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Third Committee Draft of Recommendation

BLACKBODY RADIATORS FOR CALIBRATION OF RADIATION THERMOMETERS

Calibration and Verification Procedure

Subcommittee: TC11/SC3 “Radiation Thermometers”

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CIE, International Commission on Illumination
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Contents

Explanatory Note	3
Scope.....	3
1. Terms, Definitions, Units and References	Erreur ! Signet non défini.
3. Technical Requirements for Blackbody Radiators (BBR).....	4
4. Metrological requirements for blackbody radiators; tested characteristics of radiators	5
5. Calibration and verification conditions	5
6. Methods for calibration and verification of blackbody radiators. Form of the report.	6
7. Annex.....	14
Forms of the calibration and verification certificates for the blackbody radiator	14
1., Results of the evaluation of the blackbody radiator cavity geometry	14
2., Results of the evaluation of the warm-up time, temperature drift and transition time for the blackbody radiator to pass from a stationary mode to another.....	14
3., Results of the evaluation of the blackbody radiator temperature keeping uncertainty	15
4., Results of the correction evaluation during sighting along the blackbody radiator axis	15

Explanatory Note

This Draft Recommendation deals with the metrological control in manufacturing and operating of a blackbody radiators (further named BBR) with a regulating temperature in the OIML member-states. It can be a basis for verification, calibration and certification of these instruments.

Now the great part of manufactured pyrometers are verified and calibrated against blackbody radiators, and this proportion is constantly increasing. With the growth of the number of pyrometers, also grows the number of manufactured blackbody radiators. However, no international documents describing calibration and verification of these blackbody radiators are available. Therefore the present Recommendation is quite important.

1 Scope

The present Recommendation applies to BBR intended for calibration, verification and engineering work in production, maintenance and adjustment of reference and working pyrometers, thermal imaging instruments and radiometers in the temperature range from minus 50 °C to plus 2500 °C; it sets up methods and procedures for their calibration and verification.

2. Terms, Definitions, Units and References

2.1 The Recommendation uses the following **terms** and **definitions**:

- 2.1.1 **Blackbody radiator (BBR)** – radiator with an effective emissivity ε close to one ($\varepsilon \geq 0,95$).
- 2.1.2 **Permissible uncertainty U_{pBB}** – expanded uncertainty at a specified confidence level (0,95 or 0,99) declared in the technical documentation, at which the BBR is considered fit for its intended use.
- 2.1.3 **Temperature keeping instability, T_{ki}** – instability of the BBR temperature keeping in a specified stationary temperature mode, i.e. standard deviation of the BBR temperature values measured every 10 – 15 seconds during 15 – 20 minutes with reference to their average value during the same period.
- 2.1.4 **Temperature drift, T_d** – temperature drift of the BBR during its operation in a specified stationary temperature mode, which is equal to the maximum difference of average temperature values determined every five minutes (measurements being taken every 10 – 15 seconds) during fifteen minutes.
- 2.1.5 **Transition time, t_t** – the required time for the BBR to pass from one stationary mode to another
- 2.1.6 **Warm-up time, t_w** – time elapsed from the moment of turning on the BBR till it reaches the specified working stationary temperature mode when it is allowed to determine the metrological characteristics of the BBR.
- 2.1.7 **Demountable contact sensors** – the contact thermometers, which can be removed from the BBR without its dismantling for the purpose of a separate calibration and/or verification.
- 2.1.8 **Permanent jointed contact sensors** – thermometers that cannot be removed from the BBR without the dismantling of the latter.
- 2.1.9 **BBR own thermometer** – built-in sensor and output signal (showing device, or interface, or transmitter transforming a signal of the sensor to an electric signal,

correlated with temperature).

- 2.2 Celsius degrees ($^{\circ}\text{C}$) or kelvins (K) are used as a temperature unit or a temperature difference (drift, instability etc.) in this Recommendation.

