A COMPARISON OF ITS-90, ABOVE THE SILVER POINT, AS REALISED BY NIST AND NPL

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ABSTRACT

A comparison of the radiance temperature scales between 1000 °C and 2700 °C has been performed between the National Physical Laboratory (NPL) and the National Institute of Standards and Technology (NIST). Two transfer radiation thermometers, of identical design, were prepared by NPL for the comparison. These each had a silicon photodiode detector, a spot size of 2.8 mm at 620 mm and a nominal operating wavelength of about 1000 nm. The characterisation included determination of the instrumental size of source effect, system temperature coefficient and calibration. After characterisation the devices were transported to NIST in October 1998, and calibrated using the NIST radiance temperature calibration facility. In addition, whilst at NIST, the spectral response for one of the instruments was measured.

On return to NPL the devices were re-calibrated to determine the extent of any drifts that transportation might have caused.

It was established that the ITS-90 radiance temperature scales as realised by each institute were in agreement to <0.05 % of temperature.

This paper describes the instruments used for the comparison, the realisation of scales by the two laboratories and the comparison results.

1. INTRODUCTION

The reliable realisation and dissemination of the ITS-90 [1] above the silver point is required in many sectors of industry (for example space, iron and steel, glass production). Because of this it is essential that the various realisations of the ITS-90 by National Measurement Institutes (NMIs) are demonstrably equivalent within the uncertainties of the realisation. The purpose of this work was to ensure that this was the case for the ITS-90 radiance temperature scales, as realised by NPL and NIST. This work is, in effect, a continuation of an initial comparison reported by Machin *et al* [2] and complements the comparisons performed by Sakuma [3, 4].

In this comparison two quasi-identical silicon photodiode based radiation thermometers were evaluated and calibrated by NPL. These were hand carried to, and subsequently calibrated by, NIST. They were then returned to NPL and their calibration checked to ensure that no drifts had occurred.

This paper briefly describes the equipment used in the scale realisation, the transfer instruments, the tests and calibration of the transfer instruments and the results.

2. THE TRANSFER STANDARD THERMOMETERS

Two transfer thermometers were calibrated and assessed for the purposes of the comparison. These were of identical design as described by Machin *et al* [5]. In brief the thermometers were modified versions of a commercial Cyclops 52* (supplied by Land IR, UK). They have a nominal target size of 2.8 mm at a target distance of about 620 mm. The spectral response was limited by a cut-on filter at short wavelengths, the longer

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* Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

wavelength end being limited by the cut-off in detector response. The thermometers are designated M1C52 and M2C52.

3. RADIANCE TEMPERATURE SCALES

The NPL radiance temperature scale has been described elsewhere [6, 7]. The scale is derived from a primary reference gold point blackbody [8]. This is used to calibrate a linear pyrometer (LP2) [9]. The scale is then disseminated using a graphite blackbody [10] as a transfer source, the LP2 being used to determine the temperature. For these measurements the LP2 was operated at 906 nm.

The NIST radiance temperature scale is described in detail by Gibson *et al* [11]. As at NPL the scale is derived from a gold point blackbody. The NIST primary photoelectric pyrometer is used to assign a temperature to a Quinn and Lee cylindrical envelope tungsten ribbon lamp [12] held at approximately 1256 °C. The scale is then transferred from the lamp to a variable temperature blackbody using the NIST pyrometer.

The graphite blackbody cavities used by NIST and NPL are now of identical design: this was not the case in the comparison reported in [2].

4. ASSESSMENT OF THE TRANSFER STANDARD THERMOMETERS

To obtain the best performance from the transfer instruments it is essential that they are properly characterised. For both thermometers the optimal focal distance, the size of source effect and the temperature coefficient were determined. The spectral response was obtained for M1C52 only.

The thermometers were designed to have a nominal fixed focus of 620 mm. However the actual focal distance could differ from this due to the non-ideal performance of the optical components and system. The actual focal distance was determined using the following procedure. The thermometer was mounted on an xyz translation stage on a rigid optical bench and focused on the centre of a 0.75 mm aperture placed in front of a high temperature blackbody cavity at approximately 1700 °C. The thermometer was then withdrawn 100 mm from the nominal focal position of 620 mm. It was then translated across the 0.75 mm aperture in steps of 1 mm, the signal being measured at each step, until the output fell to the background level. The thermometer was then moved forwards by 10 mm and the translation across the aperture repeated. This procedure was repeated until the thermometer was approximately 100 mm in front of its nominal focal position. The scans produced a series of bell curves (some double humped when well away from the optimum focal position) the narrowest of which indicated the best focal position. For the M1C52 this was at 615 mm and for M2C52 this was at 630 mm.

