

**PROTOCOL FOR A EURAMET  
KEY COMPARISON OF TEMPERATURE SCALES  
FROM 962 °C to 2600 °C**

**Frédéric BOURSON  
Laboratoire Commun de Métrologie LNE-Cnam  
FRANCE**

**03 November 2025**

**Version 2.5**

Foreword: The drafting of this protocol was inspired by the CCT-K10 protocol.

## 1. INTRODUCTION:

Above the silver point (961.78 °C), the temperature is defined in the ITS-90 by extrapolation from a fixed point of silver, gold (1064.18 °C) or copper (1084.62 °C) using a radiation thermometer and the Planck's law expressed in ratio form. The extrapolation generates an uncertainty which increases as the square of the temperature ratio which requires therefore a thorough and accurate characterisation of the instrument, in particular the relative spectral responsivity and the linearity. Behind its apparent simplicity, the ITS-90 is complex to perform and can be only implemented by laboratories with substantial resources.

The use of multi fixed-points is an alternative method which allows to calibrate a radiation thermometer over a wide temperature range without the need to characterise its spectral responsivity or linearity. However, the accuracy of the method depends on the distribution of the fixed-points along the temperature range and the knowledge of their thermal properties, especially the emissivity and the melting phase temperatures.

The recent redefinition of the kelvin and its *mise-en-pratique* (MeP-K) is an opportunity to use high temperature fixed points (HTFPs) to calibrate radiation thermometers as it offers the possibility to directly disseminate the thermodynamic temperature by the means of HTFPs. In the frame of the European projects InK (Implementing the new kelvin) and Real-K (Realising the new kelvin), a thermodynamic temperature has definitely been assigned (up to the next revision) to the freezing plateau of the Cu fixed point (1084.65 °C) and to the inflection points of the melting plateaus of the following high temperature fixed-points: Fe-C (1153.77 °C), Co-C (1324.24 °C), Pd-C (1491.90 °C), Pt-C (1738.28 °C), Ru-C (1953.84 °C), Re-C (2474.69 °C) and WC-C (2747.70 °C).

## 2. GOAL OF THE COMPARISON – TRACEABILITY TO THE CCT-K10:

The aim of the comparison is to validate the skills of laboratories that have felt the need to establish references in the field of high temperatures. This validation will consist of connecting the emerging laboratories of Eastern and Northern Europe to LNE-Cnam by means of the CCT-K10 key comparison [1].

The proposed key comparison will consist of a comparison of ITS-90 scale realisations over the range from the Ag fixed-point to 2600 °C using, as a transfer radiation thermometer, a Chino IR-RST65H. A transportable copper fixed-point blackbody source (IR-R0-AI) will be supplied along to follow the stability of transfer radiation thermometer throughout the comparison.

The instruments and artefacts will be circulated in the form of a semi-collapsed star or 'flower' as described below. This will enable the performance of the instruments to be checked throughout the comparison by the pilot laboratory and should help to minimise issues due to incorrect operation or drift.

The traceability of the participating laboratories to the CCT-K10 will be established by the intermediate of LNE-Cnam, by the temperature difference (LNE-Cnam – CCT-K10 RV) and the differences of each participant to LNE-Cnam (Participating lab – LNE-Cnam). The uncertainty of the participating lab at each temperature will be taken to be, the total uncertainty

of the participating lab combined with the uncertainty of the LNE-Cnam in the CCT-K10 and that of the reference value of the CCT-K10.

### 3. PARTICIPANTS:

All participants are from the Euramet region, the Regional Metrology Organisation of Europe. The details of NMI and contact person are given in Table 1 below.