2.3 References

- [1] Guide to the Expression of Uncertainty in Measurement: First edition. – ISO, Switzerland, 1993
- [2] J. Fischer et al., «CCT-WG5 on radiation thermometry, Uncertainty budgets for realization of scales by radiation thermometry», 2003, CIPM, CCT/03-03. Summary in Temperature, Its Measurement and Control in Science and Industry, 2003 vol.7, D.C.Ripple ed., Melville, New York, pp.631-638
- [3] J. Fischer et al., «CCT-WG5 on radiation thermometry, Uncertainty budgets for calibration of radiation thermometers below the silver point», Ver. 1.71, CIPM, CCT-WG5/docs-03-2008 (<http://www.bipm.org/wg/AllowedDocuments.jsp?wg=CCT-WG5>)

3. Technical Requirements for Blackbody Radiators (BBR)

3.1 Types of BBRs

- 3.1.1 The BBRs can have a point or an extensional radiating area.
- 3.1.2 The BBRs can be intended for working with the temperature fixed points (Fixed-Points-Blackbody) or for the variable temperature range (Variable-Temperature-Blackbody) and shall have a temperature adjustment system.
- 3.1.3 The BBRs are subdivided with respect to the method of the radiance temperature measurement into the following types:
 - BBRs with demountable contact sensors;
 - BBRs with permanent jointed contact sensors that are either included into the automatic temperature adjustment system, or that are operating off-line;
 - BBRs with non-contact sensors that are either included into the automatic temperature adjustment system, or that are operating off-line.
- 3.1.4 The BBRs can be portable or stationary.
- 3.1.5 Requirements to the design of BBRs.
The BBR should be equipped with a handle or an automatic temperature adjustment system and with a temperature showing device or/and with a socket or plugs of an output signal (analogue or digital) correlated with the BBR temperature value.
- 3.1.6 It is desirable (for verification - required), that characteristics of the BBR, such as:
 - the working temperature range (or fixed values),
 - the radiating area,
 - the instability,
 - the drift,
 - the effective emissivity,
 - the spectral selectivity,
 - the permissible uncertainty of the BBR temperature,
 - the warm-up time,
 - the transition time,
 - the correction factor to the readings of the BBR own thermometer –
 – should be given in its technical documentation (hereinafter referred to as TD).

If any of characteristics are not resulted in the TD, its actual value is defined

at calibration, and it is not checked at verification.

Notes.

1. Among the above mentioned characteristics, the effective emissivity is the hardest to be separately evaluated (calibrated, verified), because it considerably depends on the BBR design, on the form of the radiating area and on the materials used.

It is therefore impossible within the framework of this Recommendation, that does not deal with technological and constructive differences of BBRs, to regulate specific requirements and operations allowing to calculate or to measure this quantity. It is supposed that it has been taken into account in the correction value applied to the readings of the BBR's own thermometer and determined by the comparison with a reference BBR traceable to the primary standard of the temperature unit.

2. The spectral selectivity of the BBR is also considerably dependent on the BBR design, the form of the radiating area and the materials used. This dependence is ill-defined for the BBRs with cavity-type radiating element and can be noticeable for the BBRs with radiating surface with special coating to ensure a high blackness of radiation. In the latter case it is necessary to know the spectral curve of the dependence of the reflectance on the wavelength and this curve shall be given in the specifications.

In the case of precision BBRs, if a separate evaluation of the effect of these characteristics is required in the process of their subsequent use, it is necessary to follow the main principles and methods of their evaluation that are specified in documents [2,3] from subsection of this Recommendation.

4. Metrological requirements for blackbody radiators; tested characteristics of radiators

In the process of testing (calibration, verification) the following metrological characteristics of the BBR shall be determined:

- 4.1 Temperature range (or fixed values).
- 4.2 Size of the emitting area of the BBR.
- 4.3 Warm-up time required for the BBR to reach the specified stationary mode at the lower and upper levels of the working temperature range of the BBR.
- 4.4 Transition time required for the BBR to pass from one stationary mode to another.
- 4.5 Temperature drift during the operation in specified stationary modes.
- 4.6 Instability of temperature keeping at specified levels.
- 4.7 Corrections to the readings of the BBR own thermometer (or output signal).
- 4.8 Expanded uncertainty of the BBR temperature at a specified confidence level.

