Standards for Radiation Thermometry

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Abstract
The work of radiation thermometry calibration and usage historically has not had a great amount of guidance in the form of standards. This includes work done with infrared thermometers. Over the past few years, this situation has changed. New standards and guidelines have come from a number of sources including BIPM, IEC, and ASTM. The topics covered by these standards and guidelines include terminology, usage, calibration, testing, and uncertainty analysis. These works cover a wide variety of radiation thermometry accuracy levels from that of a national metrological institute to that of an industrial level user. This paper provides an overview of these standards and guidelines. It compares these standards and guidelines with each other and shows their applicability for different measurement scenarios.

Learning Objectives
This paper will help the reader to gain knowledge of the published standards available pertaining to radiation thermometry and infrared thermometry.

This paper will help the reader to apply published standards to measurement, calibration, and testing involving radiation thermometry and infrared thermometry.

1. Introduction
Historically, in the world of radiation thermometry, there has been a lack of published standards. However, this is slowly becoming less of a problem, as more standards for radiation thermometry have become available over the past five years. These standards come from a number of different bodies that include international and national organizations. Some of these organizations are BIPM, IEC, and ASTM. These standards cover a number a different aspects of radiation thermometry including usage, calibration, testing, and uncertainty budget calculation. They also cover a wide range of accuracy levels from the work done by a national laboratory to that done by an industrial level user.

2. Overview of Standards
Radiation thermometry is the measurement of the temperature of an object based on knowledge of the spectral emissivity of that object and the radiance exiting the object due to thermal radiation [1]. It is based on the relationship between electromagnetic radiation, mostly in the infrared region, wavelength of the radiation, and temperature as predicted by Planck's Law. A radiation thermometer generally detects a single wavelength or a band of wavelength of this

radiation.

Radiation thermometry devices are classified into three groups [2]. First, there are devices which measure the temperature of a point or area. These are commonly known as radiation thermometers. A subclass of radiation thermometers is the infrared thermometer [3]. The term infrared thermometer is generally applied to hand-held devices with a thermopile detector. Second, there are devices which measure temperature along a line and associate temperature with a one dimensional linear coordinate. These are called line scanners. Third, there are devices which measure temperature in an area and assign a measured temperature in a two dimensional coordinate system. These devices are called thermal imagers.

Table 1 is a summary of the standards discussed in this paper. It lists the standard, a generalized description of its scope and applicability to the level of use. A filled in circle represents full applicability and an empty circle represents partial applicability. The scope of this paper is generally limited to devices measuring temperature below 1000 °C.

Table 1. Summary of Radiation Thermometry Standards

Body	Standard	Usage	Calibration	Uncertainties	Test Methods	NMI	High-end	Industrial
BIPM	CCT-WG508-03			●		●	○	○
IEC	IEC 62492-1	●				●	●	○
ASTM	E1256				●	●	●	○
ASTM	E2758	●					○	●
ASTM	E2847		●	●			○	●
VDI	3511 Part 4	●				○	●	○
VDI	3511 Part 4.2	●				○	●	○
VDI	3511 Part 4.3				●	○	●	○
VDI	3511 Part 4.4		●	●		○	●	○
MSL	TG22		●		○		○	●
EMA	Technical Guide… Radiation Thermometer Calibration		●	●			●	○
● Full applicability ○ Partial applicability								

3. BIPM

BIPM is the Bureau international des poids et mesures (International Bureau of Weights and

Measures or BIPM) in Sèvres, France. It was created as a result of the Metre Convention in 1875 and maintains SI standards for weights and measure [4]. This organization also has documentation pertaining to different metrological disciplines including radiation thermometry which come under the jurisdiction of Consultative Committee for Thermometry Working Group 5 (CCT-WG5) on Radiation Thermometry [5]. The main document covering uncertainties in the region below 1000 °C is CCT-WG508-03, Uncertainty Budgets for Calibration of Radiation Thermometers below the Silver Point.

3.1 CCT-WG508-03

This document was released in 2008. Its scope is limited to radiation thermometers with readout in radiance and not temperature [6]. This excludes its use for industrial type calibrations including those of handheld infrared thermometers. This being said, it still provides a guide for these interments given the lack of other standards in the community. A list of the uncertainties covered by CCT-WG508-03 is shown in Table 2. The uncertainties are broken into four categories, blackbody, radiation thermometer, calibration equation, and usage. The calibration equation and usage uncertainties do not apply to the radiation thermometer calibration. The type of blackbody used is broken into fixed-point blackbodies and variable temperature blackbodies.

