

WORKING GROUP 5 REPORT TO CCT: June 2005

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Terms of reference (Guideline) : Development and improvement of optical methods for temperature measurement in the framework of the ITS, maintain good links/interface with the radiometry community, liaison between CCT and CCPR

Problems in radiation thermometry presently under study: Examining the base-line parameters underlying the radiation thermometry scale realisation with rigorous standard approach to uncertainty analysis, progress and function of metal-carbon eutectics (in collaboration with WG2), radiation thermometry below 962 °C and traceability in remote sensing

1. Joint CCPR and CCT Workshop

On 25 June 2004, at the TEMPMEKO 2004 conference site in Cavtat, Croatia a joint CCPR and CCT Workshop was organised by CCT-WG5 and entitled „Common Problems in Radiometry and Thermometry“.

The methods and apparatus used in radiation thermometry and radiometry are very similar and often the same problems are limiting the progress in the respective fields. Especially in the high temperature range thermodynamic temperatures are determined by radiometric measurements. On the other hand, the demanding requirements for low uncertainties in temperature measurement come from photometry and radiometry. With the development of metal-carbon eutectics a new tool is in our hands which has the potential to be extremely useful in radiometry and thermometry.

The workshop should facilitate cross-fertilisation of ideas between the radiometry and thermometry communities. Thus, it was organised by CCT-WG5 which has among their main tasks to maintain good links/interface with the radiometry community and to provide liaison between CCT and CCPR. Eight discussion rounds were held and introduced by discussion leaders :

Spectral radiation measurements of thermodynamic temperatures (Joerg Hollandt, PTB)

The present state for the measurement of spectral radiant power in the visible using a cryogenic radiometer is described by a relative uncertainty value of 10^{-5} ($k=1$). Based on this, calibration of the spectral responsivity of a filter radiometer is possible with a relative standard uncertainty of $2 \cdot 10^{-4}$. In radiometry filter radiometers are used to disseminate scales for spectral radiance and spectral irradiance. For thermometry, they can be used to reduce the uncertainties of the thermodynamic temperature assignment of the ITS-90 fixed points. In addition, presently the temperature of an eutectic fixed point near 3000 K could be determined with a standard uncertainty of about 150 mK. This uncertainty is still higher than the demand stated by the past joint CCPR and CCT working group of 50 mK at 2500 K.

Total radiation measurements based on cryogenic radiometers (Emma Woolliams, NPL)

The status of the NPL absolute radiation detector (ARD) was reviewed. This apparatus was designed to measure (i) thermodynamic temperatures in the range from 200 K to 500 K and (ii) the Stefan-Boltzmann constant with a relative uncertainty of 10^{-5} or lower. The problem with the absorptance of the light trap which led in the past the poor results is solved now and new results are expected soon.

Uncertainty requirements in temperature measurements for photometry and radiometry (Peter Sperfeld, PTB)

Three examples were given requiring the following uncertainties for temperature measurement : illuminance calibration (≤ 30 K), dominant wavelength of a colour stimulus (≤ 1 K), and realisation of spectral irradiance scales (≤ 0.5 K). The stated uncertainties can be achieved using present technology with reasonable effort.

Optimising radiation thermometer designs: understanding and reducing the size-of-source effect (Howard Yoon, NIST)

The new design of the radiation thermometers at NIST was presented. This takes into account special measures to reduce the size-of-source effect considerably, namely a low scatter single objective lens, a tilted field stop, an additional Lyot stop between field stop and detector, and low scatter inner walls of the thermometer.

Role of eutectics for the advancement of measurements in radiometry and thermometry (Yoshiro Yamada, NMIJ)

The CCT recommendation T2 of 1996 was recalled¹. To solve this problem, at present 13 different metal carbon and metal-carbid carbon eutectic fixed points are under study from 1153 °C to 3180 °C. For radiometry and thermometry they may serve as transfer standards and stable blackbody radiation sources without assigning temperature values. With thermodynamic temperatures determined thermometric scales can be realised by interpolation and thermocouples can be calibrated. For the latter purposes the reproducibility of the eutectic fixed points needs to be improved and the thermodynamic temperatures need to be determined. For the realisation of spectral irradiance scales large aperture eutectic cells are required.

Co-ordination of research in eutectics (Graham Machin, NPL)

This subgroup of WG5 led by Graham Machin has currently the following tasks :

- Investigation of SSE minimisation and correction strategies, including uncertainty estimates for correction
- Compilation of to date measurements of eutectic values, as a first step towards recommending use as secondary references via CCT-WG2
- Compilation of causes and cures of radiometer instabilities
- Optimisation of measurement conditions, furnace configuration, viewing with radiometers

Additional effort is necessary in the fields fixed point studies (super pure material availability, reliable impurity analysis, possible doping studies, cell robustness) and furnace effects (modelling effects of furnace non-isothermality, reliable experimental methods for assessing temperature uniformity, thermal conditioning affecting the transition temperature).

