

The CCPR K1-a Key Comparison of Spectral Irradiance 250 – 2500 nm: Measurements, Analysis and Results

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Abstract. The CCPR K1-a Key Comparison of Spectral Irradiance (250 – 2500 nm) was carried out to meet the requirements of the Mutual Recognition Arrangement (MRA) by 13 participating National Measurement Institutes (NMIs). The comparison artefacts were tungsten halogen lamps and because of the fragile nature of these lamps the comparison was arranged as a star comparison. The National Physical Laboratory (NPL) acted as pilot for the comparison and, by measuring all lamps, provided the link between measurements made by different participants. The comparison was analysed using a model-based method, which was able to ensure that all participants, including the pilot, were treated equitably. This paper presents the comparison philosophy, methodology, analysis and the results.

Comparison philosophy

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 for organising the key comparison and writing the Technical Protocol in discussion with a working group comprising representatives of NPL, NIST (USA) and PTB (Germany). NPL 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 [1].

In addition to NPL, 12 other NMIs participated in the CCPR K1-a Key Comparison. These were BNM-INM (France), CENAM (Mexico), CSIRO (Australia), HUT (Finland), IFA-CSIC (Spain), MSL-IRL (New Zealand), NIM (China), NIST (United States of America), NMIJ (Japan), NRC (Canada), PTB (Germany) and VNIIOFI (Russian Federation).

Because of the fragile nature of lamps, the comparison was organised as a star comparison. Each 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 participant was asked to make measurements also on two occasions. Some participants were only able to measure a lamp once.

The key comparison was designed to include redundant measurements 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 would be 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 would be expected that averaging multiple measurements would reduce the uncertainties associated with the comparison itself.

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 of “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. These lamps consist 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, which 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.

Measurements

Measurements were made between the years 2000 and 2004. All lamp measurements by the pilot were measured directly against NPL’s primary spectral irradiance scale using the high temperature blackbody as a reference source [2,3]. In addition, reference lamps were measured at NPL in order to determine and ensure stability of the reference scale. The comparison scale was maintained on a set of FELs regularly calibrated during the comparison.

All other participants calibrated their lamps with respect to their primary spectral irradiance scales. The methods used to realise the primary scale varied considerably between participants. Many participants base their primary scale on high temperature blackbodies, using radiometric or ITS-90 methods for determining the temperature; others measure the spectral irradiance of lamps using filter radiometers. NRC base part of their scale on the World Mean as represented by the 1975 comparison and MSL-IRL obtained traceability directly from NIST. Otherwise all the different realisations can be considered independent.

Discussion process

The participants supplied a full description of their measurement process and a detailed uncertainty statement. These uncertainty statements were discussed by all participants, and in some cases changed, prior to the final analysis and the publication of any results in the comparison Draft A report. This process, which lasted several months following completion of the measurements, ensured that the final data set was as reliable as reasonably possible.

Analysis

The fundamental outcomes of a key comparison are the degrees of equivalence (DoEs). These include a unilateral DoE for each NMI, concerning the deviation of a measurement made by the NMI from a key comparison reference value (KCRV), and bilateral DoEs for each pair of NMIs, concerning deviations between measurements made by the NMIs. In this case the DoEs 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 unilateral DoE. 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, as dictated by the protocol.

The analysis was based on a model that assumes that each lamp has a stable spectral irradiance and that the measurements made by an NMI are systematically influenced by a factor that applies 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 factor. The aim of the analysis was to determine an estimate of the systematic factor for each NMI. This aim was met 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 a 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 an 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 model has been described elsewhere [4] and is a

development of a method suggested by White [5].

Lamp behaviour

Before the analysis was completed, the pilot discussed with each participant individually which of the pilot’s and participant’s lamp measurements should be included as representative of the comparison between the pilot and that participant. For this process, the difference between first and second measurements made by the pilot and first and second measurements made by the participant were compared with the uncertainties associated with random effects associated with the pilot’s or participant’s measurements, respectively. As a consequence of this comparison approximately one third of the lamps had at least one measurement rejected because of changes due to transportation.

The comparison thus highlighted the difficulty facing the user community with respect to dissemination and the availability of suitable transfer standards for spectral irradiance. Whilst the use of multiple lamps allowed sufficient redundancy to ensure that all participants had a satisfactory representation, it is noticeable that overall it is the lamps’ stability that has limited the uncertainty with which this comparison was carried out.

Results

At the time of submission of this abstract the results are still confidential to the participants but it is anticipated that they will be approved and available in time to be fully reported at NEWRAD.

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