The output of a thermometer depends upon its intrinsic temperature. This is because optical components such as filters, electronic components such as amplifiers and particularly the detector itself can be temperature sensitive. Both the standard Cyclops 52 and these modified versions have built-in temperature compensation; measurements were undertaken to determine the efficacy of that correction.

The modified thermometer has an in-built temperature sensor. Flexible tubing was wrapped around the thermometer, which was then encased in a layer of insulation. The flexible tubing was connected to a thermostatted water circulator. The thermometer was focused and aligned on the front aperture of the sodium heatpipe cavity [13] at a nominal temperature of 1000 °C. The water circulator was turned to 10 °C. The output of the internal temperature sensor was monitored until it reached stability, then a reading by the thermometer was taken. The water temperature was increased by about 3 °C. This procedure was repeated over the range 10 °C to 27 °C. It was found, for both thermometers, that their signal changed by about 0.05% per °C. All readings reported in this paper have been corrected to a nominal temperature of 24.0 °C.

The size of source effect (SSE) [13] was determined in the following manner. A large area sodium heat-pipe blackbody cavity was set to nominally 1000 °C. A water cooled plate was placed in front of the cavity. This enabled blackened apertures of diameters ranging from 2.5 mm to 30 mm to be placed in turn in front of the furnace. The thermometers were, in turn, placed at their optimal focal distance from the apertures and aligned so as to view the centre of the aperture. For each aperture size the SSE was determined by measuring the thermometer output, correcting for background signal and any small drifts in blackbody radiance and dividing the result by the output at the largest aperture. The measurements were repeated four times for each aperture. The average results for thermometer M1C52 are given in Figure 1. The relative expanded uncertainty (k=2) for the determination is 0.01% or less.

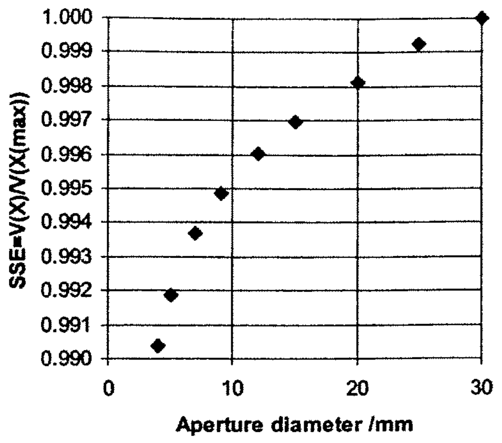


Figure 1: SSE of M1C52

The spectral response was determined for the M1C52. The instrument was mounted, at its optimum focal distance, inside the NIST visible/near IR Spectral Comparator Facility [14]. The facility contains a source, prism-grating monochromator, fore and aft optics, and standard detectors. With a bandwidth of about 4 nm, the wavelength of the monochromator was set to values from 350 nm to 1400 nm with a step size of 5 nm. The response of the M1C52 was recorded along with that from a monitor photodiode. Next, the working standards were measured; the absolute spectral flux responsivity for the standards is derived using an absolute cryogenic radiometer. The field-of-view of the M1C52 was not completely filled by the beam from the monochromator aft optics. The resulting relative spectral responsivity was used to determine the mean effective wavelength. The values were 991.5 nm at 1000 °C and 981.5 nm at 2700 °C with a bandwidth of 143 nm.

5. CALIBRATION PROCEDURES

5.1 CALIBRATION AT NPL

Both instruments were calibrated at NPL at every 100 °C between 1000 °C and 2700 °C. Each instrument had two ranges: 1000 °C to 2000 °C and 2000 °C to 2700 °C. The upper range is accessed by fitting a reflecting neutral density filter to the front of the thermometer. The data from each range was then fitted with a three term empirical Wien function [15].

Table 1: Results of fit to NPL reference calibration data set

Instrument	Temperature range /°C	rmsd^x /°C
M1C52	1000 to 2000	0.12
M1C52	2000 to 2700	0.23
M2C52	1000 to 2000	0.09
M2C52	2000 to 2700	0.09

