



Standard Test Methods for Radiation Thermometers (Single Waveband Type)¹

This standard is issued under the fixed designation E 1256; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 The test methods described in these test methods can be utilized to evaluate the following six basic operational parameters of a radiation thermometer (single waveband type):

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Calibration Accuracy	7
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Target Size	9
Response Time	10
Warm-Up Time	11
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1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 Definitions:

2.1.1 *blackbody, n*—the perfect or ideal source of thermal radiant power having a spectral distribution described by the Planck equation.

2.1.1.1 *Discussion*—The term blackbody is often used to describe a furnace or other source of radiant power which approximates the ideal.

2.1.2 *center wavelength, n*—a wavelength, usually near the middle of the band of radiant power over which a radiation thermometer responds, that is used to characterize its performance.

2.1.2.1 *Discussion*—The value of the center wavelength is usually specified by the manufacturer of the instrument.

2.1.3 *radiation thermometer, n*—a radiometer calibrated to indicate the temperature of a blackbody.

2.1.4 *radiometer, n*—a device for measuring radiant power that has an output proportional to the intensity of the input power.

2.1.5 *target plane, n*—the plane, perpendicular to the line of sight of a radiation thermometer, that is in focus for that instrument.

2.2 Definitions of Terms Specific to This Standard:

2.2.1 *reference temperature source, n*—a source of thermal

radiant power of known temperature or emissivity, or both, used in the testing of radiation thermometers.

2.2.2 *target size, n*—the diameter of a circle in the target plane of a radiation thermometer that is centered on its line of sight and contains 99 % of the input radiant power received by that instrument.

2.2.3 *temperature resolution, n*—the minimum simulated or actual change in target temperature that gives a usable change in output or indication, or both.

3. Significance and Use

3.1 The purpose of these test methods is to establish consensus test methods by which both manufacturers and end users may make tests to establish the validity of the readings of their radiation thermometers. The test results can also serve as standard performance criteria for instrument evaluation or selection, or both.

3.2 The goal is to provide test methods that are reliable and can be performed by a sufficiently skilled end user or manufacturer in the hope that it will result in a better understanding of the operation of radiation thermometers and also promote improved communication between the manufacturers and the end users. A user without sufficient knowledge and experience should seek assistance from the equipment makers or other expert sources, such as those found at the National Institute of Standards and Technology in Gaithersburg, Maryland.

3.3 Use these test methods with the awareness that there are other parameters, particularly spectral response limits and temperature resolution, which impact the use and characterization of radiation thermometers for which test methods have not yet been developed.

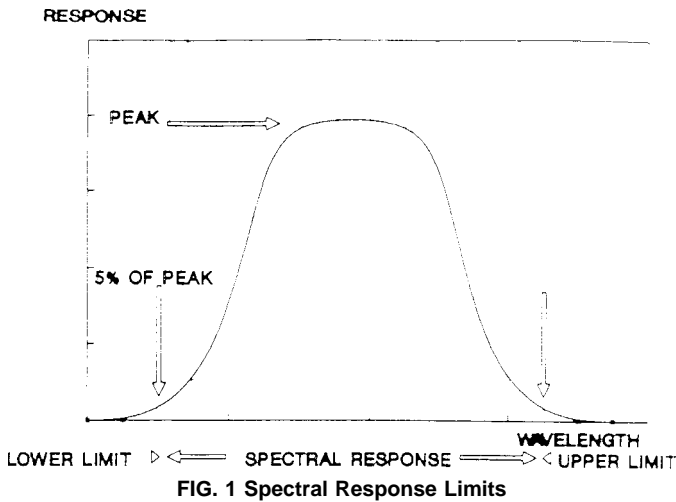
3.3.1 Temperature resolution is the minimum simulated or actual change in target temperature that results in a usable change in output or indication, or both. It is usually expressed as a temperature differential or a percent of fullscale value, or both, and usually applies to value measured. The magnitude of the temperature resolution depends upon a combination of four factors: detector noise equivalent power (NEP) or noise equivalent temperature, electronic signal processing, signal-to-noise characteristics (including amplification noise), and analog-to-digital conversion “granularity.”

