0.0	-0.5	0.2	0.1	-0.4	0.7	-0.3	-0.2	0.3	-0.2
555	0.9	0.3	-0.1	-0.3	-0.2	0.3	-0.1			-0.3	0.2	-0.2
600	0.2	0.1	-0.1	-0.7	0.4	0.8	-0.2	0.5	0.4	-0.3	0.2	-0.2
650	-0.1	0.0	-0.1	-0.9	0.1	0.6	-0.1	0.4	-0.9	-0.3	0.3	-0.1
700	-0.1	-0.1	-0.1	-0.9	0.0	0.9	-0.2	-0.4	0.1	-0.4	0.3	0.0
750	0.0	-0.1	0.1	-0.9	0.1	-0.3	-0.2	-0.1	-0.1	-0.3	0.5	0.2
800	-0.8	-0.1	0.1	-0.9	-0.1	-0.3	0.0	-0.1	-0.3	-0.5	0.6	0.2
850	-0.4	0.0	0.2	-1.0	0.1	-1.3	-0.1	0.1	-0.3	-0.3	0.8	0.4
900	0.0	0.0	0.0	-1.1		-1.7	0.0	0.3	-0.3	-0.4	0.9	0.5
950	0.0	-0.1		-1.4		-1.2	-0.1	0.2	-0.5	-0.3	0.8	0.4
1000	0.2	-0.1		-1.4		-1.4	-0.1	0.1	-0.4	-0.4	1.0	0.5
1100	-0.5	-0.3		-1.4		-1.2	-0.2	-0.2	-0.5	-0.5	1.4	0.5
1200	0.3	-0.5		-1.5		-0.5	-0.5	-1.2	-1.1	-0.5	1.6	0.3
1300	0.1	-0.4		-2.0		-0.6	-0.5	-1.2	-1.1	-0.9	1.6	0.4
1400	-0.2	-0.8		-2.4		-1.7	-0.5	0.2	-1.1	0.5	1.6	0.5
1500	-0.2	-0.5		-2.5		-1.0	-0.4	-1.5	-1.3	-0.9	1.4	0.5
1600	0.1	-0.2		-2.6		-1.0	-0.3	-1.2	-1.4	-0.6	1.4	0.8
1700	0.1	-0.5		-4.4		-1.1	-0.2	-1.3	-1.9	-0.7	1.6	0.8
1800	0.1	-0.2		-3.5		-1.5	0.0	-0.7	-1.6	0.1	1.9	1.2
1900	-0.4	0.2		-3.1		-1.4	0.0	1.1	-2.6	0.8	1.5	1.0
2000	0.0	0.8		-2.8		-1.1	0.2	0.6	-2.0	-0.4	1.6	1.1
2100	-0.6	0.4		-2.9		-0.4	-0.1	0.1	-2.1	-0.3	1.4	1.1
2200	-0.4	-0.8		-4.5		-0.1	0.4	-1.1	-2.0	-1.3	0.7	0.8
2300	-0.3	0.0				-0.9	0.5	0.1	-1.7	-0.9	0.7	1.2
2400	-0.4	0.8				-1.3	0.3	0.7	-0.5	-0.1	1.4	1.6
2500	0.3	0.7				-2.1	-0.2	6.0	-1.1	-0.1	1.7	1.7

