RADIOMETRIC TRACEABILITY AT NEW ZEALAND'S NMI AND ITS TRANSFER TO RESEARCH AND INDUSTRY USERS

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Abstract: The Measurement Standards Laboratory (MSL) is New Zealand's national metrology institute and is operated by Industrial Research Ltd (IRL). As such, it ensures that traceable measurements and calibrations are available for all users of measurements in New Zealand. This paper outlines how MSL realises and maintains its radiometric scales, and how these scales are traceably disseminated. The paper describes the development of MSL's scale of detector spectral responsivity from the ultraviolet to the near infrared and its maintenance on, and dissemination from, novel 5-element silicon photodiode trap detectors. Emphasis is given to the improvements made in the scale of spectral irradiance, the accuracy of which has improved in the ultraviolet region from 6 % to the current 2.3 %.

1. INTRODUCTION

Small national metrology institutes (NMIs) and calibration laboratories often rely on scales traceable to some other institute and, in the case of radiometric measurement scales, this can result in the degradation of the scale available to second- and third-tier users. This is often problematic in broadband detector based measurements, such as photometry and filter radiometry, and in source based measurements, such as solar spectral irradiance.

The Measurement Standards Laboratory (MSL) is New Zealand's NMI and as such realises and maintains scales of physical measurements encompassing the seven base units of the *Système International d'Unités* (SI), which includes the candela. Within the area of radiometry we have developed our own scales of absolute radiometry and detector spectral responsivity traceable to our cryogenic radiometer, and we maintain a lamp-based scale of spectral irradiance. These scales cover both detectors and sources of light and are maintained not only through the visible but also in the near infrared (NIR) and ultraviolet (UV) spectral regions.

2. NEW ZEALAND'S RADIOMETRIC MEASUREMENT SCALES

2.1 Absolute radiometry and detector spectral responsivity

Absolute radiometric measurements of optical power are made using an Oxford Instruments cryogenic radiometer [1] and coherent, vertically polarized, monochromatic radiation provided by krypton and argon lasers from 351.1 nm to 752.5 nm. These measurements of laser power are accurate to 0.016 % [1] at visible wavelengths, and rely on a well defined and stable laser beam. At MSL it is common practice to transfer these absolute measurements of optical power onto Hamamatsu S1337-11 photodiodes in a 5-element trap configuration (Figure 1) [2].

The first advantage of the 5-element geometry lies in the minimisation of the reflectance loss through to the ultraviolet [3]; indeed, the reflectance loss at 370 nm for the 5-element trap is of the order of 0.13%, compared to 2.4% for the 3-element trap and 46 % for a single photodiode (Figure 2). This minimisation of reflectance loss results in a more linearly varying response function, which extends below 300 nm. Secondly, the geometry of the configuration has been optimised to provide a total path length no greater than 120 mm and a numerical aperture of f/6.2. This extends the usefulness of this configuration to both collimated and non-collimated sources of light, although care must be taken to avoid vignetting