3.3.2 Spectral response limits are the upper and lower limits to the wavelength band of radiant energy to which the instrument responds. These limits are generally expressed in micrometers (μm) and include the effects of all elements in the

¹ These test methods are under the jurisdiction of ASTM Committee E-20 on Temperature Measurement and are the direct responsibility of Subcommittee E20.02 on Radiation Thermometry.

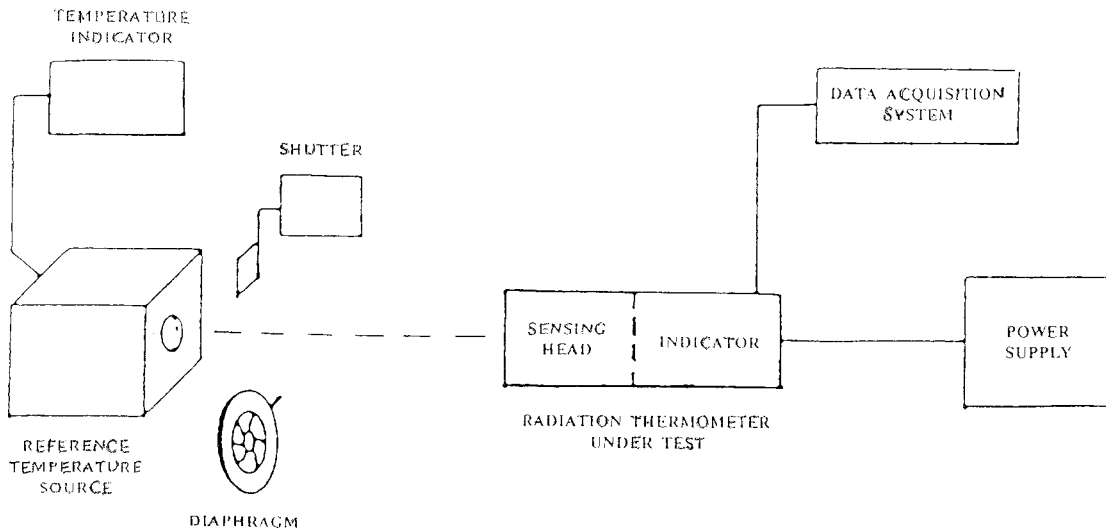
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measuring optical path. At the spectral response limits, the transmission of the measuring optics is 5 % of peak transmission (see Fig. 1).



4. Apparatus

4.1 The following apparatus, set up as illustrated in Fig. 2,



can be used to perform the standard tests for all six parameters.

4.1.1 *Reference Temperature Source*—A blackbody (or other stable isothermal radiant source of high and known emissivity) with an opening diameter at least as large as that specified in these test methods.

NOTE 1—Typical examples include nearly isothermal furnaces with internal geometries, such as a sphere with an opening small relative to its radius, or a right circular cylinder with one end closed having a radius small relative to its length. Consult footnote² for greater detail.

4.1.2 *Temperature Indicator*—Either contact or radiometric,

which accurately displays the temperature of the reference temperature source.

4.1.3 *Shutter Mechanism*—Of sufficient size so as to completely block the opening of the reference temperature source from the field of view of the test instrument. The shutter mechanism shall activate in a time interval that is short when compared with the response time of the test instrument.

4.1.4 *Iris Diaphragm*—Of sufficient size so that when fully open the iris diameter is greater than the opening of the reference temperature source. It shall be located with its opening concentric with and perpendicular to the line of sight of the radiation thermometer.

4.1.4.1 The side of the diaphragm facing the radiation thermometer should be blackened (nearly nonreflective) so as to minimize the effect of radiation reflected from the surrounding environment. In addition the iris should be shaded from sources of intense extraneous radiation. (See Note 9).