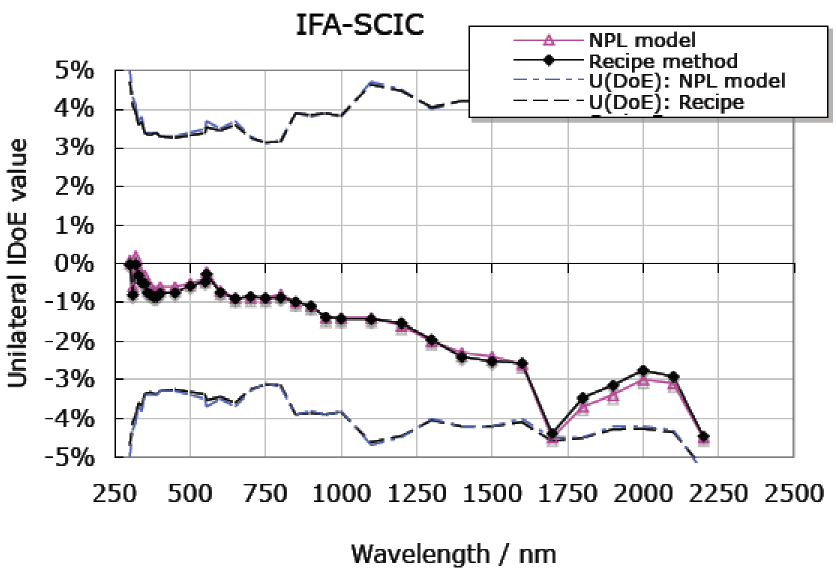
Table C-2. Uncertainty components (at the 95 % level of confidence) of the unilateral Degrees of Equivalence