^{x}root mean square deviation

5.2 CALIBRATION AT NIST AND REPEAT CALIBRATION AT NPL

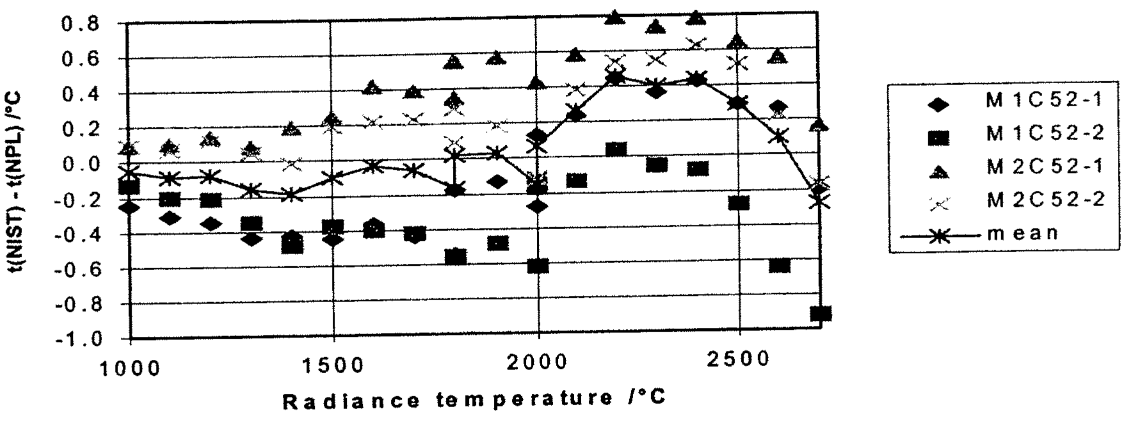
Both instruments were calibrated at NIST over the same temperature range as at NPL. The main difference between the NPL and the NIST calibration was the wavelength of the primary pyrometer: at NIST the pyrometer wavelength was 655 nm whilst at NPL it was 906 nm. However, as both the NPL and NIST blackbody cavity design are nominally identical and their measured emissivity is high, 0.998±0.002 (standard uncertainty), no correction for the emissivity is performed.

On return to NPL the calibration was repeated to determine the extent of instrumental drift during the comparison. The interval between the first calibration at NPL and the re-calibration at NPL was less than 6 weeks.

6. RESULTS OF THE COMPARISON AND DISCUSSION

The results of the comparison are given in Figure 2. These are relative to the initial NPL calibration. The average of the result t(NIST) - t(NPL) is given along with the four individual data sets.

Figure 2: Comparison result t(NIST) - t(NPL)
October 1998



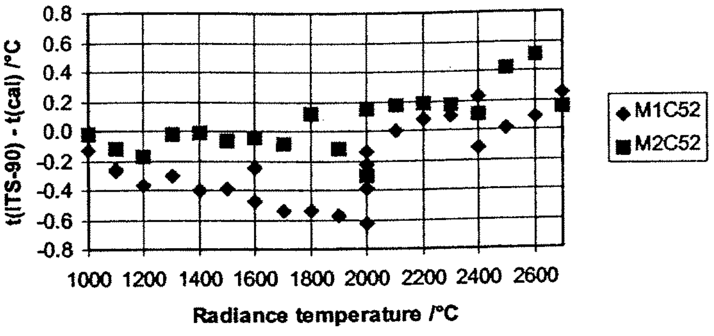
The curves are as follows: the key M1C52-1 indicates the first and M1C52-2 the second calibration run for that instrument. Similarly M2C52-1 and M2C52-2. The curve marked "mean" is the average of all four curves.

It can be seen that, although there is generally scatter of a few tenths of a degree for each individual run, the results show that the NIST and NPL scales are in agreement to within 0.5 °C at least up to 2000 °C. Above 2000 °C the agreement is generally 0.8 °C or better. The small discontinuity at 2000 °C is due to the change in fit used for values above 2000 °C. The small hump seen above 2000 °C may be due to an uncorrected emissivity effect or an artefact of the fitting procedure.

The expanded uncertainty (*k*=2) in the NPL calibration of the MC52 instruments was 0.4 °C at 1000 °C rising to 1.6 °C at 2700 °C. The uncertainty evaluation includes the following type A components: the statistical uncertainty in the blackbody temperature (reference thermometer and test thermometer), the root mean square deviation of the fit of the three term empirical Wien function, the scale realisation with the NPL reference pyrometer, the type B uncertainties due to alignment, SSE and the correction arising from the temperature coefficient of the instruments. The NIST expanded uncertainty for the measurement of the MC52 instruments is 0.5 °C at 1000 °C and 2.0 °C at 2700 °C. When the NIST and the NPL uncertainties are combined the overall uncertainty of the comparison is 0.6 °C at 1000 °C and 2.6 °C at 2700 °C. The differences observed here are well within the combined uncertainty of the comparison.

On return to the NPL the temperature scale held on the thermometers was compared to the primary scale (i.e. the NPL realisation of ITS-90). This was done to determine the extent to which the calibration of each thermometer may have drifted during the intercomparison period. This is shown in Figure 3.

Figure 3: Stability of the two transfer thermometers



The y-axis is the difference between the primary scale (ITS-90) and the temperature obtained from the thermometer calibration. These results indicate that the instruments remained generally stable to within ±0.5 °C during the comparison period.

7. CONCLUSION

Two transfer standard thermometers have been used to compare the ITS-90 at NPL and NIST between 1000 °C and 2700 °C. It has been shown that the scales as realised by the two respective laboratories agree to within 0.5 °C up to 2000 °C and 0.8 °C up to 2700 °C.

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