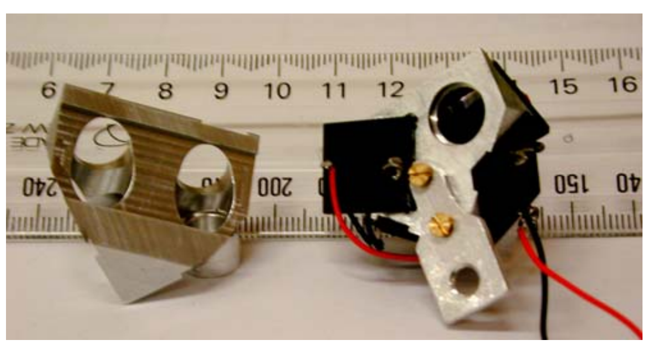

Fig. 1. *5-element trap detectors.*

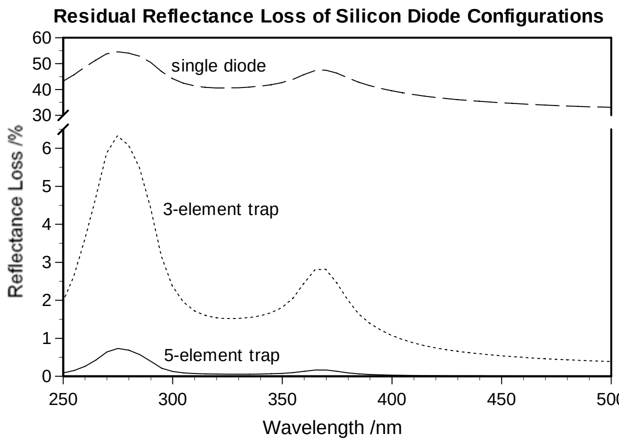

Fig. 2. *Modelled specular reflectance loss for single, 3- and 5-element configured Hamamatsu S1337-11 silicon photodiodes [2]. Calculations were made for a 30 nm silicon oxide layer and fitted to measurements at laser wavelengths in the UV and visible.*

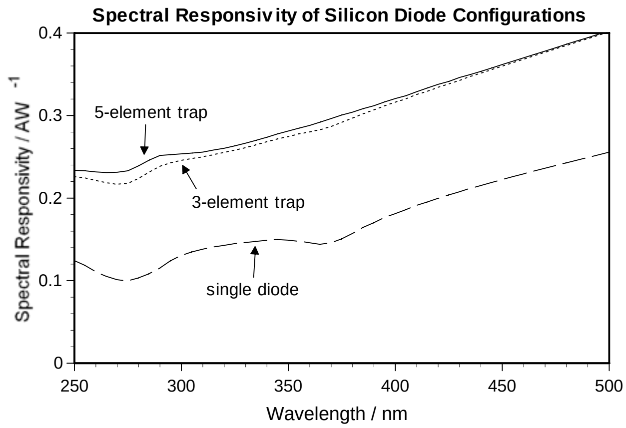

Fig. 3. *Determined spectral responsivity of single, 3- and 5-element configured Hamamatsu S1337-11 silicon photodiodes.*

effects in the latter case [4]. The combination of these characteristics makes the 5-element trap an optimal solution for detector based scales from the UV to the NIR.

Using the measured responsivity, $R(\lambda)$, of the 5-element trap detectors and their measured residual specular reflectance, $\rho(\lambda)$, corresponding values of internal quantum efficiency (IQE), $\varepsilon(\lambda)$, may be determined for each laser wavelength:

$$\varepsilon(\lambda) = \frac{R(\lambda)}{\left[1-\rho(\lambda)\right]}\frac{hc}{\lambda e}\,. \qquad (1)$$

Using these derived IQE values, a model may be fitted to obtain the continuous IQE values [5]. This model of IQE, in conjunction with measured and modelled values of spectral reflectance of the 5-element trap, is then used to obtain the spectral response through the visible and NIR regions (Figure 3). This results in a scale accurate to within ±0.04 % within the region where laser wavelengths are available, increasing in regions where the model is extrapolated (±0.06 % at 440 nm and up to ±0.12 % at 900 nm) [6].

Below 440 nm, where the model is less accurate and measurements are more difficult, our scale is determined by comparison with a flat pyroelectric detector (flat to ±0.2 % over this spectral range) and scaling of the relative response of the detector with the known responsivities in the visible region. This UV scale is accurate to ±0.5 % at 240 nm improving to ±0.3 % above 260 nm.

The scale of detector spectral responsivity is transferred onto other detectors through a high accuracy spectrophotometer (f/10), using deuterium, xenon arc and tungsten sources, and bandwidth no smaller than 1.6 nm. Transfer to similar devices (i.e. metrology grade trap detectors) through this system can be achieved with accuracies of ±0.08 % from 440 nm to 600 nm with decrease in accuracy in the UV to ±0.36 % at 250 nm. The transfer accuracy is, of course, dependent upon the devices under calibration and will be influenced by characteristics such as wavelength dependency, spatial uniformity, and inherent spectral responsivity.

