# A SCENARIO FOR REALIZING, MAINTAINING AND DISSEMINATING THE HIGH-TEMPERATURE PART OF A FUTURE ITS - 20XX WITH THE AID OF METAL-CARBON EUTECTIC FIXED POINTS

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## I. Scenario for realizing a HT-ITS-20xx in the range from the silver point to beyond 3000 °C

### 1. Introduction

Interpolating thermometers formed the backbone to the ITS-90 and its predecessors. Values assigned to the transition temperatures of the reference points, implemented, were based upon measurements of the associated thermodynamic temperatures, involving mainly gas thermometry.

Reasons for assigning definite ITS-19xx values to the reference points within the context of a scale , as defined, were twofold: (1) The reproducibility of the transition temperatures associated with the fixed points was in general much better than the uncertainty in the measurement of the associated thermodynamic temperature. (2) Measuring temperatures in accordance with the prescriptions of the temperature scales was -at the time- much easier than directly measuring thermodynamic temperatures. Not for nothing the scales prior to ITS-90 have been denominated as being practical, e.g. IPTS-68. Thus the crux of defining 'scales' is their reproducibility and their practicality. It should be stressed that here the denomination 'scale' stands for nothing more -or less- than an official document, issued under the auspices of the BIPM, containing definitions and procedures on how to establish international temperatures.

If the future decision to be made by the CCT will be that high temperatures should be better established as thermodynamic temperatures, directly measured by means of absolute filter radiometry, implying direct and continual traceability to the cryogenic radiometer, presently the prime standard in radiometry and photometry, the definition of a 'scale' would be superseded, at least in the temperature range in consideration.

In this contribution it is conjectured that one could still sensibly define a HT-ITS20xx, as a serious alternative to directly measuring thermodynamic temperatures over the whole temperature range involved, with at least one of the advantages (1) or (2) as its justification. Adopting a scale as proposed below would undoubtedly have the advantage that it could be wholly realized in a thermometric laboratory, in possession of the defining fixed points, with relatively modest additional requirements as to having at its disposal facilities for measuring non-linearity and relative spectral responsivity. The recalibration schemes involved would be relatively simple.

### 2.Scenario for realizing a HT-ITS-20xx, general outline

The scenario, essentially aims at primarily embodying the scale in narrow-band lens-based filter radiometers of which the relative spectral responsivity $s(\lambda)$ -section 3.2- and the non-linearity *NL* -section 3.3- have to be determined with adequate accuracy. The thermometric basis (denoted as n = 2 below) is provided by *two* reference points X1 and X2 -section 3.1- , of which X1 could be the Cu point (1084.62 °C), as in the ITS-90. X2 is proposed being one of the newly developed metal-carbon eutectic systems [1], for instance Re-C (2475.2 °C).

Direct traceability to the cryogenic radiometer (CR), as in absolute radiometry, would be a prerequisite only in the stage prior to establishing the scale, as indicated below; its subsequent realization, maintenance and dissemination would proceed via X1 and X2.

In order to demonstrate the intrinsic qualities of the proposed HT-ITS20xx , involving n = 2, apart from requiring on-going analysis of the MC-Eutectic(s) involved, it should be modelled at least in conjunction with the cases n = 0 (involving absolute radiometry) and n = 1, with as an important criterion the uncertainty (in terms of reproducibility for n > 0) inherent in its realization. This will be further detailed in section 7. Whereas the cases n = 0 and n = 1 (involving the gold point, 1064.18 °C) have been compared in [2] and [3], the option n = 2 has, to our knowledge, not been considered before.

## 3. Scenario for realizing a HT-ITS-20xx, main elements

### 3.1.Fixed points

It is suggested to establish the thermodynamic temperatures to be associated with the transition temperatures of X1 and X2 via an international comparison based upon the application of absolute radiometry involving lens-based filter radiometers [2,4], referred to in section 2, directly traceable to the cryogenic radiometer. The comparison should, preferably, involve sets of X1 and X2, consisting of samples originating from different sources, being characterized in terms of their transition temperatures, at the standards institutes contributing to the comparison. After a critical assessment of the results of such a comparison, ITS-20xx values *Txx1* and *Txx2* could be assigned to X1 and X2, assuming that the reproducibilities $\delta Txx1$ and $\delta Txx2$ associated with the realisation of X1 and X2 are still significantly smaller than the uncertainties $\delta(T1)$ and $\delta(T2)$,quoted for the thermodynamic temperatures *T1* and *T2*.

Remarks:

1. If it would turn out that $\delta(T1)$ and $\delta(T2)$ are essentially made up by $\delta Txx1$ and $\delta Txx2$, still for practical reasons one might choose to define HT-ITS20xx, as proposed.

2. As a matter of fact the transition temperature of the M-C-Eutectic involved should have been adequately identified before starting the comparison.

### 3.2. Relative spectral reponsivity $s(\lambda)$

Methods already established in filter radiometry can be taken advantage of. Instabilities due to thermal drifts of the filters or detectors, subjected to high flux levels at extreme temperatures should be minimized by temperature stabilizing these components including maybe flushing the radiometers with temperature-stabilized inert gases, such as to minimize the effects of high flux levels on the overall performance of the radiometers involved.