5. Calibration and verification conditions

5.1 The process of verification and calibration should be carried out in a stable indoor environment within the measurement conditions (a temperature range and the relative humidity range) accepted in each country, unless the other conditions are specified by customer; the conditions should be written down in the calibration certificate. A BBR should not be affected by shocks, vibrations, external electromagnetic fields, extraneous

radiation sources influencing the readings of measuring instruments.

5.2. The calibration shall be carried out by an accredited calibration laboratory.

6. Methods for calibration and verification of blackbody radiators. Form of the report.

6.1 Operations and means for calibration and verification of BBRs

6.1.1 The operations and measuring instruments to be used for calibration and verification are listed in Table 1.

Table 1

No	Operation	Item in the text	Verification instruments and their characteristics	Obligation of a verification procedure	
				Initial	Periodical
1	2	3	4	5	6
1	External examination	6.2	-	Yes	Yes
2	Testing	6.3	-	Yes	Yes
3	Evaluation of the BBR radiating geometry	6.4	- <u>Linear measuring instrument</u> with the scale factor, provided measurement of size of the radiating area with uncertainty 5 %.	Yes	No
4	Evaluation of the warm-up time, temperature drift and transition time of BBR from one stationary mode to another	6.5	- <u>Chronometer</u> ; - <u>pyrometer-comparator</u> with a corresponding measurement temperature range, the instability and the temperature resolution has to be in ≥ 3 times as much than U_{pBB} (permissible uncertainty of the testee the BBR), the field of view has to be smaller than the output apertures of the standard and testee BBRs; - <u>a device to measure output signal</u> (if necessary) with resolution (in a temperature equivalent) in ≥ 3 times as much than U_{pBB}	Yes	Yes
5	Evaluation of the BBR temperature keeping instability	6.6	Equipment from item 4 in this Table	Yes	Yes
6	Evaluation of the correction to the readings of the sensor of the BBR to be calibrated (verified)	6.7	- <u>Standard BBR</u> with the variable temperature in a corresponding measurement temperature range or with temperatures of the fixed points (depends on testee the BBR), uncertainties of all characteristics specified in lines 3 – 7 of this Table shall be in ≥ 3 times as less than U_{pBB} , emissivity have to be 0.99 or higher, - <u>pyrometer-comparator</u> with a corresponding measurement temperature range, the instability and the temperature resolution has to be in ≥ 3 times as much than U_{pBB} , the field of view has to be smaller than the output apertures of the standard and the testee BBRs; - <u>a device to measure or decoding an output signal</u> (if necessary) with	Yes	Yes

No	Operation	Item in the text	Verification instruments and their characteristics	Obligation of a verification procedure	
				Initial	Periodical
1	2	3	4	5	6
			resolution (in a temperature equivalent) in ≥ 3 times as much than U_{pBB}		
7	Calculation of the expanded uncertainty of the BBR temperature	6.8	Calculation of the uncertainty should be carried out with according to [1]	Yes	Yes

- 6.1.2 All measuring instruments specified in Table 1 shall be calibrated traceable to national standards and provided with the corresponding legal documents about their verification or calibration.
- 6.1.3 Standard BBRs shall be calibrated traceable to national standards and the International Temperature Scale (the ITS-90).
- 6.1.4 Measuring instruments are prepared for operation in accordance with their valid documentation.
- 6.1.5 Demountable BBR own thermometers shall have valid calibration or verification certificates.
- 6.1.6 The experts qualified for performance of verification in the field of temperature and radiometric measurements, are admitted to verification and calibration.

6.2 External examination

During external examination the following points shall be checked:

- 6.2.1 Correspondence of the completeness of BBR set to the requirements of its valid documentation;
- 6.2.2 Correspondence of the BBR to the safety requirements specified in the TD;
- 6.2.3 Absence of external damage of the calibrated (verified) BBR set that may adversely affect its metrological performance and main functions.
- 6.2.4 BBR that does not comply with the requirements of item 6.2.3 is not subject to calibration or verification.

6.3 Testing

- 6.3.1 The BBR is connected to a power supply and its serviceability is tested in compliance with the valid documentation.
- 6.3.2 A BBR in which a defect was found during the testing (for example: inability to look some of the display readout, apparent instability, etc.) is rejected for a farther calibration (verification).