Table 2. Summary of Uncertainties covered by BIPM

Blackbody	**Radiation Thermometer**	**Calibration Equation and Use**
Calibration temperature **	Size-of-source effect	Interpolation error
Impurities *	Non-linearity	Drift
Plateau identification *	Reference temperature	Unknown temperature
Blackbody emissivity, isothermal	Ambient temperature	
Blackbody emissivity, non-isothermal **	Atmospheric absorption	
	Gain ratios	
Reflected ambient radiation	Noise	
Cavity bottom heat exchange		
Convection **		
Cavity bottom uniformity **		
Ambient conditions **		

* Fixed point blackbody only
** Variable temperature blackbody only

CCT-WG508-03 suggests the use of the Sakuma-Hattori Equation in the Planckian Form, as shown in Equation (1), for the calibration equation [6].

$$S(T) = \frac{C}{\exp\left(\frac{c_2}{AT+B}\right)-1} \tag{1}$$

where:
c_2: Second Radiation Constant
A, B, C: fitted parameters
T: temperature of blackbody
S: signal received by radiation thermometer

CCT-WG508-03 not only provides the structure for the uncertainty budget, but it also provides equations to calculate uncertainty and examples of calculated uncertainties at temperatures and wavelengths of interest. For instance, in the case of atmospheric attenuation, the guide provides guidelines for a measuring distance of less than 1 meter. In this case, the expanded uncertainty is 0.0006 of radiance for normal usage and 0.0002 of radiance for best usage. For 20 °C and a 10 µm instrument, this translates to expanded uncertainties of 0.019 K and 0.0063 K respectively [6]. This is useful, as it allows the user the freedom to not have to consult a standard atmosphere to make a calculation which can be cumbersome [7].

3.2 Other Standards from BIPM

In addition to the standard discussed in the previous section, CCT-WG5 also has CCT/03-03, “Uncertainty budgets for realization of scales by radiation thermometry”. It covers work done above the silver-point (961.78 °C) using fixed-points as blackbody sources [8].

4. IEC

The International Electrotechnical Commission (IEC) has one standard for radiation thermometry. It is part of a proposed series of standards covering definitions, specifications and test methods related to radiation thermometry.

4.1 IEC 62492-1

IEC 62492-1, “Industrial process control devices - Radiation thermometers - Part 1: Technical data for radiation thermometers” covers terms, definitions and abbreviations. In addition, it covers how to state technical data based on these terms all related to radiation thermometry. A list of the terms covered by IEC 62492-1 is listed in Table 3.

Table 3. Terms covered by IEC 62492-1

- Measuring temperature range
- Measurement uncertainty (accuracy)
- Noise equivalent temperature difference
- Measuring distance
- Field-of-view
- Distance ratio
- Size-of-source effect
- Emissivity setting
- Spectral range
- Influence of the internal instrument or ambient temperature (temperature parameter)
- Influence of air humidity (humidity parameter)
- Long-term stability
- Short-term stability
- Repeatability
- Interchangeability
- Response time
- Exposure time
- Warm-up time
- Operating temperature range and air humidity range
- Storage and transport temperature range and air humidity range

One example of a definition is field-of-view. It is defined as “A usually circular, flat surface of a measured object from which the radiation thermometer receives radiation” [9]. In the technical data section it further shows examples of field-of-view data. One way to report field-of-view is “3.4 mm diameter (90%), measuring distance: 400 mm” [9].

4.2 Work Items

IEC 62492 is proposed to have two more parts. Part 2 is currently being drafted. It deals with specifications for radiation thermometers. Work on Part 3 has not yet started. It will cover test methods for radiation thermometers.

5. ASTM

The ASTM International (ASTM) Committee E20 on Temperature Measurement is the group which coves various aspects of temperature measurement. It contains a number of subcommittees. A sampling of these subcommittees is shown in Table 4. The E20.02 Subcommittee on Radiation Thermometry is responsible for standards related to radiation thermometry. Recently a decision was made to create a road map that would get the widest amount of users to do proper measurements. The number one need was a guide for the use of handheld infrared thermometers, typically of the 8 – 14 μm spectral bandwidth. The secondary need was a guide for calibration of these devices [10]. Currently the E20.02 has 3 published standards.

Table 4. Subcommittees in of ASTM Committee E20 on Temperature Measurement

Designation	Title
E20.02	Radiation Thermometry
E20.03	Resistance Thermometers
E20.04	Thermocouples
E20.05	Liquid-in-Glass Thermometers and Hydrometers
E20.06	New Thermometers and Techniques
E20.07	Fundamentals in Thermometry
E20.09	Digital Contact Thermometers
E20.90	Executive
E20.91	Editorial and Terminology
E20.94	Publication

5.1 ASTM E1256

ASTM E1256, Standard Test Methods for Radiation Thermometers (Single Waveband Type), is a long standing standard. It covers a number of test methods essential to radiation thermometry. These methods are listed in Table 5. The term in parenthesis represents a replaced term used in the standard prior to 2011.

