INTERNATIONAL
DOCUMENT

OIML D 24

Edition 1996 (E)

Total radiation pyrometers

Pyromètres à radiation totale

OIML D 24 Edition 1996 (E)

ORGANISATION INTERNATIONALE
DE MÉTROLOGIE LÉGALE

INTERNATIONAL ORGANIZATION
OF LEGAL METROLOGY

Contents

Foreword 3

1 Scope and field of application 4

2 Units of measurement 4

3 Technical and metrological characteristics of total radiation pyrometers 5

4 Technical and metrological characteristics of calibration equipment 6

5 Calibration of total radiation pyrometers 7

6 Metrological control 11

Foreword

The International Organization of Legal Metrology (OIML) is a worldwide, intergovernmental organization whose primary aim is to harmonize the regulations and metrological controls applied by the national metrological services, or related organizations, of its Member States.

The two main categories of OIML publications are:

- **International Recommendations (OIML R)**, which are model regulations that establish the metrological characteristics required of certain measuring instruments and which specify methods and equipment for checking their conformity; the OIML Member States shall implement these Recommendations to the greatest possible extent;

- **International Documents (OIML D)**, which are informative in nature and intended to improve the work of the metrological services.

OIML Draft Recommendations and Documents are developed by technical committees or subcommittees which are formed by the Member States. Certain international and regional institutions also participate on a consultation basis.

Cooperative agreements are established between OIML and certain institutions, such as ISO and IEC, with the objective of avoiding contradictory requirements; consequently, manufacturers and users of measuring instruments, test laboratories, etc. may apply simultaneously OIML publications and those of other institutions.

International Recommendations and International Documents are published in French (F) and English (E) and are subject to periodic revision.

This publication – reference OIML D 24 (E), edition 1996 – was developed by the OIML subcommittee TC 11 */SC 3 Radiation thermometers*. It was approved by the International Committee of Legal Metrology in 1993.

OIML publications may be obtained from the Organization's headquarters:

Bureau International de Métrologie Légale
11, rue Turgot - 75009 Paris - France
Telephone: 33 (0)1 48 78 12 82 and 42 85 27 11
Fax: 33 (0)1 42 82 17 27
E-mail: biml@oiml.org
Internet: www.oiml.org

TOTAL RADIATION PYROMETERS

1 Scope and field of application

1.1 This International Document applies to total radiation pyrometers that measure radiance temperature by making use of the relationship between the radiance of the source, integrated over the major part of the spectrum of thermal radiation, and its temperature.

1.2 This Document is designed to:

- ensure that all total radiation pyrometers give correct readings (within limits of permissible errors) when measuring the temperature of a black body;
- specify means and conditions for the calibration of total radiation pyrometers with a given degree of accuracy and reliability.

1.3 This Document specifies for total radiation pyrometers:

- measurement units,
- general technical characteristics,
- characteristics of the auxiliary equipment used for calibration,
- basic methods to be used to ensure uniformity of calibration,
- basic requirements for calibration.

1.4 The use of other calibration and verification methods for total radiation pyrometers is permitted, provided that such methods ensure the same accuracy as that specified in this Document.

1.5 This Document applies to total radiation pyrometers graduated in units of temperature, and to sensors of these pyrometers [*]. It also applies to pyrometers which give a value of an electrical signal as output, and which are supplied with data or other means for converting that value into an indication of temperature.

2 Units of measurement

2.1 Pyrometers shall be calibrated in accordance with the 1990 International Temperature Scale. Temperature shall be expressed in degrees Celsius (°C), or in kelvins (K).

2.2 Pyrometers may not give a direct temperature reading provided that for pyrometers of this type, the relationship between the output signal and the temperature measured is indicated (table, calibration curve, etc.). The relationship indicated can be individual (valid for a particular instrument), or standardized (valid for all instruments of a given type).

(*) A total radiation pyrometer generally comprises two parts: a sensor (optical system and detector) providing an electrical signal proportional to the received thermal radiation flux, and a secondary unit converting the sensor output signal into temperature readings.

2.3 The instrument's indication (result of temperature measurement) may be either a direct reading on a scale or display in units of temperature, or the result of a calculation of the temperature using a calibration table or curve.

3 Technical and metrological characteristics of total radiation pyrometers

3.1 Total radiation pyrometers are characterized by the following basic parameters:

- measurement range
- intrinsic error
- repeatability
- target distance and size of target area
- nominal target aperture and nominal distance
- response time
- normal ambient operating temperature, and ambient operating temperature limits.

3.1.1 The intrinsic error characterizes the accuracy of the instrument. This error is equal to the difference between the mean value of a sufficient number of indications given by the pyrometer, under reference conditions (see 3.2) when measuring the temperature of a black body at constant temperature, and a conventional true value of the temperature of that body.