4.1.5 *Aperture Set*—If an iris diaphragm is not available, an aperture disc set of appropriate diameters can be used. Each aperture should be blackened and also mounted and protected from extraneous sources of radiation as discussed in 4.1.4.1.

4.1.6 *Data Acquisition Systems*—Of appropriate speed and storage capacity to measure and record the output signal of the

radiation thermometer in the Response Time Test Method, Section 9.

4.1.7 *Power Supply*—Capable of supplying the proper voltage and frequency, if necessary, to the radiation thermometer.

5. Calibration Accuracy Test Method

5.1 *Summary*—This test method outlines the procedure to be used to evaluate the maximum deviation between the temperature indicated by the radiation thermometer and the known temperature of a reference temperature source, including the uncertainty of the reference temperature source relative to the current International Temperature Scale.

5.2 Test Conditions:

5.2.1 Rated supply voltage and frequency.

² DeWitt, D. P., and Nutter, G. D., eds., "Theory and Practice of Radiation Thermometry," John Wiley and Sons, New York, NY.

5.2.2 Prescribed warm-up period.

5.2.3 After execution of internal standardization check (if available).

5.2.4 Emissivity compensation set to one (1).

5.2.5 Minimum opening of the reference temperature source shall not obstruct the field of view of the radiation thermometer with the test aperture as specified by the manufacturer.

5.2.6 Laboratory ambient temperature range (20 to 25°C).

5.2.7 Manufacturer shall specify any special conditions such as atmospheric absorption effects, target distance, etc.

5.2.8 Manufacturer shall specify the output for determining the indicated temperature.

5.3 Test Method:

5.3.1 The radiation thermometer is sighted at the reference temperature source whose temperature is sequentially stabilized at three calibration points distributed uniformly over the measurement range of the instrument.

5.3.2 The temperature of the reference temperature source and the temperature indicated by the radiation thermometer are recorded, then the difference between the two values is calculated and recorded (see Fig. 3).

5.3.3 The test sequence is repeated twice for the same three calibration points, and an average temperature difference is calculated and recorded for each calibration point.

5.4 Test Result—The value for the calibration accuracy of the temperature indication of the radiation thermometer is taken to be the largest of the three average temperature differences determined in 5.3.2 plus or minus the uncertainty of the temperature of the reference temperature source relative to the current International Temperature Scale.

NOTE 2—The calibration accuracy is generally expressed as a temperature difference or a percent of full scale value, or both.

NOTE 3—The value applies across the entire measurement range.

NOTE 4—If the reference temperature source is measured with other than a calibrated reference or secondary standard radiation thermometer, then the emissivity of the source enters into the calibration of the test radiation thermometer.

6. Procedure

6.1 Detailed directions for evaluation of each parameter listed in 1.1 are included in each parameter test method.

6.2 Each parameter test method is organized by: parameter term, summary, test conditions, test method, test result, and applicable notes.

7. Repeatability Test Method

7.1 Summary—This test method outlines the procedure to be used to evaluate the repeatability of the temperature indication of a radiation thermometer for a number of consecutive measurements made under the same conditions over a specified interval of time.

7.2 Test Conditions:

7.2.1 Rated supply of voltage and frequency.

7.2.2 Prescribed warm-up period.

7.2.3 After execution of internal standardization check (if available).

7.2.4 Diameter of the reference temperature source opening shall be greater than the radiation thermometer target size, as specified by the manufacturer.

7.2.5 Laboratory ambient temperature range (20 to 25°C).

7.2.6 Emissivity compensation, if any, set to one (1).

7.2.7 Manufacturer shall specify any special conditions such as response time, atmospheric absorption effects, target distance, etc.