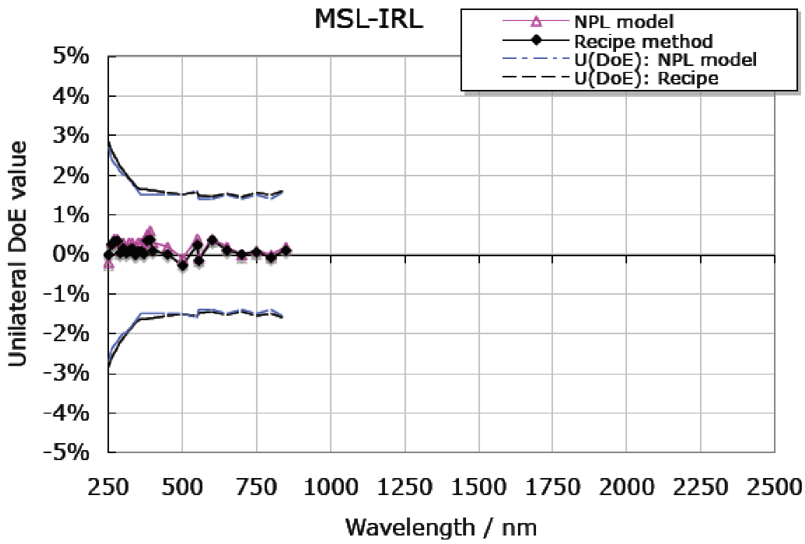
wave-length / nm	BNM-INM	CSIRO	HUT	IFA-SCIC	MSL-IRL	NIM	NIST	NMIJ	NRC	PTB	VNIIOFI	NPL
250		3.8			2.8	2.0	1.9	3.7	6.9	1.5	2.6	4.9
260		2.5			2.6	1.7	1.7	3.5	4.8	1.4	2.0	4.6
270		2.4			2.5	1.6	1.7	3.5	4.1	1.4	1.8	4.4
280		2.2			2.4	1.5	1.6	3.4	3.4	1.4	1.6	3.4
290		2.0	2.9		2.2	1.5	1.5	3.3	2.9	1.3	1.4	2.4
300	3.8	1.8	1.9	4.7	2.1	1.4	1.5	3.3	20.1	1.3	1.4	1.3
310	3.8	1.7	1.7	4.1	2.0	1.3	1.4	3.2	14.2	1.1	1.3	1.3
320	3.8	1.6	1.6	3.9	1.9	1.3	1.3	3.2	12.2	1.1	1.3	1.2
330	2.5	1.5	1.6	3.6	1.8	1.3	1.3	3.2	10.1	1.1	1.2	1.2
340	2.5	1.5	1.6	3.7	1.7	1.2	1.2	3.1	8.1	1.1	1.2	1.2
350	2.5	1.4	1.5	3.4	1.7	1.2	1.2	3.1	6.2	1.1	1.1	1.2
360	2.5	1.4	1.5	3.3	1.6	1.2	1.2	3.1	6.1	0.9	1.1	1.3
370	2.5	1.3	1.5	3.3	1.6	1.2	1.1	3.1	6.1	0.9	1.1	1.4
380	2.5	1.3	1.5	3.4	1.6	1.2	1.1	3.1	6.1	0.9	1.1	1.5
390	2.5	1.2	1.5	3.4	1.6	1.1	1.1	3.1	6.1	0.9	1.1	1.4
400	2.0	1.1	1.3	3.3	1.6	1.1	1.1	3.1	4.2	0.9	1.0	1.3
450	2.0	1.0	0.9	3.3	1.6	1.0	0.9	3.0	4.2	0.8	0.8	0.8
500	1.9	0.9	0.9	3.3	1.5	1.0	0.8	2.8	3.5	0.7	0.8	0.7
550	1.9	0.9	0.9	3.4	1.6	1.0	0.8	2.9	3.5	0.7	0.8	0.7
555	1.9	0.8	0.9	3.5	1.5	1.0	0.8			0.7	0.8	0.7
600	1.9	0.9	0.8	3.4	1.5	0.9	0.7	2.9	3.5	0.7	0.7	0.6
650	1.9	0.9	0.8	3.6	1.5	0.9	0.7	2.9	3.5	0.8	0.7	0.6
700	1.9	1.0	0.8	3.3	1.5	0.9	0.6	3.0	1.7	0.8	0.7	0.6
750	1.9	1.1	0.8	3.1	1.6	0.9	0.6	3.0	1.6	0.8	0.7	0.6
800	1.9	1.1	0.8	3.1	1.5	0.9	0.6	3.0	1.7	0.8	0.7	0.5
850	1.7	1.2	0.8	3.9	1.6	0.9	0.6	3.0	1.7	0.6	0.7	0.5
900	1.7	1.2	0.8	3.9		0.9	0.5	3.0	1.6	0.6	0.6	0.5
950	1.7	1.3		3.9		0.9	0.5	3.1	1.6	0.6	0.7	0.5
1000	1.7	1.3		3.8		0.9	0.5	3.1	1.6	0.6	0.7	0.5
1100	2.0	1.5		4.6		0.9	0.5	3.1	1.5	0.9	0.8	0.5
1200	2.0	1.6		4.5		0.9	0.5	3.1	2.1	0.9	0.8	0.5
1300	2.0	1.7		4.0		0.9	0.5	3.1	2.1	0.9	0.7	0.6
1400	2.0	1.8		4.2		1.0	0.5	3.2	2.2	2.0	0.7	0.6
1500	2.9	1.9		4.2		1.0	0.5	3.2	2.1	2.0	0.8	0.6
1600	2.9	2.3		4.1		1.0	0.5	3.2	2.1	2.0	1.1	0.6
1700	3.0	2.4		4.6		1.0	0.6	3.1	2.7	2.1	1.1	0.7
1800	3.0	3.1		4.5		1.0	0.6	3.2	2.6	2.1	1.2	0.9
1900	3.0	2.8		4.3		1.0	0.6	3.2	3.8	2.1	1.2	1.0
2000	2.0	3.0		4.3		1.0	0.6	3.3	3.2	2.1	1.2	1.2
2100	2.0	3.1		4.4		1.0	0.7	3.4	3.7	2.5	1.2	1.2
2200	2.0	3.1		5.3		1.1	0.7	3.2	4.2	2.5	1.4	1.3
2300	2.1	3.4				1.1	0.8	3.3	4.7	2.5	1.4	1.5
2400	2.1	4.0				1.2	1.0	3.8	5.4	2.5	2.1	2.0
2500	2.2	3.2				1.5	1.3	5.7	8.6	2.5	2.1	2.3