Table 1: Participants for the key comparison

NMI or DI	Organisation legal full name	Address and contact person	Country
CNAM	Conservatoire national des arts et métiers	Laboratoire Commun de Métrologie 61, rue du Landy – 93210 La plaine Saint Denis – France  Contact: Frédéric Bourson and Mohamed Sadli Email: frederic.bourson@lecnam.net Email: mohamed.sadli@lecnam.net	France
CMI	Cesky Metrologicky Institut	Český metrologický institut/Czech Metrology Institute Okružní 31 63800 Brno, Czech Republic  Contact: Lenka Knazovicka Email: lknazovicka@cmi.cz	Czechia
DFM	Danish National Metrology Institute	Danish National Metrology Institute Kogle Allé 5   DK - 2970 Hoersholm   Denmark  Contact: Sønnik Clausen Email: slc@dfm.dk	Denmark
DTU	Danmarks Tekniske Universitet	Technical University of Denmark Anker Engelunds Vej 1, Bygning 101A, 2800 Kongens Lyngby, Denmark  Contact: Andreas Næsby Rasmussen Email: anr@dfm.dk	Denmark
JV	Justervesenet	Justervesenet - The Norwegian Metrology Service Po.box 170 NO-2027 Kjeller, Norway  Contact: Åge Andreas Falnes Olsen, Karsten Opel and Reidun Anita Bergerud Email: aao@justervesenet.no Email: kop@justervesenet.no Email: rab@justervesenet.no	Norway
LNE	Laboratoire national de métrologie et d'essais	Laboratoire Commun de Métrologie 61, rue du Landy – 93210 La plaine Saint Denis – France  Contact: Olga Kozlova Email: olga.kozlova@lne.fr	France
RISE	Research Institutes of Sweden AB	RISE Research Institutes of Sweden Brinellgatan 4, 50462 Borås, Sweden  Contact: Magnus Holmsten and Patrik Broberg Email: magnus.holmsten@ri.se Email: patrik.broberg@ri.se	Sweden
SMU	Slovenský Metrologický Ústav	Slovak Institute of Metrology Karloveska 63 Bratislava - Slovakia  Contact: Peter Pavlasek and Milan Ioan Maniur Email: pavlasek@smu.gov.sk Email: maniur@smu.gov.sk	Slovakia

TÜBİTAK UME	Türkiye Bilimsel ve Teknolojik Arastırma Kurumu	Thermodynamics Metrology Laboratory TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr.Zeki Acar Cad. No:1 41470 Gebze / KOCAELİ  Contact: Humbet Nasibli and Can Gozonunde Email: humbet.nasibli@tubitak.gov.tr Email: can.gozonunde@tubitak.gov.tr	Turkey
UL	Univerza v Ljubljani	Laboratorij za metrologijo in kakovost Fakulteta za elektrotehniko Tržaška cesta 25, SI-1000 Ljubljana, Slovenija  Contact: Jovan Bojkovski, Vincencij Zuzek and Vid Mlacnik Email: jovan.bojkovski@fe.uni-lj.si Email: vincencij.zuzek@fe.uni-lj.si Email: vid.mlacnik@fe.uni-lj.si	Slovenia

#### 4. CIRCULATING INSTRUMENTS

The circulating instruments will be:

- a Chino radiation thermometer IR-RST65H and its positioning stage, supplied by LNE-Cnam (Table 2) referred below as “transfer radiation thermometer” or “Chino radiation thermometer”
- a Chino furnace IR-R0-AI including a Cu fixed point used to check the stability of the Chino radiation thermometer during its travelling and one spare Cu fixed-points supplied by LNE-Cnam (Table 3)

The technical specifications of each of the instruments are given in the following tables. Operational guidelines for the use of each instrument are given in Appendix 1. Additionally, the transfer radiation thermometer and the furnace are supplied with an operating manual giving further details. Participants should carefully read the operating manuals for each instrument before starting measurements to minimise the risk of accidental damage or incorrect operation.

Table 2: Specifications for the Chino radiation thermometer

<b>Chino transfer radiation thermometer</b>	
Model	IR-RST65H
Serial number	IS-0246C0001
Spectral range	650 nm, FWHM 12 nm
Measuring temperature range	960 °C to 3000 °C
Distance Ratio (Distance / Target size)	650 (400 mm / Ø 0.6 mm)
Output	Voltage: 0 to 10 V Internal temperature monitor signal: 0 to 5 V (0 to 50 °C)
Focusing distance	400 mm to ∞
Warm up time	Half a day
Power requirements	24 VDC, DC power supply (for 220-240 VAC) accompanies the instrument

Important remark: The transfer radiation thermometer should be set at a working distance of 800 mm. The distance should be measured from the front of the thermometer casing to the front face of the source.

Table 3: Specifications for the copper fixed point blackbody

<b>Transportable copper fixed-point blackbody source</b>	
Furnace model	IR-R0-AI
Serial number	AX021PA04-3
Fixed-point blackbody	Cu fixed point CuM7 + spare CuM6
Blackbody cavity	Ø 4 mm × 55 mm, with 120 °conical end
Effective emissivity	0.9999
Plateau duration	Approximately 20 min
Heat-up time	Approx. 2 hours from room temperature to 1085 °C
Cool-down time	Approx. 2 hours from 1085 °C to 150 °C
Power	110-120/ 220-240VAC, 50 –60 Hz, 750 VA max
Gas requirements	Pure argon – flow rate 0.8 l/min
Temperature control	PID control by a pre-programmed controller

## 5. SHIPPING

The laboratory performing the measurements should arrange for the thermometers and cells to be transferred to the next laboratory by the date given in the schedule in Appendix 2. Wherever possible, the appropriate means of transport must be chosen to minimise the risk of damage to the instruments.