Table 5. Methods outlined in ASTM E1256

Test Name
Calibration Accuracy Test Method
Repeatability Test Method
Field-of-View Test Method (Target Size Test Method)
Response Time Test Method
Warm-Up Time Test Method
Long-Term Stability Test Method (Long-Term Drift Test Method)

Recently, an effort has been made to harmonize the terminology in E1256 with that of IEC 62492-1 which came out in 2008. These terminology changes are summarized in the Table 6.

Table 6. Terminology changes in ASTM E1256

New Term	Old Term
long-term stability	long-term drift
field-of-view	target size
spectral range	spectral response
noise equivalent temperature difference	noise equivalent power
measuring temperature range	measurement range
measuring distance	target distance
measuring distance	distance

5.2 ASTM E2758

ASTM E2758, Standard Guide for Selection and Use of Wideband, Low Temperature Infrared Thermometers was released in 2010. It covers basic usage of infrared thermometers. In addition it gives information on issues that may arise when using infrared thermometry. It includes a number of test methods to determine emissivity, transmissivity and reflected temperature. The appendix contains a graphical summary of equations for infrared thermometry, and mathematical methods to determine the error caused by emissivity miscalculation, reflected temperature miscalculation and atmospheric effects. The mathematical methods use the Sakuma-Hattori Equation (1) and contain worked examples.

5.3 ASTM E2847

ASTM E2847 is the work item for the "Standard Practice for Calibration and Accuracy Verification of Wideband Infrared Thermometers". This work item was released in 2011

This practice covers the comparison of an "infrared thermometer to the radiance temperature of a radiation source" [11]. The thermal radiation sources covered by the guide include cavity blackbody sources and flat-plate sources. The flat-plate sources are used commonly for infrared thermometers with wide field-of-view. It discuses other equipment needed for an infrared thermometer calibration. A list of this equipment is contained in Table 7 [11].

Table 7. Equipment needed for infrared thermometer calibration

Equipment	Remarks
Thermal Radiation Source	Cavity blackbody or flat-plate
Aperture *	Used to control scatter / size-of-source effect
Transfer Standard	Contact (Scheme I) or Radiometric (Scheme II)
Ambient Temperature Thermometer	Monitors laboratory conditions
Distance Measuring Device	Used to set measuring distance
Purge *	Used to eliminate other water or oxygen from calibrator

* Optional Equipment

E2847 discusses two traceability schemes to calibrate the thermal radiation source, which are based on definitions from VDI/VDE [12]. These two schemes are shown in Figure 1. Scheme 1 uses contact thermometry to establish traceability of the thermal radiation source. Scheme II uses radiation thermometry to establish traceability. It also covers preparation of the equipment and gives a calibration procedure. It then speaks to uncertainty estimation and speaks to a measurement equation and an uncertainty budget structure to include methods to calculate the uncertainties. A comparison of the uncertainties covered by this standard and those discussed in the BIPM document are shown in Table 8.

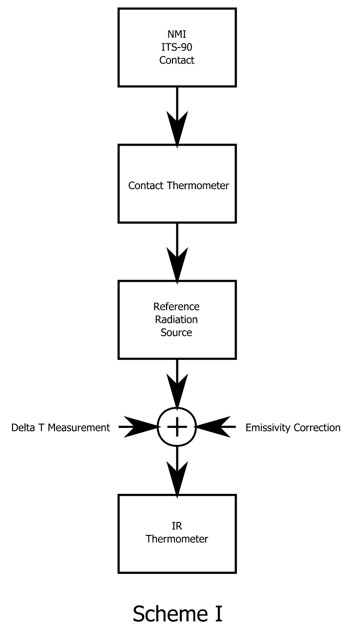

Figure 1. Traceability schemes for calibration of radiation sources

Table 8. Comparison of uncertainty budget elements

BIPM CCT-WG505-03	**ASTM E2847**
Blackbody	**Source**
Calibration temperature	Calibration Temperature
Blackbody emissivity, isothermal Blackbody emissivity, non-isothermal	Source Emissivity
Reflected ambient radiation	Reflected Ambient Radiation
Cavity bottom heat exchange	Source Heat Exchange
Convection Ambient conditions	Ambient Conditions
Cavity bottom uniformity	Source Uniformity
Radiation Thermometer	**Infrared Thermometer**
Size-of-source effect	Size-of-source effect
Reference temperature Ambient temperature	Ambient temperature
Atmospheric absorption	Atmospheric absorption
Non-linearity Gain ratios Noise	Noise
	Display Resolution

The appendices of E2847 include a sample calibration report, a summary of uncertainty calculation to include examples, and a method to determine detector temperature.