6.4 Evaluation of the BBR radiating geometry

- 6.4.1 The outlet diameter of the BBR radiating size and the cavity depth (in case of a cavity BBR) shall be measured once by means of a linear measuring instrument.

The difference between the measured values and the values specified in the TD, shall not exceed 5 % with reference to the declared values.

- 6.4.2 If relative differences calculated according to 6.4.1 exceed the limits $\pm 5\%$, the calibration (verification) certificate shall specify actual dimensions and the recommendation to the customer to amend the TD and to update (vindicate) the emissivity value.
- 6.4.3 In case of doubts concerning value of the effective emissivity or in case of special demands it is necessary to obey the maintenance and the recommendations resulted in [2] and [3].
- 6.5 Evaluation of the warm-up time, temperature drift and transition time for the BBR to pass from one stationary mode to another
- 6.5.1 The warm-up time of the BBR is interrelated with its temperature drift. Therefore these parameters shall be determined simultaneously.
- 6.5.2 The warm-up time of the BBR at the lower temperature limit is determined by setting the value corresponding to the lower temperature limit on the temperature control device of the BBR control unit. The BBR is turned on and entered in the specified stationary mode in compliance with TD.
- 6.5.3 When the BBR reaches the stationary mode after the time t_w , its radiance temperature is determined every 10-15 seconds during fifteen minutes by the readings of the radiance temperature measuring device having a sufficient resolution (see Table. 1). Simultaneously it is being carried out the reading the indications of the BBR own thermometer.
- 6.5.4 The average temperature values are determined in accordance with the measurement results during the first five minutes, second five minutes and third five minutes. The difference between the average temperature values shall not exceed the temperature drift value specified in the TD.
It is being carried out and for the radiance temperature values, and for temperatures defined under indications of the BBR own thermometer.
- 6.5.5 If in the process of verification the maximum difference between the average temperature values of the BBR is bigger than the drift value, the BBR is rejected as defective.
In the process of calibration the warm-up time of the BBR is determined with more precision through additional measurements. With this purpose, the operations of items 6.5.3 – 6.5.4 are repeated until the measured temperature drift becomes equal to the value specified in the TD.
- 6.5.6 If the measured drift value agrees with the value specified in the TD, the BBR warm-up time being less than $2t_w$, a new value of the BBR warm-up time is indicated in the TD.
If the measured drift value exceeds the value specified in the TD at the BBR warm-up time being equal to $2t_w$, the BBR is rejected as defective.
- 6.5.7 The BBR transition time from one stationary mode to another (t_t) is determined by setting, on the temperature setter of the BBR control unit, the value corresponding to the next temperature mode of the BBR, and, after the time specified in the TD as the transition time from one stationary mode to another expires, the operations mentioned in items 6.5.2 – 6.5.6 are repeated.
- 6.5.8 The transition time of the BBR to the stationary mode at the upper temperature

limit is determined after disconnecting the BBR from the power supply and cooling down to the room temperature. Then the value corresponding to the upper temperature limit is set on the temperature setter of the BBR control unit. The BBR is turned on again and, when the transition time of the BBR to the stationary mode at the upper temperature limit (t_{w2}) expires, the operations of items 6.5.2 – 6.5.6 are repeated, and the values t_{w2} and $2t_{w2}$ substitute the values t_w and $2t_w$.

6.6 Evaluation of the temperature keeping instability of the BBR

6.6.1 The value corresponding to the lower temperature limit is set on the temperature setter of the BBR control unit and then the BBR is adjusted to this temperature value according to its operation manual.

6.6.2 When the BBR reaches the stationary mode, the radiance temperature value T_i is measured every 10-15 seconds during 15...20 minutes by the readings of the temperature measuring device with a resolution no worse than 0,1 °C.

The average temperature value during the period $t = 15 \dots 20$ min T_a and the experimental standard deviation of the current temperature value $u(T_i)$ are calculated using the formulae:

$$T_a = \frac{\sum_{i=1}^n T_i}{n} ; , , , u(T_i) = \sqrt{\frac{\sum_{i=1}^n (T_i - T_a)^2}{n-1}} , , , (1)$$

where T_i is the i -th temperature measurement result.