3.1.2 The repeatability characterizes the scatter of individual indications in repeated measurements of the same temperature.

3.1.3 The target distance is the distance between the radiation source and the optics of the total radiation pyrometer. This distance may be measured from another point on the pyrometer, indicated in an accompanying document.

3.1.4 The target area is that part of a plane perpendicular to the optical axis at the target distance, the image of which just covers the pyrometer detector (or the field diaphragm, if any). The diameter of the target area determines the minimum dimensions of an object whose temperature can be measured by the pyrometer within limits of permissible errors.

3.1.5 The target aperture is the ratio of the diameter of the target area to the target distance.

3.1.6 The nominal target aperture n is a target aperture for a specified target distance L such that the temperature of a radiation source with the diameter $D = n \times L$ can be measured accurately. The nominal target aperture is usually fixed for a distance of 1 m. However, the instrument may be set for other target distances provided that these distances are indicated in the accompanying documents.

3.1.7 The response time is the time taken by the total radiation pyrometer, following an abrupt change ΔT of the source temperature to give a change $\eta\Delta T$ in the indication of the pyrometer, where η is the value given in the pyrometer specification.

3.1.8 The reference operating temperature is the temperature of the pyrometer housing at which the intrinsic error of the pyrometer is determined. At all other temperatures the total error of the pyrometer is the sum of the intrinsic error and the complementary error due to the influence of change in ambient temperature.

3.2 The intrinsic error shall be determined under the following reference conditions:

- the object whose temperature is measured is a radiation source of the black-body type,
- the target distance is 1 m as indicated in 3.1.6,
- the diameter of the radiation source is n × 1 m, where n is the nominal aperture,
- the ambient temperature is maintained at the reference value, for example 20 °C ± 5 °C,
- the relative humidity of the ambient air does not exceed 80 %.

3.3 The intrinsic error of a total radiation pyrometer may be given for other conditions, i.e. for other values of target distance, source diameter, ambient temperature and humidity, provided that the conditions are indicated in the accompanying document. For other values of the operating conditions, complementary errors caused by the difference between actual operating conditions and reference conditions shall be given.

3.4 Intrinsic errors and complementary errors for total radiation pyrometers may be expressed in °C (or K) or in relative quantities. However, this must be done in such a way that an error in °C (or K) may be determined for each temperature measured.

4 Technical and metrological characteristics of calibration equipment

4.1 Technical and metrological characteristics of radiation sources

4.1.1 For the calibration of total radiation pyrometers, radiation sources of the black-body type with apertures greater (usually, two times greater) than the visual field of the pyrometer are used.

4.1.2 These sources shall meet the following requirements.

4.1.2.1 Total emissivity(*) shall be not less than 0.99.

(*)Ratio of the radiance of an isothermal source to the radiance of a perfect black-body having the same temperature as the source.

4.1.2.2 Effective total emissivity(**) shall be at least 0.99, and not greater than 1.01.

4.1.2.3 The source shall have a means for measuring and adjusting the temperature of its surfaces in order to meet the requirements in 4.1.2.2.

4.2 Technical and metrological characteristics of standard measuring instruments and calibration equipment

4.2.1 Mercury-in-glass thermometers, resistance thermometers, thermocouples, or optical pyrometers may be used as standard instruments for measuring the temperature of the radiation source (depending on the temperature range).

4.2.2 Errors of the standard instruments shall be no more than:

0.1 °C	below		200 °C
0.2 °C from		200 °C to	300 °C
0.5 °C from		300 °C to	600 °C
3.0 °C from		600 °C to	1 100 °C
7.0 °C from		1 100 °C to	2 000 °C
16.0 °C from		2 000 °C to	2 800 °C

4.2.3 Equipment used to measure electrical quantities (voltage, resistance, etc.) that are output signals from standard thermometers (pyrometers), shall meet the accuracy requirements corresponding to the values indicated in 4.2.2.

4.2.4 Equipment used to measure the output signals of pyrometers not having scales graduated in °C or K shall be capable of measuring the output signals with an error (when converted to temperature) not exceeding one tenth of the maximum permissible error of the total radiation pyrometer to be calibrated.

4.2.5 For varying the temperature of the housing of the pyrometer under calibration, it is advisable to use the accessories protecting the pyrometer head (such as a water jacket), through which water, heated or cooled to the required temperature, circulates.

The thermostat controlling the temperature of the water circulating in the water jacket, shall maintain the water temperature stable to within 0.4 °C.

5 Calibration of total radiation pyrometers

5.1 Procedure

5.1.1 The intrinsic error of a total radiation pyrometer is determined by measuring the temperature of a radiation source of the black-body type with the pyrometer concerned, and the conventional true value of this temperature using a standard instrument, as mentioned in 4.2.1.