### 3.3. Non-linearity *NL*

Here we will restrict ourselves to considering the case in which the non-linearity (NL) affecting the filter radiometers (FRs) to be characterized is measured in-situ by means of stable blackbody radiators, available in a thermometric standards laboratory, i.e. disregarding the application of coherent sources, common in radiometry. It is suggested considering the filter method [5] an option to measure *NL* -or checking linearity- over the whole temperature range to be covered; the (neutral density) filter could be a (movable) component integrated in the design of the FR; this would add however to the complexity of the instrument. High-temperature variable-temperature blackbody radiators (HTBBRs) with adequate stability, encompassing the whole temperature range to be covered by the HT-ITS20xx, such as the ones developed at VNIIOFI [4], should provide a convenient flexibility in measuring *NL* by means of the filter method. It should be stressed that the temperatures of the blackbody radiators to be implemented in determining the *NL* have not to be known, only temperature stability is required.

Remark:

Variation of the instrument temperature $T_I$ (optics, filter, detector) with source temperature $T$ could in principle be made a component co-determining the non-linearity parameter *NL*, under the condition that a univocal relation exists between $T_I$ and $T$. It is suggested checking whether monitoring the surface temperatures of the critical components within the instrument using non-contact methods such as fibre-coupled external temperature-stabilized radiation detectors would be feasible.

## 3.4. Signal versus temperature representation .

3.4.1. The following scheme [6] could be envisaged. Defining *S(Txx1)* as the signal measured at X1: signal ratio's $X(T) = S(T) / S(Txx1)$ can be related to the ratio's $Y(T) = Q(T)/Q(Txx1)$, where the transfer integral $Q(T) = \int P(\lambda,T).s(\lambda)d\lambda$ integrates the product of Planck function $P(\lambda,T)$ and the relative spectral responsivity $s(\lambda)$, as follows :

$$Y(T) = A1 . [ 1 + \Sigma_{i=1}^{m-1} (A_{i+1}/A_1) . X(T)^i ] . X(T) . \quad (1)$$

The coefficients $A_i$ , for i =1 to m, where we suppose m ≥ 2, and thus $A_1$ and the non-linearity coefficients $a_i = A_{i+1}/A_1$ can be directly derived from the non-linearity data, referred to in section 3.3 [5]. A small offset term $A_0 \approx [X(Txx2) - Y(Txx2)] / [X(Txx2) - 1]$ on the right-hand side of eq. (1) has been neglected. From the ratio's *Y(Txx2)* and *X(Txx2)* specified at the second reference point X2, with $Txx2 > Txx1$, a more accurate value of the main coefficient $A_1$ can be obtained. Eq. (1) allows us to define the non-linearity factor *NLF(T)* :

$$NLF(T) = 1 + \Sigma_{i=1}^{m-1} a_i .X(T)^i . \quad (2)$$

3.4.2. When taking differences $Y(T) = Q(T) - Q(Txx1)$ and $X(T) = S(T) - S(Txx1)$, instead of ratio's for the variables in eq. (1), any offset term is eliminated [6]. In that case the non-linearity data would provide only the non-linearity coefficients $a_i = A_{i+1}/A_1$ , and $A_1$ has to be necessarily derived from *Y(Txx2)* and *X(Txx2)*.

3.4.3. Alternative expansion schemes should be considered, such as to eventually deal in an optimum way with the non-linearity characteristics of the detectors inherent in the utilized filter radiometers.

# II. Maintaining the proposed HT-ITS-20xx

## 4. Recalibration schemes.

4.1. Two-point recalibration schemes of the filter radiometers carrying the HT-ITS-20xx on mid-term time scales (1 year ?) based upon recalibrations at X1 and X2 only can be envisaged.

4.2. On a long-term time scale (2 years or more ?) complete (re)calibrations involving (re)determining $s(\lambda)$ and *NL* , as well as (re)calibrations at X1 and X2 are imposed. As to the measurement of *NL*, the application of HTBBRs with high enough stability, covering the required temperature range, such as the ones developed at VNIIOFI, would be a prerequisite .

Remark:

These radiators would suit the transfer of radiance temperatures and radiometric or photometric quantities over large continuous ranges of the parameters involved, but at the same time, in conjunction with appropriate M-C Eutectics, would provide special standards in these fields [1].

## III. Disseminating the proposed HT-ITS-20xx.

### 5.Dissemination schemes

5.1. Standard filter radiometers (SFRs) in conjunction with variable-temperature HTBBRs

SFRs with full-scale calibrations, described in sections 4.1. and 4.2, in conjunction with high-quality HTBBRs would allow quasi-continuously calibrating transfer filter radiometers (TFRs) to provide traceability in the temperature range defined by the cross-section of the ranges covered by TFR and HTBBR.