6.6.3 Similar procedure is carried out for values of temperature which are received on the BBR own thermometer.

6.6.4 For calculations of an expanded uncertainty greatest of values of the temperature received in item 6.6.1 - 6.6.3 gets out.

6.6.5 The expanded uncertainty of the temperature keeping instability depends on the confidence probability p , and is equal to the standard deviation value multiplied the coverage factor k (for example, $k = 2$ when $p = 0,95$).

6.6.6 If the standard deviation exceeds half of the temperature keeping instability specified in the TD, the BBR shall be rejected as defective.

6.6.7 Operations in items 6.6.1 – 6.6.4 are repeated for the BBR with regulated temperature at the mid and maximum temperature values in the working range.

6.7 Evaluation of the correction to apply to the readings of the BBR own thermometer

6.7.1 The correction to the readings of the BBR own thermometer is determined by comparing it with a standard BBR by a pyrometer-comparator, or by direct measuring of its radiance temperature with a standard radiation thermometer.

A standard BBR and a standard radiation thermometer shall be calibrated on radiance temperature traceable to national standards and the International Temperature Scale (the ITS-90) by an accredited calibration laboratory.

6.7.2 The correction to the readings of the BBR own thermometer of the BBR to be calibrated (verified) in the low temperature range (from minus 50 °C to about plus 300 °C) is determined by comparing it with a standard BBR by a pyrometer-

comparator working in a full radiation or in a spectral interval 8 – 14 μm , or by direct measuring of its the radiance temperature with a standard radiation thermometer working in a such spectral interval.

- 6.7.3 A BBR to be calibrated (verified) is placed on a test bench connected to the power supply and adjusted to the specified lower stationary temperature mode.
- 6.7.4 Comparisons are performed by means of a comparator using the equal signals method. With this purpose, the comparator is placed in such a way that its optical axis lies in the axis of the standard BBR and passes through the centre of its radiating aperture. The operation is carried out using a measuring rule, a crosshair stop inserted into the radiating aperture, and a comparator viewfinder. The comparator is turned on and its output signal (display indication, voltage, current, code) is measured.
- 6.7.5 Then the comparator is directed at the tested BBR. The temperature of the tested BBR is selected in such a way that the comparator signal were equal to the signal from the standard BBR. The standard BBR temperature and the readings of the calibrated (verified) BBR own thermometer are specified. The measurements shall be repeated 10 times. The average temperature values of the standard BBR and of the BBR own thermometer to be calibrated (verified) are calculated.
- 6.7.6 The correction to the readings of the BBR own thermometer to be calibrated (verified) is determined as a difference of the average temperature values of the standard and calibrated (verified) BBRs.
- 6.7.7 In the calibration of the variable temperature BBR, the standard BBR and the BBR to be calibrated (verified) are entered in the next stationary temperature mode and operations are carried out according to items 6.7.3 – 6.7.6. These operations are repeated at all the specified in TD (or required by customer) temperature modes of the BBR.
- 6.7.8 In the verification of the variable temperature BBR the number of specified temperature modes may be reduced to three (including minimal and maximal temperatures).
- 6.7.9 The correction values obtained during the calibration are specified into the certificate of calibration, if they exceed a half value of the expanded (permissible) uncertainty of the BBR temperature.
- 6.7.10 If the correction value obtained during the verification differs from the correction value given in the TD by more than a half value of the permissible expanded uncertainty of the BBR temperature even at one temperature mode, the correction shall be revised at all specified temperature modes of the BBR. The obtained new correction values are specified in the TD of the BBR in the same way as during the calibration.
- 6.7.11 If the corrections are determined by means of a standard pyrometer, they are calculated as a difference of the average readings of the standard pyrometer and the BBR own thermometer to be calibrated (verified).
- 6.7.12 The correction to the readings of the BBR own thermometer to be calibrated (verified) in the mid temperature range (about from 300 °C to 1000 °C) is determined by comparing it with a standard BBR by means of pyrometer-comparators with the partial spectral range, or standard pyrometers with two or three partial spectral ranges, e.g., with the ranges 2 – 5 and 8 – 14 μm . The operations described in items 6.7.3 – 6.7.11 are carried out for each spectral intervals.
- 6.7.13 If the correction obtained with different spectral intervals (within one temperature

mode) do not agree with each other within a half value of the permissible expanded uncertainty, they shall be averaged over all spectral intervals and the maximum deviation of the correction from its average value shall be taken into account as half of an uncertainty component of temperature u_{si} . Otherwise $u_{si}=U_{pbb}$