The laboratory performing the measurements is required to arrange the safe transportation of the instruments to the next laboratory and for paying the transport costs. Therefore, it is strongly recommended that the laboratory arranging the shipping takes out insurance in case of loss or damage of the instruments and cells during transportation. The value of the goods, for insurance purposes, should be taken to be in the region of € 30000. The laboratory receiving the instruments should carry out the checks described in Section 9.1 and confirm to the pilot laboratory by e-mail that the instruments have arrived safely. The approximate dimensions and weights of each of the items are given in Table 4.

LNE-Cnam will provide all necessary documentation including customs documentation for shipping the instruments from LNE-Cnam to the particular region and then back to LNE-Cnam. For customs purposes, during the comparison the instruments will be considered to be a temporary export out of the LNE-Cnam. It is important that all the items within the shipment are kept together and transported as one consignment with all the accompanying paperwork.

Table 4: Approximate dimensions and weights of items in consignment

<b>Items</b>	<b>Packaging</b>	<b>Dimensions L x l x h /cm</b>	<b>Gross weight / kg</b>	<b>Number of units</b>
- Chino radiation thermometer IR-RST65H - Power supply of the Chino IR- RST65H - Chino transfer Cu fixed point IR-R0-AI - Power supply of the Chino IR- R0-AI “Bronson TI 1500” - Positioning stage - Spare cell CuM6	One flightcase	85 x 45 x 65	50	1

## 6. PROBLEMS

During the measurement process, participants should endeavour to make sure that all the instruments are safely and correctly handled while they are at their laboratory. If desired, insurance may be taken out to cover against loss or damage. The laboratory arranging shipping to the next participant will be responsible should anything go wrong during the shipping process resulting in any damage to any of the instruments. It is therefore strongly recommended that insurance is taken out in case of loss or damage of the instruments or the cells during transportation.

Should the results of the copper fixed point check (Section 9.1.5) indicate that there is a problem with the transfer radiation thermometer, then it might be necessary to return the thermometer to the pilot laboratory so that a further assessment can be carried out.

Should any problems arise with the operation of the instruments, the LNE-Cnam supplying the equipment should be contacted.

## 7. PREPARATION FOR MEASUREMENTS

Prior to receiving the instruments each participant should prepare for the measurements. Please ensure sufficient time is given for this activity so the measurement schedule in Appendix 2 is not delayed.

## 8. MEASUREMENTS AT THE PILOT LABORATORY (LNE-Cnam)

LNE-Cnam will calibrate and characterise the Chino radiation thermometer and validate the transfer Cu fixed point prior to the start and at the end of the comparison. The calibration / validation will consist of:

- size-of-source effect measurements
- range ratio measurements as appropriate
- validation of the transfer Cu fixed point source by direct comparison to the LNE-Cnam primary Cu fixed point
- measurement of the Transfer radiation thermometer outputs using the transfer Cu point (to provide a baseline reference signal)
- calibration of the Chino radiation thermometer over the full temperature range of the comparison, namely 962 °C, 1100 °C, 1300 °C, 1500 °C, 1700 °C, 1800 °C, 2000 °C, 2200 °C, 2400 °C and 2600 °C using the LNE-Cnam high temperature blackbody source and primary reference thermometer (radiance comparator)

When the instruments are returned to the pilot during the comparison a limited number of the above measurements will be carried out in order to check the correct operation and stability of the instruments. These measurements will be:

- check of the operation of the transfer Cu fixed point using the LNE-Cnam primary Cu fixed point

- check of the output of the transfer radiation thermometer using the melt/freeze transition of the transfer Cu fixed point source
- re-calibration of the Chino radiation thermometer at the temperature points listed above, including check of gain ratios

## **9. MEASUREMENTS AT THE PARTICIPATING LABORATORIES**

### **9.1 Inspection on delivery**

A visual inspection of the packaging and all the instruments and the spare cell should be made on arrival of the equipment at each laboratory. Any evidence of damage should be reported immediately both to the pilot and the laboratory responsible for the shipment using the form in Appendix 3.

