Advancements in NRC's Primary Spectral Irradiance Scale Realisation

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The primary spectral irradiance scale at the National Research Council (NRC) Canada has transitioned from a detector-based approach in the range of 700 nm to 1600 nm to a detector and source-based realisation from 250 nm to 2500 nm. A high temperature blackbody (HTBB) is now the primary light source for the calibration of FEL spectral irradiance standard lamps. The thermodynamic temperature of the HTBB is measured using an NRC-designed wide-band filter radiometer, with spectral responsivity traceable to the NRC optical power scale. The design of the NRC spectral irradiance facility, measurement procedure, and uncertainty analysis will be discussed.

INTRODUCTION

Over the past decade, the National Research Council (NRC) Canada has been developing a new facility for a source and detector-based primary realisation of the spectral irradiance scale [1]. The previous scale for spectral irradiance measurements from 250 nm to 2500 nm at NRC was a composite of three sources of traceability in different wavelength regions. In the spectral range of 300 nm to 700 nm, the scale was maintained on 500 W quartz-halogen lamps calibrated using the CIE World Mean of 1975 scale. From 250 nm to 300 nm and from 1600 nm to 2500 nm, the scale was traceable to FEL lamps purchased from the National Institute of Standards and Technology in the United States. In the near infrared range from 700 nm to 1600 nm, NRC realised the spectral irradiance scale by using interference filters and absolute radiometers to calibrate tungsten-halogen lamps [2]. NRC now has a spectral irradiance facility equipped with a high temperature black body (HTBB) which is implemented as a primary light source. The thermodynamic temperature of the HTBB is measured using a wide-band filter radiometer [3], which has a spectral responsivity calibration traceable to the NRC cryogenic radiometer, giving a source and detector-based spectral irradiance scale realisation (Fig. 1).

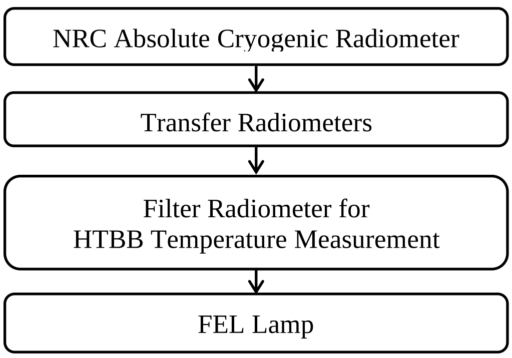

Figure 1. Optical radiation traceability chain for the NRC spectral irradiance scale.

SPECTRAL IRRADIANCE FACILITY

A simplified diagram of the NRC primary spectral irradiance measurement facility is shown in Figure 2. The HTBB in this facility is model BB3500M, manufactured by VNIIOFI, Russia. Two FEL lamp stations and the HTBB are installed on separate optical tables. The filter radiometer and monochromator system are installed on a third optical table equipped with a rail and lead screw system as well as a linear encoder which facilitates two metres of translation. A custom software program enables the automatic positioning of different sources and detectors: alignment positioning of the HTBB and filter radiometer, the HTBB and monochromator, and of the FEL lamps and monochromator. For spectral data collection, a single grating, one metre focal length, monochromator was used with various combinations of two diffraction gratings (blaze of

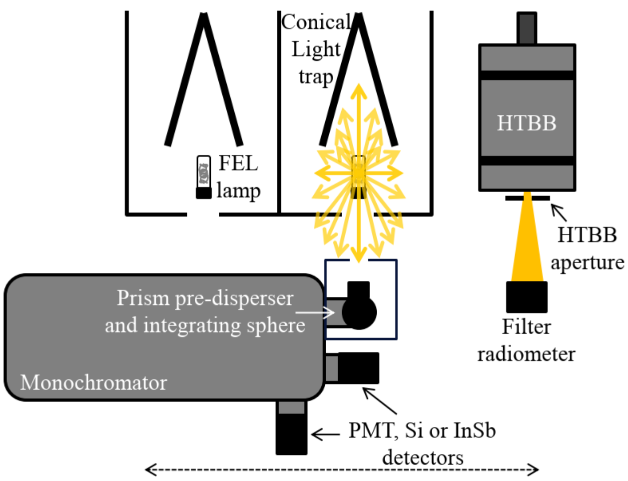

Figure 2. Schematic diagram of the NRC primary spectral irradiance facility.

400 nm or 2700 nm) and three photodetectors (photomultiplier tube (PMT), Si, and InSb detectors) to cover the range of 250 nm to 2500 nm.