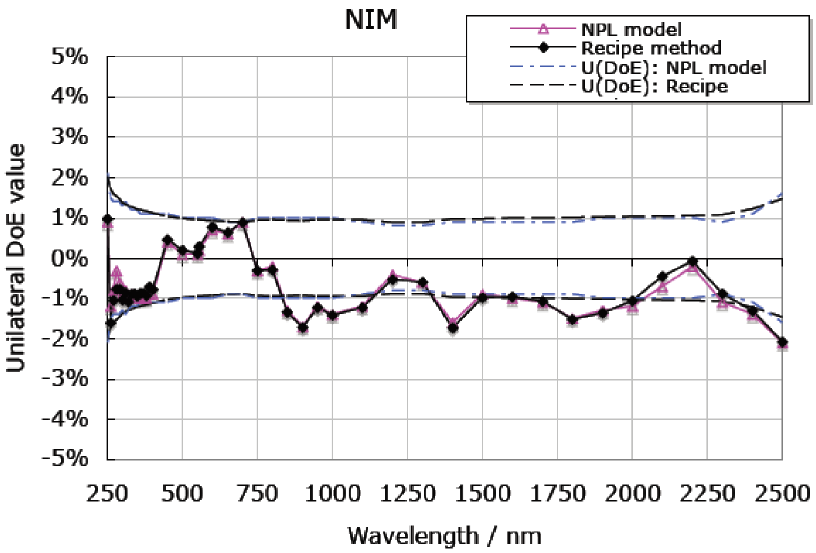

BNM-INM
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
Unilateral IDoE value
Wavelength / nm

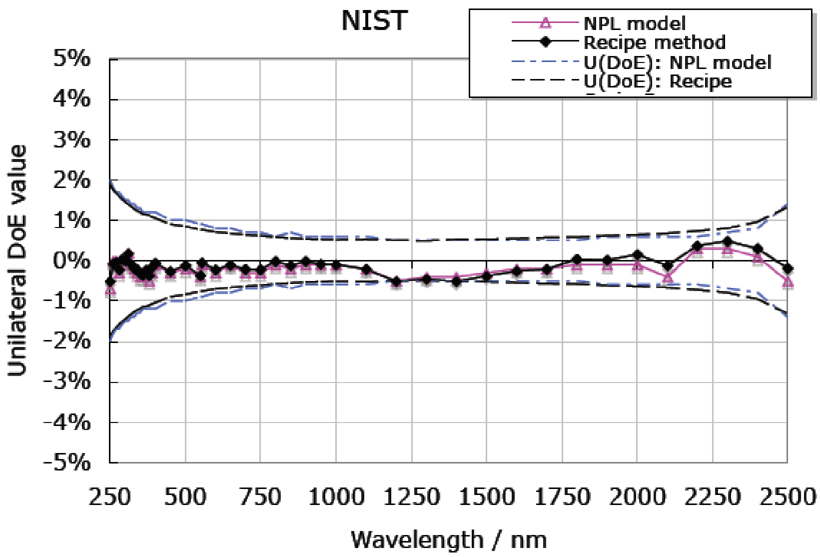

CSIRO
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
Unilateral IDoE value
Wavelength / nm