The Cu cell remains in the furnace during shipment. It should be carefully inspected using a light source, before and following transportation for any obvious damage. Both on receipt of the cells (the one in the furnace + the spare) and before shipping them, each participant should report their appearance, if appropriate with a photograph, by sending an email to the pilot and the previous participant (on receipt) or next participant (before posting).

As a further check of the Chino transfer thermometer, to make sure that it has not been damaged during transport, within one week of the receipt the output of the radiation thermometer should be measured using one melt/ freeze cycle of the supplied Cu fixed-point blackbody source (refer to Section 9.1.5) and the result reported to the pilot.

#### **9.1.1 Stabilisation / warm up**

The stabilisation time (warm up) for the Chino radiation thermometer is given in Tables 3 and must be adhered to. The thermometer should subsequently be left switched on for the duration of all the measurements.

#### **9.1.2 Lens cleaning**

Superficial dust should be blown off of the front lens of the radiation thermometer using clean air or other means but otherwise, the lens should not be cleaned. The protective lens cap should be placed on the front of the Chino radiation thermometer between measurements and great care should be taken not to touch the front lens.

#### **9.1.3 Positioning**

The Chino radiation thermometer should be set up and aligned at the prescribed working distance, namely 800 mm from the front of the thermometer casing to the source, according to the local procedure, with reference to any specific instructions supplied with the thermometers.

#### **9.1.4 Background (dark signal) measurements**

Background measurements (dark signal) should be carried out by placing the protective lens cap on the front of the Chino radiation thermometer.

#### **9.1.5 Check using transfer Cu fixed-point source**

Within one week of their receipt, the output of the Chino radiation thermometer should be measured by one melt / freeze cycle of the supplied Cu fixed-point blackbody source, using the supplied instructions for using the source (refer to Appendix 1 and the instruction manual

supplied with source). Another melt / freeze cycle should be carried out at the end of all the other measurements and before shipment to the next laboratory in order to provide better information about the stability of the transfer thermometer.

The fixed-point aperture is located 115 mm from the furnace opening as indicated in figure 1. The measurements should be made at the prescribed working distance (800 mm for the Chino radiation thermometer measured from the front of the thermometer casing to the fixed-point aperture), with the thermometer focused and aligned on the centre of the Cu fixed-point aperture.

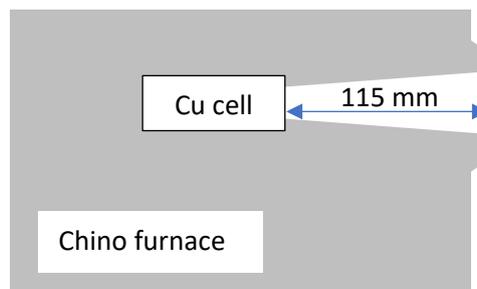


Figure 1: distance between the front face of the cell and the furnace opening

The Cu fixed point must be measured with the Chino radiation thermometer set to gain L. The corresponding response is the average output signals of the thermometer issued from the Cu melting and freezing plateaus and corrected for dark signal. The temperature difference between the melting and the freezing temperatures must be less than 10 mK. The reported output signal should be the average measured at the maximum of two freezing plateaus, each of them corresponding to the maximum of the plateau averaged for at least 1 minute. For one plateau, the standard deviation of one measurement should be within 10 mK. Measurements should be corrected for the dark signal (background) and sent to the pilot as soon as possible and before starting the pyrometer calibration.

During the copper point measurement, the internal temperature of the thermometer and the laboratory ambient conditions, should be e-mailed to the pilot laboratory using the template form in Appendix 4, within one week of receipt of the thermometer. The results of the second check measurement (before shipping to the next participant) should be included in the laboratory measurement report. The participant must alert the pilot in case the results of this second check differ significantly (temperature difference  $> 50$  mK) from those of the first measurement.

## 9.2 Comparison measurements

The purpose is the comparison of temperature scales. Each laboratory will calibrate the transfer radiation thermometer using their own realisation of temperature scale. This can be:

- a set of HTFPs of known thermodynamic temperature used to calibrate a reference radiation thermometer by the mean of Sakuma-Hattori equation and a blackbody source whose temperature has been set using the calibrated radiation thermometer
- a reference radiation thermometer calibrated in relative spectral responsivity and linearity and a blackbody source whose temperature has been set using the calibrated radiation thermometer

### 9.2.1 Calibration of the transfer radiation thermometer

The calibration of the transfer radiation thermometer should be carried out according to the local procedure for the calibration of such devices using the participant's high temperature blackbody (HTBB) source, the temperature of which should be assigned according to the usual method at the laboratory. The calibration should be performed with the radiation thermometer set at the prescribed working distance from the blackbody source, i.e. 800 mm from the front of the thermometer casing to the opening of the blackbody aperture.