- 6.7.14 The corrections to the readings of the BBR own thermometer to be calibrated (verified) at the temperature 800 °C and higher can be determined by comparing it with a standard BBR by means of a spectrocomparator with a narrow spectral band depending on the purpose of the BBR to be calibrated (verified). During the verification it is allowed to use the pyrometers-comparators, or the standard pyrometers with the partial spectral interval instead of the spectrocomparator.
- 6.7.15 If the BBR to be calibrated (verified) is intended for calibration of pyrometers of a concrete type, it is possible to calibrate (verify) the BBR by means of this type a pyrometer calibrated as reference pyrometer or a pyrometer-comparator and meet to requirements of the table 1, irrespective of the temperature range.
- 6.7.16 If the BBR to be calibrated (verified) is able to be applicable for calibration of pyrometers with wide-angle objectives, the dependence of correction on view angle shall be determined. With this purpose, the operations from items 6.7.2 - 6.7.15 are carried out for each view angle depending on the temperature mode. The average correction value is determined by all view angles. If the correction obtained higher a half value of the permissible expanded uncertainty, the maximum deviation of the corrections from the average value by all view angles is taken into account as the uncertainty component u_{va} . Otherwise $u_{si}=U_{pbb}$
- 6.7.17 The dependence of correction to the radiating surface non-uniformity shall be determined only for BBRs with the extensional radiating surface. With this purpose, the average correction value is determined as the maximum difference between radiance temperature values from ≥ 5 points of the surface (in the center and on periphery) and their average value. It is taken into account as the uncertainty component u_{rs} .
These measurements are made according to items 6.7.2 – 6.7.13. In this case the dependence of correction on the view angle is not determined. Usually it needs at temperatures lower than 300 °C

6.8 Evaluation of the uncertainty of the BBR temperature

The basic components of the uncertainty budget in calibration (verification) of a BBR:

6.8.1 Uncertainty of the standard measuring instruments

a) Calibration (verification) option by comparison with a reference BBR using a comparator:

Uncertainty of temperature relating to the reference BBR

u_{sb} – includes the uncertainty of its calibration; its instability; uncertainty due to its positioning against the optical axis of the comparator; uncertainty of measuring instruments used to maintain the conditions of its operation; uncertainty due to the effect of the ambient conditions.

u_{sb} shall be specified in its calibration certificate. It (uncertainty) shall be expressed in terms of extended uncertainty with the confidence level of $p=0,95$. If it is expressed as standard uncertainty, its value should be reduced to the standard value by multiplying by the coverage factor $k_p=2$ determined by this probability.

Uncertainty due to pyrometer-comparator.

For the pyrometer-comparator the following sources of uncertainty shall be known:

u_1 – uncertainty component caused by the effect of ambient temperature fluctuations during the calibration;

u_2 – uncertainty component due to instability of the measurement transducer efficiency;

u_3 – uncertainty component due to resolution of the instrument measuring the output signal;

u_4 – uncertainty component due to the difference in the dimensions of the reference radiation source and the radiation source under calibration (effect of the source dimensions)¹.

The combined uncertainty of the standard measuring instruments shall be calculated by formula:

$$u_{st} = \sqrt{(u_{sb}^2 + u_1^2 + u_2^2 + u_3^2 + u_4^2)}, \quad (3)$$

b) Calibration (verification) option by direct measurement using the reference pyrometer:

Uncertainty of temperature related with the reference pyrometer.

u_{sp} – is the uncertainty due to the reference pyrometer, it includes: the uncertainty of its calibration; its instability; uncertainty due to its positioning against the optical axis of the comparator; uncertainty due to the effect of ambient conditions.