5.2. Transfer Filter Radiometers (TFRs) in conjunction with selected sets of M-C Eutectics.

TFRs, specified at least for relative spectral responsivity, calibrated against selected sets of M-C Eutectics, MC[i], with *T20xx[i]* assigned to them, would entail traceability in the sub-ranges in temperature, covered by the selected MC[i]. This will be further detailed in section 8.

## IV. Uncertainties.

### 6. Evaluation of uncertainties

Uncertainties associated with the high-temperature representation of the ITS-20xx, with n=2, as proposed above, should be evaluated, to be compared with uncertainties inherent in alternative scenario's, such as the ones referred to above in Section 2 and below in Section 7, involving at least n=0 and n=1.

## V. Appendix: ramifications

### 7. Reference systems

7.1. Apart from n = 0, the case n = 1 deserves to be reconsidered, as reference to the case n = 2, proposed above. For n = 1 the modelling of a scale definition should probably proceed via a MC-Eutectic fixed point *Txx0*, with *Txx1*< *Txx0* ≤ *Txx2,* -qualified as indicated in section 3.1- rather than via a fixed point (Ag, Au, Cu) selected in the ITS-90, from which the scale, involving again *s(λ)* and *NL*, could be stretched out beyond *Txx1* and *Txx2*, wherever the *NL* parameter could be experimentally established. This sets however strict requirements as to the reproducibility of *Txx0.*

Remarks:

1. In principle two different filter radiometers might be used above and below *Txx0,* albeit at the cost of introducing formal complications, associated with the continuity of the signal vs. temperature representation at *Txx0*. It would have the advantage of allowing two filters being used with differing relative spectral responsivity functions *s1(λ)* and *s2(λ)* below and above *Txx0* , such as to achieve the highest possible accuracy over the whole range covered by the HT-ITS20xx . Cf. the analogue situation in the SPRT range of the ITS-90, where SPRTs of a different kind are used below and above the triple point of water. In this respect it seems worthwhile to consider standardizing the responsivity functions $s_i(\lambda)$ inherent in the definition of the HT-ITS-20xx.

2.Here we refrain from considering in addition the case implying the definition of two overlapping sub-ranges, each of them denoted as n = 1, with associated reference temperatures *Txx01* and *Txx02.*

7.2. Whether or not the case n=3 should be referred to as well, still involving *NLF(T)* and -as a matter of fact- *s(λ),* such as to provide the highest interpolation accuracy, remains to be considered. This would imply three reference points *Txx1, Txx0, Txx2* being selected, where again *Txx0* is suitably chosen between *Txx1* and *Txx2.* Now, if indeed a third intermediate reference point *Txx0* with adequate reproducibility would be available, in eq. (1) a more accurate value, not only for the coefficient $A_1$ , but also for $A_2$ could be obtained.

Remark:

Implementing two sub-ranges, each of them denoted as n=2, with a common *Txx0* would again have the advantage of allowing in principle two different filter radiometers being used above and below *Txx0* .

## 8. Special options

8.1. Dissemination of the proposed HT-ITS-20xx in sub-ranges to be explicitly defined could be envisaged. One obvious approach would be using selected sub-sets MC[i] of the available M-C Eutectics, specified for their transition temperatures in terms of the HT-ITS20xx, to (re)calibrate standard radiation thermometers (≡standard filter radiometers), (re)specified at least for their relative spectral responsivity *s(λ),* on the basis of interpolation schemes involving again eq. (1). In this way the non-linearity factor *NLF(T)*, eq. (2), characterizing the radiometer to be calibrated would be indirectly (re) established [6], which would allow monitoring also this instrument function in the course of time. Scheme 8.1. would suit the purpose of disseminating the HT-ITS-20xx to its users in the sphere of science and industry.

8.2. An alternative would be e.g. using the Hattori-Sakuma equation [7] rather than eq. (1) as the fitting equation in scheme 8.1. In this case instrument functions are not explicitly involved.

Remarks:

1.In a sense the M-C Eutectics, referred to in section 8.1, would take over the role of the tungsten-strip lamp used in the dissemination of the ITS-90 above the silver point. Obviously, the essential advantage inherent in their use, as in the case of reference points in general, would be that physically reproducing MC[i] would entail reproducing the associated transition temperatures *T20xx[i]*.

2. It might be of advantage to initially include the assembly of M-C Eutectics [1] as developed at NMIJ in determining the *NL* of the FRs involved in realizing the HT-ITS-20xx. Apart from Ag and Cu, the assembly could include e.g. Fe-C, Ni-C, Pd-C, Rh-C, Pt-C, Ru-C, Ir-C, Re-C, TiC-C,… possibly up to NbC-C, in conformity with the range to be covered by the HT-ITS20xx. The advantage would be that as soon as the HT-ITS-20xx would have been defined along the lines drawn in section 2, the ITS-20xx values *T20xx*[i], excepting the defining points X1 and X2, of the MC-Eutectics MC[i] involved would have been implicitly determined in the course of characterizing the FRs via the associated signals *S*[i], measured in determining the *NL* by means of the filter method [5].

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