The calibration of the radiation thermometer is to be performed at all of the following temperatures, although the maximum calibration temperature can be reduced to fit the particular capability within an NMI: 962 °C, 1100 °C, 1300 °C, 1500 °C, 1700 °C, 1800 °C, 2000 °C, 2200 °C, 2400 °C and 2600 °C. The calibration at all temperatures should be carried out using a high-temperature blackbody set to be within 5 °C of the specified temperatures. The gain/range settings should be set appropriately for each temperature as specified in Appendix 5.

Participants should repeat the measurements at a minimum of three of the above calibration temperatures spread over the range, for instance:

- 962 °C, 1800 °C and 2600 °C for a temperature range from 962 °C to 2600 °C
- 962 °C, 1300 °C and 1800 °C for a temperature range from 962 °C to 1800 °C

Participants should measure the range / gain ratios of the transfer radiation thermometer using a stable blackbody source maintained at a temperature appropriate for the range/ gain ratio being measured. This is so that any changes in the ratios with time can be monitored and can be taken into account in the results analysis if appropriate.

Participants are not asked to measure the size-of-source effect (SSE) of the transfer radiation thermometer, measurements will be given by the pilot. To provide comparable measurement to the pilot, independently to the radial temperature distribution of the blackbodies of each participant, the SSE correction will be applied considering a source diameter of 10 mm.

Any additional supplementary measurements should also be carried out if these form part of the usual necessary calibration procedure for a high temperature radiation thermometer (for example if they are required to fully assess the calibration uncertainties).

The report giving measurement method, details of equipment used, calibration results for the thermometer and estimated calibration uncertainties should be sent to the pilot within one month of completion of the measurements. For further details of the reporting format refer to Section 10.

### 9.2.2 Furnace radial temperature uniformity for SSE correction

The radial temperature distribution of the furnace used to disseminate the temperature scale should be measured to correct from SSE. Participants may find further information in [4], paragraph 3.2.

## REPORTING

The following information should be provided to the pilot laboratory within one month of completion of the measurements.

### 9.3 General information

This should take the form of a Word document and should contain a description of the equipment and the measurement method used at the laboratory, including:

- make, model, serial number and geometry of the high temperature blackbody source used for the calibration of the radiation thermometer
- methodology used in the scale realisation: fixed point + the spectral relative responsivity of the standard radiation thermometer, interpolation between three or more fixed points, any other method ...). All information (fixed points used, method to determine the spectral responsivity ...) must be specified
- methodology used in the calibration of the transfer radiation thermometer (procedure followed, additional checks or measurements performed ...)

### 9.4 Calibration of the Chino radiation thermometer

The results should be provided in the form of an Excel spreadsheet and should include the following information (value and uncertainty). Templates for reporting the results and uncertainties are given in Appendix 5 and 6.

- stability at the transfer Cu fixed-point
- temperature of the blackbody source
- thermometer output/ reading (corrected for the dark reading) measured with the appropriate gain or range
- internal temperature of the thermometer
- laboratory ambient temperature
- range/ gain ratio measurements
- uncertainty budget identifying all components of uncertainty and their values, and the total expanded uncertainty. The budget should take the form of the template supplied in Appendix 6 and should include:
  - uncertainty in the scale realisation with all components identified
  - temperature stability of the blackbody source
  - effect of emissivity of the blackbody source due to difference in wavelength between the participant reference thermometer and the wavelength of operation of the Chino radiation thermometer
  - uncertainty due to alignment on the blackbody source
  - repeatability / reproducibility of the calibration measurements
  - correction of the results to the reference source size of 10 mm diameter. The SSE of the pyrometer and the instructions will be given by the pilot
  - Any additional uncertainty components not listed above

## 10. ANALYSIS OF FINAL RESULTS

The pilot laboratory will analyse the overall final results taking into account its measurements made before, during and after the comparison and the results of the individual participants. The analysis method will be as follows:

The results of the transfer thermometer (background corrected output versus the ITS-90 temperature) at each nominal comparison temperature will first be normalised (corrected) to a common comparison temperature,  $t_{nom}$ , using the sensitivity of the radiation thermometer (Equation 1).