The uncertainty of the standard pyrometer shall be specified in its calibration certificate. In the same way as mentioned in the previous section, this uncertainty shall be expressed in terms of the expanded uncertainty with the probability level of $p=0,95$. If it is expressed as standard uncertainty, its value shall be reduced to the standard value by multiplying by its coverage factor $k_p = 2$ determined by this probability.

The uncertainty due to the difference between dimensions of the BBR used in calibration of the reference pyrometer and the dimensions of the BBR to be calibrated is explained in Note 1 to Section 6.8.1a.

The uncertainty of the standard measuring instruments u_{st} in this case shall be equal to u_{sp} .

The standard uncertainty estimated by Type A, represents the standard deviation

¹ Usually, in the process of calibration in the conditions of laboratory the fluctuations of the ambient temperature are negligibly small; the requirements for instability and resolution of the instrument measuring the output signal of the comparator given in Table 1 also allow to ignore these uncertainty components. What is really shall be taken into account is the uncertainty due to the difference in the dimensions of the compared BBRs. According to the estimates of [2] and [3] the normal standard value of this uncertainty in the case of different dimensions of the compared BBRs varies between 0.1 and 0.2 %. If it is necessary to calibrate with an uncertainty below 0.5 %, one shall be guided by the rules and estimates given in [2] and [3].

of the measurement result obtained in determining the correction to the calibrated BBR thermometer readings; it is calculated by the formula:

$$u_A(T) = \frac{T_a}{\sqrt{n}}, \quad (4)$$

where:

T_a is the average temperature of measurements have being carried out in accordance of 6.6.2;

n is the number of measurements

6.8.2 The standard uncertainty of the BBR temperature estimated by Type B – $u_B(T)$ – is calculated by the formula:

$$u_B(T) = \sqrt{\frac{1}{3}(u_{st}^2 + u_{ci}^2 + u_{si}^2 + u_{va}^2 + u_{rs}^2)}, \quad (5)$$

where:

u_{st} -, is the expanded temperature uncertainty of the standard measuring instruments;

u_{ci} -, is the instability of the own thermometer of the BBR to be calibrated (verified) during the calibration interval, the limits of which have to be given in the TD;

u_{si} -, is the uncertainty due to the difference between the corrections to the BBR own thermometer to be calibrated (verified) in different spectral intervals and at different view angles; it depends on the calibration (verification) limits of uncertainty according to 6.7.15;

u_{va} -, is the uncertainty due to the difference between the corrections to the own thermometer of the BBR to be calibrated (verified) at different view angles, which depends on the calibration (verification) limits of uncertainty according to 6.7.16;

u_{rs} -, is the uncertainty due to the difference between the temperatures by the radiating surface of the BBR to be calibrated (verified), which depends on the calibration (verification) limits of uncertainty according to 6.7.16.

All components of the budget have to be expressed as extended uncertainties of limits of permissible values

6.8.3 The combined standard uncertainty of temperature measurement of a BBR to be calibrated (verified) – $u_\Sigma(T)$ – is calculated by the formula:

$$u_\Sigma(T) = \sqrt{u_A^2 + u_B^2}, \quad (6)$$

6.8.4 The expanded uncertainty of the temperature value of the BBR to be calibrated (verified) with the confidence probability p determined by the factor k , is calculated by the formula:

$$U = k \cdot u_\Sigma(T), \quad (2)$$

where k is the coverage factor depending on the confidence probability p (at $p = 0,95$ $k = 2$, at $p = 0,99$ $k = 3$);

- 6.8.5 The obtained expanded uncertainty of the temperature value of the BBR to be verified shall not exceed the corresponding uncertainty specified in the TD.
- 6.8.6 The calibration interval lasts usually for one or two years in case of BBRs with permanent jointed thermometers or in case of BBRs with demountable thermometers, respectively, if the other characteristic not specified in the TD.
- 6.9 Drawing up the results
- 6.9.1 The calibration and verification results are entered into the protocols, the forms for which are given in the Annex.
- 6.9.2 A verification or calibration certificate is issued if the verification or calibration results are favorable. If the verification or calibration results are unfavorable, a notice on unserviceability of the instrument is issued, and the reasons being identified.
- 6.9.3 The following data and parameters shall be specified in calibration or verification certificates:
- 1) radiating area dimensions of the BBR (cavity dimensions in case of the cavity BBR);
 - 2) warm-up time of the BBR;
 - 3) transition time for the BBR to pass from one stationary mode to another;
 - 4) temperature drift of the BBR;
 - 5) temperature keeping instability of the BBR at the specified stationary mode;
 - 6) correction to the BBR own thermometer indication;
 - 7) expanded uncertainty of the BBR temperature value;
 - 8) positions of the temperature setter (if it given) of the BBR control unit depending on temperature (in the table form);
 - 9) indication about using the BBR as a reference one;
 - 10) calibration (verification) interval of the BBR.