(**)Ratio of the radiance of non-isothermal source to the radiance of an ideal black-body whose temperature is that which is indicated by a standard instrument that measures the source temperature.

5.1.2 Conformity of the pyrometer with all other requirements may be verified simultaneously with the determination of the intrinsic error, or separately. Radiators whose effective emissivity is less than 0.99 may be used for tests related to these other requirements.

5.2 Preparation for calibration

5.2.1 The total radiation pyrometer to be calibrated shall be placed at a distance of 1.00 m ± 0.02 m from the radiator aperture, which shall be covered by a removable polished metal diaphragm. The diameter of the aperture shall be equal to the nominal target aperture multiplied by 1 m. If the target distance indicated in the technical documentation differs from 1 m, the pyrometer shall be placed at the specified distance and an appropriate diaphragm diameter shall be selected.

5.2.2 The pyrometer shall be so positioned that its optical axis passes through the center of the diaphragm.

5.2.3 If the pyrometer is provided with means for the adjustment of temperature indications for measured surfaces with emissivities ε below 1, this adjustment shall be set to the position $\varepsilon = 1$ during the calibration procedure.

5.3 Determination of intrinsic error

5.3.1 The intrinsic error shall be determined at black-body temperatures given in the second column of Table 1 and which lie within the range of calibration.

Table 1

Temperature range (°C)	Black-body temperatures (°C)	Permissible deviation of calibration temperature (*) (°C)	Permissible rate of change of source temperature (°C/s)
20 to 150	50, 100, 150	± 5	0.01
150 to 600	200, 300, 400 500, 600	± 5	0.02
> 600	800, 1 000, 1 200 1 400, 1 600, 1 800 2 000, 2 200	± 10	0.05

If fewer than three of the temperatures indicated in Table 1 fall within the full measurement range of the pyrometer to be verified, the intrinsic error shall be determined at three black-body temperatures: at the lowest, middle and highest values of the calibration range.

5.3.2 The intrinsic error shall first be determined at the temperature closed to the lowest end of the measurement range; the temperature shall be chosen according to 5.3.1.

(*) Deviation of the calibration temperature from that specified in the second column; see 4.2.2 concerning the accuracy of measurement of the black-body temperatures.

5.3.3 The source temperature shall not differ from the required temperature by more than the amount indicated in the third column of Table 1, and the rate of the temperature change shall not exceed that specified in the last column of Table 1.

5.3.4 The radiation source temperature t_o shall be measured at least five times, and at least four pyrometer temperature readings t shall be taken alternately. The mean values of the radiation source temperature $\bar{t}_o$ and pyrometer reading $\bar{t}$ shall be calculated, and the intrinsic error of the pyrometer shall be determined from:

$$\Delta t = \bar{t} - \bar{t}_o$$

Note: For instruments that are not provided with an indicating device graduated in temperature units, the initial calibration is used to establish the relation x = f (t_o) where x is the output parameter. The difference Δt may then apply at the recalibration (verification).

5.3.5 The operations indicated in 5.3.3 and 5.3.4 shall be executed at all temperatures at which the pyrometer is to be calibrated in accordance with 5.3.1.

5.4 Determination of repeatability

5.4.1 The repeatability shall be determined at three temperatures, corresponding to the lower, middle and upper values of the pyrometer temperature range. These temperatures shall be selected in accordance with 5.3.1.

5.4.2 To determine the repeatability, eleven measurements of the radiation source temperature t_o and ten pyrometer readings t shall be taken alternately.

5.4.3 The difference for each pyrometer reading t_i is calculated from:

$$\delta_i = t_i - 1/2\,(t_{o,i} + t_{o,i+1}) \qquad (i = 1, 2, ...10)$$

where $t_{o,i}$ and $t_{o,i+1}$ are the temperatures of the source, measured directly before and after reading t_i.

5.4.4 The standard deviation shall then be calculated, using the value thus obtained, from the formula:

$$\sigma = 1/3 \left[\sum_{i=1}^{i=10} \left(\delta_i - \bar{\delta} \right)^2 \right]^{1/2}$$

where $\bar{\delta}$ is the mean value of δ_i.

5.5 Determination of the influence of an increase of the target size.

5.5.1 For the determination of the influence of a change in the target size, a radiation source shall be used, for which the aperture diameter is not less than 1.5 times the diameter of the pyrometer target area defined in accordance with 3.1.4.

5.5.2 The pyrometer shall be positioned in front of the radiation source as specified in 5.2.1 and 5.2.2.

5.5.3 When proceeding as in 5.3.3, the radiation source shall be set to the highest temperature from the series 100, 200, 300, 600, 800, 1 100, 1 200, 1 400, 1 600, 1 800, 2 000 °C which falls within the measurement range of the pyrometer and within the working range of the installation used for calibration.