(e.g. suppose a participant provides results for  $t_{90} = 1300.6$  °C, then the thermometer output will be corrected to give the equivalent output at  $t_{nom} = 1300.0$  °C).

$$\Delta S = \Delta T \frac{c_2}{\lambda T^2} S \quad (1)$$

where  $\Delta S$  is correction to be applied to the thermometer output signal  $S$ ,  $\Delta T$  is the difference between the participant measurement temperature  $T$  ( $= t_{90}$  in K) and the comparison temperature  $T_{nom}$  ( $= t_{nom}$  in K),  $c_2$  is the second radiation constant and  $\lambda$  is the thermometer nominal wavelength.

The results of the measurements using the transfer Cu fixed-point blackbody will be used to assess whether or not there has been any drift of the transfer radiation thermometer over the course of the comparison. If any drift is evident then the radiation thermometer output signal will be corrected to take into account the drift, using the change in output signal at the Cu point from the start of the comparison (the first set of measurements by the pilot). The results at each  $t_{nom}$  will be corrected using the Cu point drift and the sensitivity of the radiation thermometer at that  $t_{nom}$  (i.e. the drift will be scaled according to  $t_{nom}$ ). An additional component of uncertainty will be included to take into account the radiation thermometer drift. The proposed analysis method follows that given in section 5 of [1].

The results of the transfer radiation thermometer by the pilot laboratory over the entire period of the comparison will be averaged for each  $t_{nom}$ , after correction of the possible drift of the radiation thermometer. The final uncertainty associated with the pilot results will include the standard deviation of the pilot measurements (after correction of results for any drift).

Where a participant obtains more than one result for a particular  $t_{nom}$ , as a result of carrying out repeated measurements, then the results will be averaged to give one result for that  $t_{nom}$  for that participant and this will be used in the subsequent analysis.

The reference value of the transfer radiation thermometer will be calculated for each  $t_{nom}$  using the weighted mean (or possibly the median in case where the consistency check fails - see Equation 6 below) with cut-off of all the participant results, including the average pilot results, at that  $t_{nom}$ . The weight for each participant, including the pilot, is the inverse of the square of the standard measurement uncertainty for that participant at that  $t_{nom}$ . The cut-off values for the weights will be the average of the uncertainty values of those participants that reported uncertainties smaller than or equal to the median uncertainty of all the participants. The weighted mean,  $y$ , will be calculated according to Equation 2.

$$y = \frac{x_1/u^2(x_1) + \dots + x_n/u^2(x_n)}{1/u^2(x_1) + \dots + 1/u^2(x_n)} \quad (2)$$

where  $x_1$  through to  $x_N$  are the results from participants 1 through to N, and  $u(x_1)$  through to  $u(x_N)$  are the associated standard uncertainties for participants 1 through to N, which will include any additional uncertainty components such as that due to the thermometer drift (if any).

If, as is likely, the participant uncertainties are expressed in terms of temperature, then the equivalent uncertainty in terms of thermometer output signal will be calculated using the radiation thermometer sensitivity at that temperature (Equation 1) before calculating  $y$  using Equation 2. The standard deviation  $u(y)$  associated with  $y$  will be calculated according to Equation 3.

$$\frac{1}{u^2(y)} = \frac{1}{u^2(x_1)} + \dots + \frac{1}{u^2(x_N)} \quad (3)$$

A consistency check of the results will be carried out in the form of a chi-squared test by calculating the observed chi-squared value,  $\chi_{obs}^2$ , according to Equation 4 and assigning the degrees of freedom,  $\nu$ , according to Equation 5.

$$\chi_{obs}^2 = \frac{(x_1 - y)^2}{u^2(x_1)} + \dots + \frac{(x_N - y)^2}{u^2(x_N)} \quad (4)$$

$$\nu = N - 1 \quad (5)$$

The consistency check will be regarded as failing if

$$Pr\{\chi^2(\nu) > \chi_{obs}^2\} < 0.05 \quad (6)$$

where  $Pr$  denotes ‘probability of’.

Provided that the consistency check does not fail, then  $y$  will be accepted as the comparison reference value CRV for the transfer radiation thermometer with an associated standard uncertainty of  $u(y)$ . If the consistency check fails then an alternative method for calculating the CRV, such as the median of all the participant results, will be considered following the procedure given in section 6 of [1].

The degrees of equivalence for each participant and for each  $t_{nom}$  will be calculated using the difference between the result of that participant and the CRV at that  $t_{nom}$  and the uncertainty of the difference, which will be the participant uncertainty combined with the uncertainty of the KCRV.