One possible outline of events for the future implementation of eutectic fixed points has been identified:

- 2004/5 – establish M-C eutectic reproducibility
- 2004 – establish provisional framework for ITSxx
- 2005/6 - radiometers of sufficient quality established
- 2005/6 - preferred future ITS cells selected (Co-C, Pt-C, Re-C, TiC-C)?
- 2005/6 – establish comparison protocol for M-C eutectics
- 2006/7 - make X independent sets (approx. four) of fixed-points
- 2007/8 - establish their equivalence of radiance temperatures [achieve new KC in process?] and measure absolute temperatures by radiometry
- 2009/10 – international agreement of thermodynamic temperatures
- 2011/12 - recommendations from CCT-WG5 to CCT concerning the adoption of M-C eutectics as alternate (lower uncertainty) means of realising high temperature part of ITS-90

This will be revised in May 2005 and more detailed plans will be presented at the forthcoming CCT-WG5 meeting (see Section 3.3 below).

A thermodynamic basis for interpolation equations in radiation Thermometry (Peter Saunders, MSL)

Calibration schemes have been extensively studied and established using none (absolute radiometry), one to three, and more than three (least square fit) temperature points. For $n = 1$ the Au point (ITS-90) or the TiC–C point (3034 K) was considered, for $n = 2$ the Au point and the TiC–C point, and for $n = 3$ the Au point, Pt–C point (2011 K) and TiC–C point.

Suitable blackbody designs to realise high temperatures and to fit large area eutectics (Victor Sapritsky, VNIIOFI)

The high-temperature furnaces developed by Nagano Ltd., Japan and VNIIOFI were discussed. The Nagano furnace has a three-zone carbon-fiber reinforced carbon composite heater for temperatures of up to 2500 °C. The newest version of the pyrolytic graphite furnaces of VNIIOFI, the BB3500MP, operates up to 3500 K, has an inner diameter of 57mm, and can fit eutectic cells providing a cavity of 16mm diameter for spectral irradiance realisation.

2. Low temperature uncertainty paper

Recently, the CCT-WG5 prepared a working document cataloguing each uncertainty component in the realisation of ITS-90 by radiation thermometry above the silver point (CCT/03-03). Radiation thermometry is also widely used below the silver point, particularly in many industrial applications. While the ITS-90 technique is in principle applicable in this temperature range, difficulties associated with direct measurement of the relative spectral responsivity at the longer wavelengths preclude its use. Instead, because of the availability of multiple fixed points and contact thermometers that can measure the temperature of blackbodies according to ITS-90, simpler methods are used to calibrate radiation thermometers below the silver point. These methods involve determining (or approximating) the relationship between thermometer signal and temperature without measuring the spectral responsivity. The new document presents an analysis of all the uncertainty components contributing to the approximation of ITS-90 below the silver point. Specific examples are presented for three thermometers with typical operating wavelengths and bandwidths, and associated temperature ranges: 1.6 μm from 150 °C to 962 °C, 3.9 μm from –20 °C to 962 °C, and 8 μm to 14 μm from –40 °C to 500 °C.

At the CCT-WG5 meeting at 13 May 2003 the tasks and the outline had been defined and subsequently the contributions were worked out. The first version of the complete paper was circulated in May 2005 and it is expected to finalise it during the forthcoming WG5 meeting just before CCT-23.

3. Progress and function of metal-carbon eutectics

3.1 Actions arising from the CCT-WG5 meeting on 13 May 2003

- Action on NPL : to draft letter on behalf of CCT-WG5 strongly endorsing international collaboration in the development on M-C eutectics. The letter was circulated.
- Action on NIST with the co-operation of NMIJ (and possibly IMGC/IKE) : to survey extant knowledge with respect to SSE minimisation and correction, possibly presenting results of survey at TEMPMEKO 2004. Howard Yoon became the NIST CCT-WG5 representative. He has performed research into the origins and mitigation strategies for SSE, this was presented at TEMPMEKO 2004. The SSE can now be reduced to such a level as to no longer be a significant problem in M(C)-C eutectic/high temperature thermometry research.
- Action on CNAM-INM : CCT WG2 requested that a compilation of M-C and MC-C eutectic temperatures (with quoted uncertainties) should be made with a view to recommending them as secondary reference points of ITS90. A paper was presented at TEMPMEKO 2004 giving a detailed summary of the temperature measurements to date. This established that the fixed-points are far superior to many currently recommended secondary references. A recommendation will be made to WG2 for their adoption.
- Action on PTB : to undertake a literature study into the reported origins of radiation thermometer/filter radiometer instabilities, drift minimisation and correction, possibly to be presented at TEMPMEKO 2004. A joint CCT/CCPR workshop on all aspects of M(C)-C eutectic research including instrumentation effects was held at TEMPMEKO 2004 under the auspices of CCT-WG5 (see above) and a paper was presented.
- Action on NPL : to undertake a study on the optimisation of measuring conditions and procedures for optimising fixed-point geometry, furnace configurations and viewing geometry of filter radiometers. More work needs to be done in this area in particular understanding the minimum requirements for a furnace suitable for high performance M(C)-C eutectic realisation.