5.4 Future Work Items

The E20.02 subcommittee has a five year road map. Besides the periodic five-year reviews required of all ASTM standards, a standard on the classification of infrared thermometers and a test method for emissivity determination are on the road map [13]. In addition the E20.94 subcommittee is working on a manual for radiation thermometry.

6. VDI/VDE

The German standards bodies Verein Deutscher Ingenieure (VDI) and Verband der Elektrotechnik, Elektronik und Informationstechnik (VDE) have a set of standards covering radiation thermometry. The set of standards is called *VDI/VDE 3511 Blatt 4 Technische Temperaturmessung Strahlungsthermometrie* (VDI/VDE 3511 Part 4 Temperature measurement in industry – Radiation thermometry). It is a set of four documents covering radiation thermometry, specification of radiation thermometers, test methods for radiation thermometers, and calibration of radiation thermometers. The documents are written in both German and English.

The main document, Part 4, discusses basic theoretical and practical considerations concerning radiation thermometry. This includes reasons to use radiation thermometry, the relationship between radiance and temperature to include blackbody theory, measuring systems to include criteria for design, emissivity, optical considerations, design types, criteria for selection of devices, inspection, and practical issues.

Part 4.2 contains the “Maintenance of the specification for radiation thermometers”. It covers sources of error and how to avoid them, maintenance by the user, and regular testing of radiation thermometers.

Part 4.3 is entitled “Standard test methods for radiation thermometers with one wavelength range”. The topics covered are listed in Table 9. It is worth noting that many of these tests are similar to those in ASTM E1256 as is shown in Table 9. The ‘Warm-up Time’ and ‘Influence of the internal instrument temperature’ are similar, but not close enough to consider them covering the same class of test.

Part 4.4 is entitled, “Calibration of radiation thermometers”. It discusses different calibration schemes. These include both radiaiometric and contact. It also discusses equipment preparation, calibration procedure, and uncertainty estimation.

Table 9. Comparison of VDI/VDE 3511 Part 4.3 and ASTM E1256

VDI/VDE 3511 Part 4.3	ASTM E1256
Measuring Temperature Range	
Measurement uncertainty (accuracy)	Calibration Accuracy
Influence of the internal instrument temperature	
Long-term stability	Long-Term Stability
Repeatability	Repeatability
Noise equivalent temperature difference	
Spectral range	
Target/target size	Field-of-view
Response time	Response Time
Exposure time	
Operating ambient temperature	
Storage temperature range	
	Warm-Up Time

7. MSL

The national metrological institute of New Zealand is the Measurement Science Laboratory (MSL). Their contributions to metrology include an extensive selection of guides that are available online for free. The guide covering infrared thermometers is, "MSL Technical Guide 22, Calibration of Low-Temperature Infrared Thermometers". It is a document geared towards handheld infrared thermometers. It discusses how infrared thermometers measure temperature. It then discusses influences on infrared thermometer measurement including introduction of a measurement equation. It then talks about how the signal is processed and about measurement errors. It discusses calibration and calibration sources including the concepts of calibrating the source by contact thermometry or by radiation thermometry. It ends with a method to determine detector temperature for an infrared thermometer.

8. EMA

The *Entidad Mexicana de Acreditación* (Mexican Accredidation Entity) has a guide entitled "*Guía Técnica Sobre Trazabilidad e Incertidumbre en la Calibración de Termómetros de Radiación*" ("Technical Guide on Traceability and Uncertainty for Radiation Thermometer Calibration"). It is purely in Spanish, so it may not be of use outside Spanish speaking countries. However, it is interesting to note what is covered in this standard. Besides covering traceability and uncertainty, the guide also covers calibration equipment calibration schemes, and good practice for radiation thermometry metrology.

9. Conclusion

The standards discussed here are ones available for radiation thermometry. The different standards available cover various aspects of radiation thermometry to include measurement, calibration, test methods, and special issues. They also cover a wide range of instruments from handheld infrared thermometers used for industrial measurements to instruments used in a national laboratory. Knowledge of the standards available assists radiation thermometer users in making better and more accurate measurements. The importance of learning about new standards is stressed. With learning about new standards, the user is able to keep up-to-date with the latest information available.

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