The final result will therefore be, for each temperature given in § 8, the difference from the laboratory to the KCRV, along with the overall combined expanded uncertainty ( $k = 2$ ) of the comparison at that temperature, which will include the participant uncertainty, the uncertainty in the KCRV value and any other associated uncertainties of the comparison, for example due to thermometer drift. All the differences and the associated uncertainties will be expressed in terms of temperature.

## 11. REFERENCES

- [1] Helen McEvoy et al 2024 *Metrologia* 61 03003. **DOI** 10.1088/0026-1394/61/1A/03003
- [2] Cox, M G, The evaluation of key comparison data, *Metrologia*, 2002, 39, pp 580 – 595. DOI 10.1088/0026-1394/39/6/10
- [3] Fischer, J et al, Uncertainty budgets for realisation of scales by radiation thermometry, CCT-WG5 document, CCT/03-03, 2003
- [4] F Bourson *et al* 2022 *Metrologia* 59 015003. **DOI** 10.1088/1681-7575/ac3a67

## APPENDIX 1

### OPERATIONAL GUIDELINES FOR THE USE OF THE TRANSFER INSTRUMENTS

A summary of the steps necessary for the correct setting-up, use and re-packing for each of the transfer radiation thermometer and the transfer copper fixed point is given below. Note that this includes key points only. For full operating instructions please refer to the instruction manuals supplied with the instruments.

Check that all items and accessories are present. Note how the items are packed into the crate, and how the spare fixed points are packed in the inner cardboard box, so that they can be repacked in the same manner.

#### 1. User instructions for the Chino radiation thermometer on receipt and setting up for use:

- Check that all items and accessories are present. Note how the items are packed into the crate so that they can be repacked in the same manner
- Connect the signal cable to the back of the thermometer. Connect the output terminals to two digital voltmeters, one for reading the thermometer radiance signal output, and the other for monitoring the instrument's internal temperature. If only one voltmeter is used, the internal temperature must be measured every day, at least before and at the end of the measurements
- Connect the AC power cable of the DC power supply unit of the thermometer then connect the DC power supply cable to the back of the thermometer
- Plug the power supply into the mains. The LED on the rear of the thermometer will light up red, and will change to green when the thermometer has warmed up
- Select the appropriate gain using the knob at the back of the instrument
- Allow the thermometer to warm up for at least half a day before starting measurements
- Put the lens cap back on the objective of the radiation thermometer when measurements are finished

#### Shipment to the next participant:

- Replace the lens cap on the thermometer objective
- Disconnect the DC power cable from the back of the thermometer and the AC power cable from the 230 V mains
- Disconnect the signal cable from the back of the thermometer
- Pack everything carefully into the packing crate in the same manner in which the instrument arrived

#### 2. User instructions for the Chino copper fixed point source on receipt and setting up for use:

- Connect the rubber hose to a argon inlet with a minimum flow rate of 1 l/min

- Connect the power cable to the 220V/110V power supply
- Set the argon flow rate to 0.8 l/min on the flow regulator
- Turn on the mains power supply switch
- Check that the freeze/melt button is in the freeze position
- Press the heater on/off switch. The temperature increases automatically to the freezing temperature set at 1076 °C in about 2 hours. The argon gas starts flowing automatically when the furnace temperature reaches 250 °C (a popping sound can be heard). Check that the gas flow light is red and check the flow periodically
- The melting and the freezing setpoints are adjusted to respectively 1094 °C and 1076 °C to keep the same setpoints all along the comparison. They must not be modified. These temperatures were set to take into account the temperature gradient along the cell and the supercool. The corresponding responses of the Chino radiation thermometer should be approximately 28 mV and 22.5 mV. When the temperature setpoint is reached, check the furnace temperature is stabilised (within +/- 0.5 mV) then turn the freeze/melt button to the melt position to induce the melt
- At the end of the melting plateau, check the furnace temperature is stabilised (within +/- 0.5 mV) then turn the freeze/melt button to the freeze position to induce the freeze
- At the end of the melt/freeze cycle, the difference between the melting and the freezing plateaus must be within 5 µV. If not, check the viewing conditions (Chino radiation thermometer alignment, focus distance ...) and repeat the measurements. If yes, switch the heater off.
- DO NOT turn off the main power supply switch until the argon gas automatically shuts off. DO NOT turn off the argon gas supply until the furnace reaches the temperature for automatic gas shut-off.