5.5.4 After taking the pyrometer reading t_1 (first having measured the temperature of the black-body source), the diaphragm restricting the size of the cavity outlet shall be rapidly removed and a new reading t_2 on the pyrometer under calibration shall be taken.

5.5.5 The difference $t_2 - t_1$ determines the influence caused by an increase in the size of the radiation source.

5.6 Determination of response time

5.6.1 The total-radiation pyrometer shall be placed in front of the radiation source, and the procedure described in 5.2.1 and 5.2.2 shall be carried out.

The pyrometer output shall be coupled to an automatic recorder whose time constant does not exceed 0.1 of the time constant of the pyrometer under calibration. The radiation source temperature shall be selected as indicated in 5.5.3.

5.6.2 The thermal radiation flux emitted by the radiation source and striking the entrance to the pyrometer shall be cut off completely by means of an opaque screen. The screen shall be removed rapidly ten minutes later. Before removing the screen, the final value of the pyrometer reading, V_0, shall be determined from the recorded output signal.

5.6.3 The final value of the pyrometer reading without the screen, V_1, shall be determined from the recorded output signal. The temperatures t_1 and t_0 corresponding to V_1 and V_0, and $t_2 = \eta \times (t_1 - t_0) + t_0$ corresponding to output signal V_2, are calculated according to the calibration table or curve.

5.6.4 The time τ between the opening of entrance to the pyrometer and the moment when the output signal reaches value V_2, shall be determined from the recorded output signal. τ is the pyrometer response time.

5.6.5 If the pyrometer is provided with an indicating device graduated in units of temperature, the procedure for determining the response time shall be as follows.

5.6.5.1 The thermal radiation flux emitted by the radiation source and striking the entrance to the pyrometer shall be cut off completely by means of an opaque screen. The screen shall be removed ten minutes later. Before removing the screen, the final value of the pyrometer reading t_0 shall be determined.

5.6.5.2 With the pyrometer entrance open, the stabilized reading t_1 is found, after which $t_2 = \eta \times (t_1 - t_0) + t_0$ is calculated.

5.6.5.3 The pyrometer entrance is shut for ten minutes and then opened abruptly; at the same time a chronometer is started, for measuring the response time τ necessary for obtaining a temperature indication of t_2.

5.7 Determination of the influence caused by a change in the ambient operating temperature of the pyrometer sensor

5.7.1 The sensor of the total radiation pyrometer complete with protective accessories (water jacket), shall be positioned in front of the radiation source as in 5.2.1 and 5.2.2.

5.7.2 The radiation source shall be set at the temperature selected as in 5.5.3.

5.7.3 Water shall be circulated in the protection system at the normal operating sensor temperature $t_k \pm 0.5$ °C, and the pyrometer sensor shall be warmed up for at least 30 minutes.

5.7.4 When the procedure described in 5.3.3 and 5.3.4 has been completed, the error at the normal operating temperature of the sensor housing t_k shall be determined.

5.7.5 The above procedure shall be repeated at other water temperatures whose values are multiples of 10 °C and which fall within the ambient temperature range indicated in the accompanying document.

5.7.6 The difference between the errors obtained at these other temperatures and at t_k determines the influence caused by a change in the ambient temperature.

5.7.7 The influence of the change in the ambient temperature surrounding the secondary units of the pyrometer, separated from the sensor unit, shall be determined using standard methods for testing the electrical measuring instruments. An electrical signal corresponding to the temperature indicated in 5.5.3 shall be applied to the input of the secondary unit.

6 Metrological control

6.1 Total radiation pyrometers shall be calibrated and verified using radiation sources that meet the requirements specified in 4.1.1 and 4.1.2 and standard instruments that meet the requirements specified in 4.2.2.

6.2 If the sensor of the total radiation pyrometer is separate from a secondary electrical measurement device, and is provided with a separate calibration table or curve, the sensor and the secondary device shall be calibrated independently. The pyrometer sensor shall, in this case, be verified in accordance with the requirements of this Document. The secondary measurement device shall be calibrated as an electrical measuring instrument. The values of the electrical signals given in the calibration table for the sensor at the temperatures indicated in Table 1 shall be applied to the input of the secondary device.

The intrinsic error shall be the sum of the intrinsic error of the sensor and the intrinsic error of the electrical measurement device.

The repeatability shall be calculated as the square root of the sum of the square of the standard deviation of the sensor and the square of the standard deviation of the electrical measurement device.

6.3 The results of calibrations carried out in accordance with the requirements of this Document shall be confirmed by a certificate and by a mark on the pyrometer indicating the issue of such certificate.