MEASUREMENT PROCEDURE

The irradiance of the HTBB depends on its thermodynamic temperature as well as several geometric factors:

$$\boldsymbol{E_{\lambda,HTBB}} = \left(\frac{\pi r_{HTBB}^2}{(d^2+r_{FR}^2+r_{HTBB}^2)}\right) \times \left(\frac{2\varepsilon hc^2}{\lambda^5 n^2 e^{hc/_{n\lambda kT}}-1}\right) (1)$$

where T is the thermodynamic temperature of the HTBB, r_{HTBB} and r_{FR} are the radii of the HTBB and filter radiometer precision apertures, d is the distance between these apertures, ε is the HTBB emissivity, h is the Planck constant, c is the speed of light, n is the refractive index of air, and k is the Boltzmann constant. For spectral irradiance measurements, the HTBB is operated at a temperature of 2950 K. The first step of the measurement procedure is the determination of T using the wide-band filter radiometer. The monochromator system is then implemented to collect spectral data from the HTBB output. T is then measured a second time to verify temperature stability of the HTBB. Spectral data from an FEL lamp is then collected using the monochromator system. The spectral irradiance of an FEL standard lamp, $E_{\lambda,FEL}$, at a given wavelength λ, is then determined using the equation:

$$E_{\lambda,FEL} = E_{\lambda,HTBB}\frac{S_{\lambda,FEL}}{S_{\lambda,HTBB}} \qquad (2)$$

where $S_{\lambda,FEL}$ and $S_{\lambda,HTBB}$ are the measured FEL lamp and HTBB photodetector signals from the monochromator system.

MEASUREMENT UNCERTAINTIES

The total uncertainty for the calibration of FEL standard lamps depends on the uncertainties in the scale realisation as well as in the lamps spectra and electrical current measurements. The majority of the uncertainties in the scale realisation rely on the determination of T, which have been most recently discussed in Ref. 4. A similar approach to uncertainty evaluation is taken in this work, where a sensitivity coefficient is used to convert the relative value of each uncertainty component to an uncertainty in T. Relative values of the filter radiometer calibration, r_{FR}, d, r_{HTBB}, HTBB radiance uniformity, HTBB emissivity, and n [5] are taken into account. For the FEL lamp measurements, the lamp to monochromator

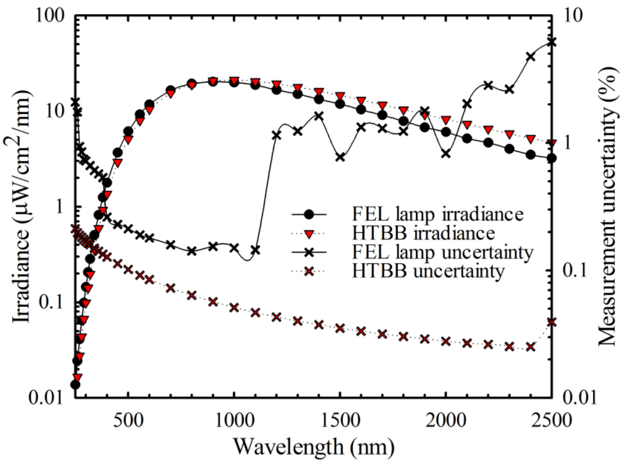

Figure 3. Measured FEL lamp (1000 W) and HTBB (2950 K) irradiance data with associated uncertainties (k=1).

distance, current stability as well as repeatability and reproducibility of the spectral measurements are considered. Spectral irradiance data for the HTBB at 2950 K and for a 1000 W FEL lamp, as well as their associated uncertainties, are shown in Figure 3.

SUMMARY

NRC now has a complete primary spectral irradiance scale from 250 nm to 2500 nm. A HTBB is implemented as a standard radiometric source and an NRC-designed filter radiometer, with spectral responsivity traceable to the NRC absolute cryogenic radiometer, is utilized to measure the thermodynamic temperature of the HTBB. This source and detector-based realisation will be the basis for calibrating 1000 W FEL spectral irradiance standard lamps.

REFERENCES

1. A. A. Gaertner, Spectral irradiance calibrations at the National Research Council of Canada (NRC), Journal of Modern Optics, 56, 1488-1496, 2009.
2. 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.
3. L. P. Boivin, C. Bamber, A. A. Gaertner, R. K. Gerson, D. J. Woods, and E. R. Woolliams, Wideband filter radiometers for blackbody temperature measurements, Journal of Modern Optics, 57, 1648-1660, 2010.
4. E. R. Woolliams, *et. al.*, Thermodynamic temperature assignment to the point of inflection of the melting curve of high-temperature fixed points, Philosophical Transactions of the Royal Society A, 374, 20150044, 2016. (Supplementary Material)
5. A. A. Gaertner, Consultative Committee for Thermometry Working Document CCT/10-11 (2010). https://www.bipm.org/cc/CCT/Allowed/25/D11_CCTdraftAAG.pdf.