3.2 European research project HIMERT

The EU-FP5 project HIMERT was successfully completed in April 05. The project has led to many fruitful collaborations between the project partners as well as NMIJ and NIST. Comparisons of M-C cells were undertaken at NPL in February 2003 and PTB in May 2004. These studies indicated that construction methods still need some improvement. Nevertheless intra-cell temperature values achieved in the PTB comparison (NMIJ, INM and NPL) agreed at the ± 100 mK level for Co-C, Pt-C and Re-C indicating that the community is close to meeting the CCT recommendation [CCT/96 T2¹]. Other cells studied, Pd-C and Ru-C, agreed at the ± 400 mK level but impurity problems may well have been the cause of this larger discrepancy. Joint intensive modelling efforts by the University of Valladolid and NMIJ led to growing understanding of the eutectic process, the role of impurities and pointed the way forward to calculating the temperature drop across a fixed-point blackbody back wall. Comparisons of temperature scale between NPL and NIST have been performed using these cells to sub K difference to the Re-C point, the results of this were presented at TEMPMEKO 2004. A summary of the HIMERT project will be presented at Metrologie 05 by the eutectic co-ordinator, and other papers will appear at SICE 2005, Japan and Newrad 2005, Switzerland.

On 14/15 April 2005 an industrial workshop on M-C eutectics was held at PTB. Although participation of industrialists was limited their attendance and contribution demonstrated a growing awareness of the potential of M-C eutectics to solve particular industrial temperature measurement problems. A follow-up workshop "High temperature fixed-point workshop 2006 – Research and Industry Solutions" is being planned for 6/7 June 2006 at LNE. It is anticipated that representatives of the thermometry and radiometry metrology and user communities will be present.

¹ Develop a fixed point above 2300 K with 100 mK repeatability.

3.3 Future plans

A technology roadmapping exercise will be undertaken at NMIJ in May 2005 to identify:

- The desired goals/outcomes of M-C eutectic research, including timescales
- Take stock of the current state of world research in this area
- To identify roadblocks and propose solutions to M-C eutectic development to achieve the desired outcomes

A non-exclusive list of items to be discussed at NMIJ are:

- Remaining roadblocks on eutectic implementation, e.g. reliable construction
- A plan to redefine ITS-90 above the silver point with reduced uncertainty
- A multi-national co-operation agreement to forward M-C eutectic research
- Improving the current realisation of ITS-90 using M-C eutectics - maybe to feed into any revision of "approximations to the ITS-90"/secondary reference fixed-points
- A possible representative key-comparison using M-C eutectics as the lamp comparison was not sufficient to demonstrate laboratories capability, in fact this may only be done through the use of drift less artefacts like M-C eutectics
- Other possibilities – e.g. defining a minimum requirement for a furnace suitable for realising high performance M-C eutectic fixed-points

The results of the Joint Industry Workshop at PTB held on 14/15 April 2005 will also be taken into account. The outcome of these exercises will be either CCT discussion documents or a series of recommendations arising from CCT-WG5 to the CCT.

In contact thermometry currently research is taking place mainly in three NMIs, LNE, NMIJ and PTB. The aim of the research is to assess the metrological importance of M-C eutectics for contact thermometry applications, these investigations are being performed with Pt-Pd thermocouples. A longer-term aim is to improve the calibration of high temperature thermocouples up to the Pd point, reducing calibration uncertainties by at least a factor of 2. In addition research is being undertaken up to the Ru-C point (1953 °C) for assessing/calibrating W-Re and other more novel thermocouple types, though insulation resistance is a problem at the higher temperatures. At present co-operation has been within the HIMERT project, as this has now finished a EUROMET project has been proposed between LNE, NPL and PTB to take forward contact thermometry research into M-C eutectics, a kick-off meeting is being held at NPL on 11/12 July 2005. It is anticipated that co-operative work will continue between the EUROMET partners and NMIJ in this field.