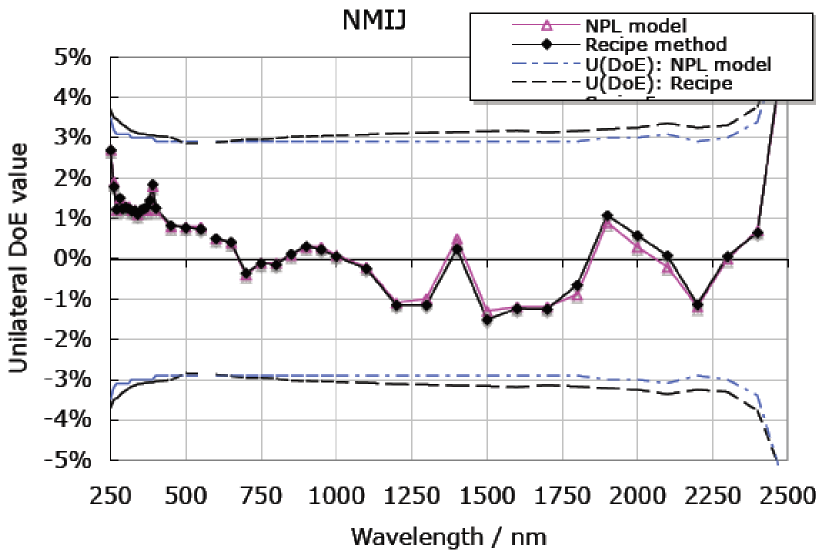

HUT
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
Unilateral IDoE value
Wavelength / nm


IFA-SCIC
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
Unilateral lDoE value
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
250 500 750 1000 1250 1500 1750 2000 2250 2500
Wavelength / nm


MSL-IRL
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
Unilateral DoE value
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
250 500 750 1000 1250 1500 1750 2000 2250 2500
Wavelength / nm


NIM
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
Unilateral DoE value
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
250 500 750 1000 1250 1500 1750 2000 2250 2500
Wavelength / nm


NIST
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
Unilateral DoE value
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength / nm


NMIJ
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
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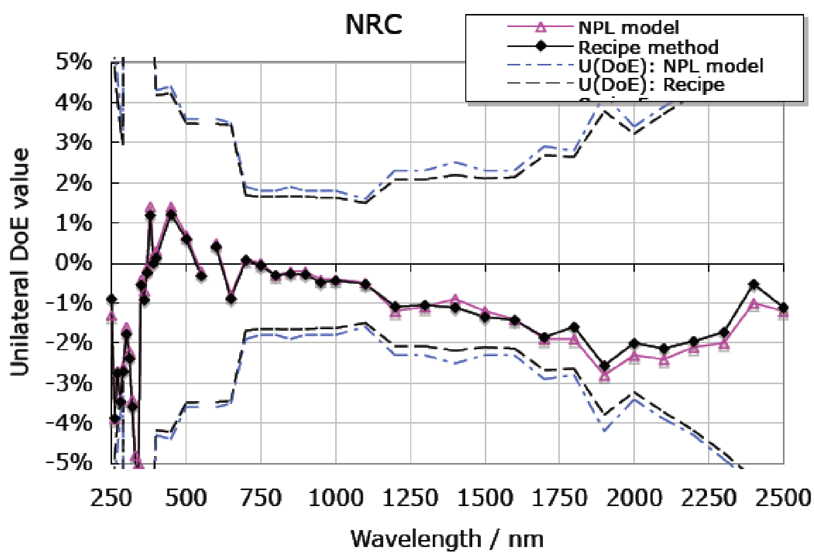
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
Unilateral DoE value
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength / nm