2.2 Spectral irradiance

Spectral irradiance standards are commonly used to calibrate spectroradiometers for their spectral irradiance responsivity (A.nm.m^2/W). These are used in a variety of measurements, such as lamp colour temperature and solar irradiance monitoring. In New Zealand we maintain a scale of spectral irradiance on a set of 1 kW tungsten halogen lamps traceable to NIST [7] in the USA.

Until recently, this scale was disseminated using a commercially available spectroradiometer. This method of transfer resulted in a degradation in the accuracy of the scale at 250 nm to ±6 %. This was due to several reasons, including temporal instability of the instrument, wavelength accuracy and signal-to-noise ratio.

We have developed a dedicated and well characterised spectral irradiance calibration facility currently operating over the wavelength range of 250 nm to 850 nm. The system is based upon a McPherson

0.35 m double monochromator with a photomultiplier tube (type EMI 9130QA/350) as the detector (Figure 4). In establishing this system two options for input optics to the monochromator were investigated: a flat diffusing plate and an integrating sphere, both made using compressed halon (PTFE) powder and able to be aligned alternately between the two sources being compared using a rotating table (to within ±0.05° of the required alignment). The diffusing plate was chosen as the input optic over the integrating sphere method so as to maximise the signal-to-noise ratio at the shorter wavelengths (200:1 for the sphere compared to 150:1 for the plate at 250 nm) for lamp calibrations requiring a relatively narrow bandwidth (no less than 2 nm).

The scale transferred from MSL using this method is accurate to ±2.3 % at 250 nm improving to ±1.3 % at 400 nm, only slightly degrading the original scale transferred from NIST. This improvement in capability is of particular benefit to the atmospheric research community, who have been monitoring the solar UV levels in New Zealand over the past 20 years.

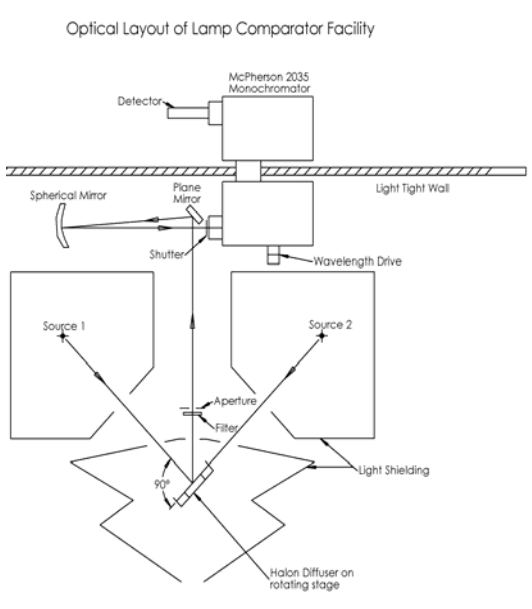

Fig. 4. *Schematic of the MSL spectral irradiance calibration facility. Each source is mounted normal to the rotating halon diffuser with the diffuser at 45° to the entrance optics of the monochromator. In the case of the integrating sphere method the sphere replaces the diffuser with its exit port normal to the entrance optics of the monochromator. The entrance port of the sphere is at 90° to the exit port; the sphere rotates 180° about the entrance optics' axis. The Source 1 and 2 positions are located either side of the sphere normal to the entrance port.*

3. MEASUREMENT TRACEABILITY

Traceability is a property of a measurement demonstrating that it is an accurate representation of the measurand in terms of the SI. To demonstrate traceability the supplier of a calibration or piece of equipment must be able to guarantee an unbroken chain of calibrations back to the SI and that the supplier has been externally assessed to perform the relevant calibration procedures.

As the NMI for New Zealand, MSL demonstrates that the traceability of our scales is maintained when disseminated from our laboratory by accreditation to ISO 17025. This is also supported by participation in international comparisons of our measurement capabilities. Indeed, over the past thirteen years MSL has taken part in international comparisons of all the aforementioned radiometric scales, including a comparison of detector spectral responsivity CCPR K2b [6], cryogenic radiometers CCPR S3 [8] (Figure 5), and spectral irradiance CCPR K1a [9] (Figure 6).