7. Annex

Forms of the calibration and verification certificates for the blackbody radiator

1., Results of the evaluation of the blackbody radiator cavity geometry

Outlet diameter, mm		Distance from the outlet to the back wall of the BB model, mm	
Permissible value	Measured value	Permissible value	Measured value

2., Results of the evaluation of the warm-up time, temperature drift and transition time for the blackbody radiator to pass from a stationary mode to another

Temperature $T, ^\circ\text{C}^*$	Readings of the BBR own thermometer to be calibrated (verified), $^\circ\text{C}$	Average temperature values at the time intervals $t_1, t_2, t_3, ^\circ\text{C}$			Maximum difference of the average temperature values at the time intervals $t_1, t_2, t_3, ^\circ\text{C}$	
		t_1 (0–5 min)	t_2 (5–10 min)	t_3 (10–15 min)	Permissible value	Value calculated by the measurement data

3., Results of the evaluation of the blackbody radiator temperature keeping uncertainty

Temperature $T, ^\circ\text{C}$	Readings of the thermometer of a BBR to be calibrated (verified), $^\circ\text{C}$	Average temperature value, $^\circ\text{C}$	Maximum deviation from the average temperature value, $^\circ\text{C}$	
			Permissible value	Value calculated by the measurement data

4., Results of the correction evaluation during sighting along the blackbody radiator axis

4.1 Results of the correction evaluation using full radiation comparators

Temperature $T, ^\circ\text{C}$	Thermometer readings of a BBR to be calibrated (verified), $^\circ\text{C}$	Radiance temperature of a standard BBR, $^\circ\text{C}$	Difference between the radiance temperature of a standard BBR and thermometer readings of a BBR to be calibrated (verified), $^\circ\text{C}$

4.2 , Results of the correction evaluation using pyrometers-comparators with a partial spectral range

Temperature $T, ^\circ\text{C}$	Spectral range, μm	Thermometer readings of a BBR to be calibrated (verified), $^\circ\text{C}$	Radiance temperature of a standard BBR, $^\circ\text{C}$	Difference between the radiance temperature of a standard BBR and thermometer readings of a BBR to be calibrated (verified), $^\circ\text{C}$

The average temperature difference for all spectral ranges, $^\circ\text{C}...$

The maximum deviation from the average temperature difference, $^\circ\text{C}...$

4.3 Results of the correction evaluation depending on the view angle of a BBR to be calibrated (verified)

The table is filled for each view angle according to 4.2. Then the results are summarized in the following table:

Temperature T , °C	View angle, α_i , $i=1\dots m$, grad	Differences between the standard BBR temperature and temperature indicated by the thermometer of the calibrated (verified) BBR thermometer for $j=1\dots n$ spectral bands, °C		Uncertainty of correction for each band and angle, °C	Average value [*] of the temperature correction for all spectral ranges and angles, °C
		The j -th band	Average by all angles		
⋮	⋮	⋮	⋮	⋮	⋮

The maximum deviation from the average temperature correction for all spectral ranges and angles, °C...

4.4 Results of the correction evaluation depending on the location of sighting at a BBR to be calibrated (verified)

Temperature T , °C ²	Thermometer readings of a standard BBR, °C	Coordinates of the location of view, mm	The BBR own thermometer readings, °C	Difference between the thermometer readings of a standard BBR and a BBR to be calibrated (verified), °C
⋮	⋮	⋮	⋮	⋮

The average temperature difference for all sighting locations, °C...

The maximum deviation from the average temperature difference, °C...

² T is the temperature set measured by the own thermometer of the BBR to be calibrated (verified)