NRC
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
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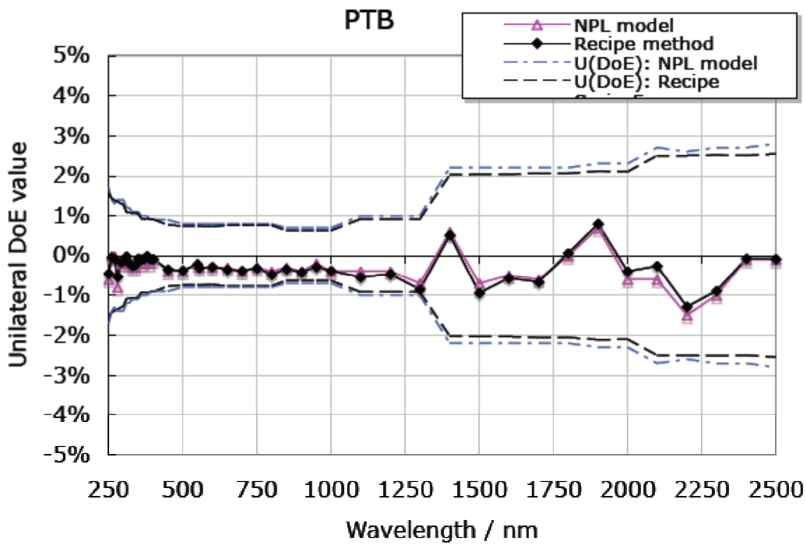
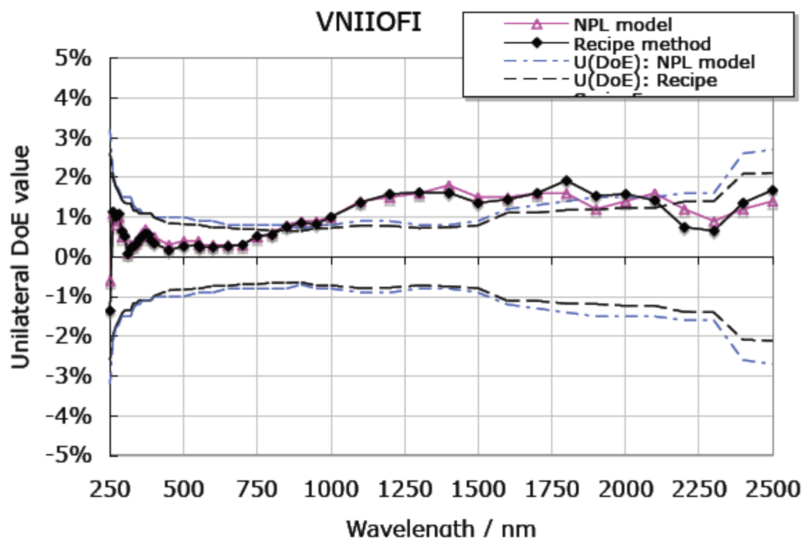
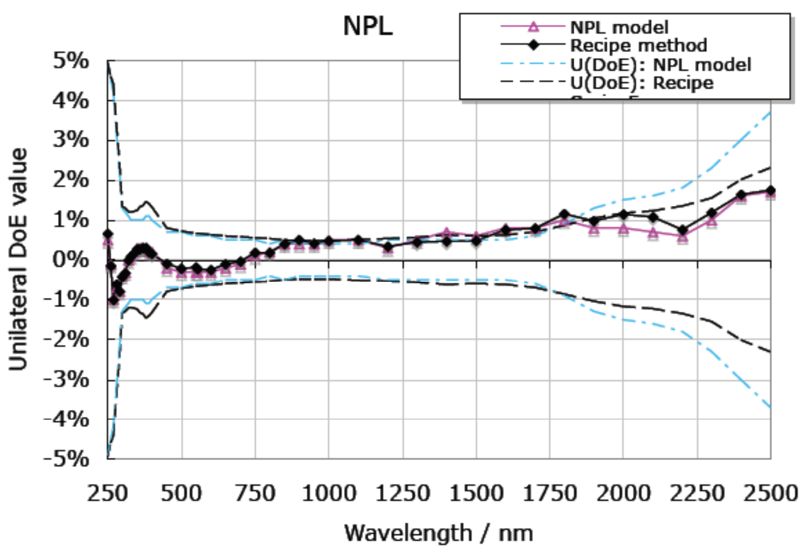
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
Unilateral DoE value
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength / nm


PTB
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
Unilateral DoE value
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
250 500 750 1000 1250 1500 1750 2000 2250 2500
Wavelength / nm


VNIIOFI
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
Unilateral DoE value
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
250 500 750 1000 1250 1500 1750 2000 2250 2500
Wavelenath / nm


NPL
NPL model
Recipe method
U(DoE): NPL model
U(DoE): Recipe
Unilateral DoE value
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
250 500 750 1000 1250 1500 1750 2000 2250 2500
Wavelength / nm