The impact of traceable measurements is recognised both internationally and nationally in, for example, the move toward traceability for all climate data [10]. The underlying need in this case is for reliable data, both spatially and temporally, when making decisions relating to climate change, as has been the case in the programme of UV monitoring in New Zealand over the past 20 years.

On a more local note, a New Zealand manufacturer of UV water disinfection systems required accurate measurements of the irradiance of medium pressure mercury lamps. The UV radiometer used to measure

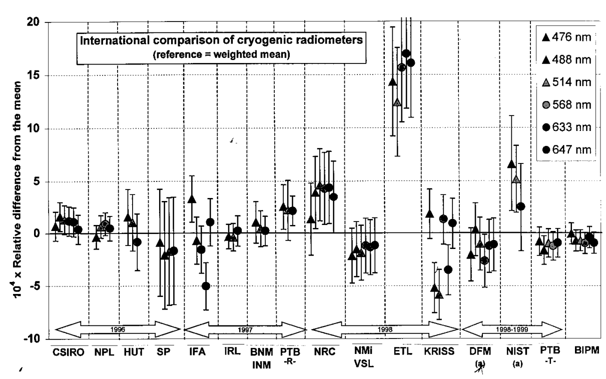

Fig. 5. *Results of the comparison of cryogenic radiometers, CCPR S3. MSL participated in the comparison under the name of its parent company IRL.*

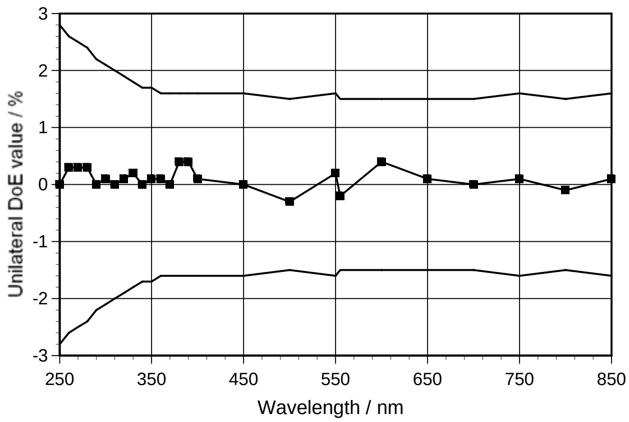

Fig. 6. *International Comparison results CCPR-K1a, spectral irradiance for MSL. The graph shows the unilateral degree of equivalence for the laboratory over the spectral range measured. The upper and lower curves denote the uncertainties for the degree of equivalence (DoE) [9]*

the lamps indicated the output of the lamps was lower than required for the application. The manufacturer decided to have the radiometer recalibrated in spite of its having a current “traceable” calibration from its supplier. The meter was not only found to be measuring 30 % low in terms of irradiance, but also had cosine response to ±5° not the ±60° required. This example highlights the need for users of turn-key measurement solutions to verify the claims of manufacturers that measurements made by their equipment are traceable.

4. CONCLUSIONS

At MSL the radiometric scales of spectral irradiance and detector spectral responsivity are maintained at the highest level of accuracy. These scales are disseminated traceably to second- and third-tier users, and confidence in the dissemination is supported by participation in the key comparisons of the CCPR.

Through the new lamp comparator facility developed at MSL our NIST traceable scale, held on a set of 1 kW tungsten lamps, can be disseminated at accuracies of ±2.3% at 250 nm close to those of the original scale, ±1.8% .

In addition, the characteristics of 5-element traps (spatial uniformity and approximately linear response function above 300 nm) and the accuracy in their calibration makes them an ideal reference upon which to hold and maintain the scale of detector spectral responsivity; this would be of particular interest to NMIs with no access to a cryogenic radiometer.

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Note: all measurements uncertainties are expanded uncertainties at the 95 % confidence level.