**Shipment to the next participant:**

- Ship the furnace with the fixed-point cell inside and make sure it is cold before packing.
- Pack everything carefully into the packing crate in the same manner in which the instrument arrived

**3. Opening the furnace to change the crucible:**

The pilot must be informed before replacing the crucible. If the furnace shows visible external damages or if there is a significant temperature difference between the melting and freezing plateaus seen by the Chino radiation thermometer ( $> 10 \mu\text{V}$ ), the cell must be inspected and replaced if necessary. For any handling, it is recommended to take photos to see how the various components are assembled.

- Unscrew and remove the ‘top plate’ cover of the furnace
- Unscrew and remove the metal protection plate at the rear of the furnace
- Remove the argon inlet rubber hose
- Unscrew the four cables from the connector (identify the cables clearly)
- Remove the rear alumina insulation disc
- Remove the insulation block containing the cell by pulling on the argon inlet tube. Leave the felt insulation discs in place

- Unscrew the front plate of the cell holder
- Remove and change the cell (no specific orientation required)
- Reassemble the furnace by repeating the same operations in the reverse order. Do not forget to connect the rubber hose on to the centre tube

## APPENDIX 2

### PROVISIONAL CIRCULATION TIMETABLE

Laboratory	Measurement Period	Instruments to be received at next lab in early	Month
Cnam		Nov. 25	M30
SMU	Nov. 25	Dec. 25	M31
RISE	Dec. 25	Jan. 26	M32
Tubitak UME	Jan. 26	Feb. 26	M33
Cnam	Feb. 26	Mar. 26	M34
UL	Mar. 26	Apr.26	M35
CMI	Apr. 26	May 26	M36
DFM	May 26	Jun. 26	-
JV	Jun. 26	Jul. 26	-
Cnam	Jul. 26		-

### APPENDIX 3

#### RECEIPT OF INSTRUMENTATION

**Receiving laboratory:**

**Date:**

Artefact/ component	Received (yes/ no)	Damage (yes/ no)	Nature of damage
Chino thermometer Lens cap DC power unit Signal cable Lens blower Operating manual Power unit manual			
Chino Cu fixed point (CuM6) Rubber gas tube Transformer Bronson TI 1500 Operating manual Spare cell CuM7			
Positioning stage			
Flyghtcase			

## APPENDIX 4

### INITIAL STABILITY MEASUREMENT CHECK USING THE TRANSFER COPPER FIXED POINT

#### Laboratory:

Date of check (day, month, year): Thermometer identification	Gain/ range	Output signal* /V	Dark signal (background) /V	Ambient temperature / °C	Thermometer internal temperature / V
Chino	L				

\* the output signal must not be corrected for dark reading (background)

The working distance (distance from the fixed-point aperture to the front of the thermometer casing) should be as prescribed in Section 4, namely 800 mm.

The reported output signal should be the average measured at the maximum of two freezing plateaus, each of them corresponding to the maximum of the plateau averaged for at least 1 minute. For one plateau, the standard deviation of one measurement should be within 10 mK. Measurements should be corrected for the dark signal (background).

The results of the second stability check (before onward shipment of instruments) should be included in the laboratory measurement report.

## APPENDIX 5

### CALIBRATION RESULTS FOR THE COMPARISON RADIATION THERMOMETER

Nominal temperature  / °C	ITS-90 temperature  / °C	Output signal*  / V	Dark signal (background)  / V	Gain setting	Chino internal temperature / V	Ambient temperature  / °C	U ( <i>k</i> = 2)  / °C
962				L range			
1100				L range			
1300				L range			
1500				L range			
1700				L range			
1800				L range			
2000				M range			
2200				M range			
2400				H range			
2600				H range			

Working distance (distance from front of thermometer casing to blackbody) = ..... mm

Aperture diameter of HT blackbody = ..... mm

\* the output signal must not be corrected for dark reading (background)

## APPENDIX 6

### SAMPLE UNCERTAINTY COMPONENTS

Example of uncertainty components to be included for the radiation thermometer calibration

Uncertainty in the reference radiation thermometer (uncertainty in ITS-90 realisation)	Reference fixed point uncertainty
	Reference fixed point measurement
	Gain ratios
	Repeatability
	Residual errors from the Sakuma–Hattori equation
	Drift
	Ambient conditions
	HTBB uniformity
Uncertainty in the comparison	HTBB temperature stability
	HTBB emissivity
	HTBB effective source diameter and correction to reference diameter of 25 mm)
	Transfer device alignment on HTBB
	Transfer device short term stability
	Digital voltmeter
	Repeatability