7.3 Test Method:

7.3.1 Once a day for twelve consecutive working days, the radiation thermometer is sighted at the reference temperature

Calibration Points	Run #1			Run #2			Run #3			Average Value	Difference
	T _{ref}	T ₁	$\frac{\Delta T_1}{(T_{ref}-T_1)}$	T _{ref}	T ₂	$\frac{\Delta T_2}{(T_{ref}-T_2)}$	T _{ref}	T ₃	$\frac{\Delta T_3}{(T_{ref}-T_3)}$	$\frac{\Delta T_1 + \Delta T_2 + \Delta T_3}{3}$	$\Delta T_{max} - \Delta T_{min}$
Approx 10% of Span											
Approx 50% of Span											
Approx 90% of Span											

- Note 1 Uncertainty in temperature of reference temperature source ± _____ °C
- Note 2 Instrument span (See Note B below) _____ °C
- Note 3 Maximum average value _____ °C
- Note 4 Maximum difference _____ °C

- Note A This is only a sample worksheet. More replicates will increase the significance of the results.
- Note B For instruments with more than one range (span), each range is calibrated as if it were a separate instrument.
- Note C Special care must be taken not to infer too much significance from this test because of the small number of observations.

FIG. 3 Worksheet for Calibration Accuracy Test Method

source whose temperature is stabilized at the approximate midpoint of the radiation thermometer calibration range.

NOTE 5—The selected reference temperature source temperature shall be reproduced for each of the twelve consecutive tests.

7.3.2 The temperature of the reference temperature source and the temperature(s) indicated by the radiation thermometer during each day's test are recorded.

7.3.3 The radiation thermometer shall be switched off after each series of measurements.

7.4 *Test Result*—The value for the repeatability of the readings of the radiation thermometer is taken to be the standard deviation of the twelve recorded readings.

$$S.D. = \sqrt{\frac{\sum_{i=1}^N (X_i - \bar{X})^2}{N - 1}} = \sqrt{\frac{\sum_{i=1}^N X_i^2 - \frac{(\sum_{i=1}^N X_i)^2}{N}}{N - 1}}$$

where:

S.D. = standard deviation,

N = number of measurements,

X_i = value of the i th measurement, and

\bar{X} =

$$\text{average of the twelve measurements} = \frac{\sum_{i=1}^N X_i}{N}$$

NOTE 6—The repeatability of the temperature indication is generally expressed as a temperature difference or a percent of full scale value, or both.

NOTE 7—The value for the repeatability can be applied across the entire measurement range, or, the same test can be performed at other selected temperatures across the measurement range in order to assess the repeatability of the radiation thermometer at those temperatures.

8. Target Size Test Method

8.1 *Summary*—This test method outlines the procedure to be used to evaluate the diameter of the circle located in the target plane of the reference temperature source, at a known distance along and perpendicular to a radiation thermometer's line of sight, and from which 99 % of the radiant power received by the radiation thermometer is collected (see Figs. 3 and 4).

8.2 *Test Conditions:*

8.2.1 Rated supply voltage and frequency.

8.2.2 Prescribed warm-up period.

8.2.3 After execution of internal standardization check (if applicable).

8.2.4 Laboratory ambient temperature range (20 to 25°C).

8.2.5 Minimum opening of the reference temperature source shall be large enough so as to not obstruct the optical path of the radiation thermometer, as specified by the manufacturer,

when it is sighted through an aperture that is twice the diameter of the instrument's target size at the plane of the aperture.

NOTE 8—Some radiation thermometers have a target size so large that a commercially available reference temperature source cannot be used; a separate test method is under preparation for use in such cases.

8.2.6 Manufacturer shall specify any special conditions such as atmospheric absorption effects, distance, how and when to clean the radiation thermometer lens, etc.

8.3 *Test Method:*

8.3.1 The temperature of the reference temperature source is stabilized at a value near the top of the calibration range of the radiation thermometer.

8.3.2 The iris is positioned in the front of and concentric with the opening of the reference temperature source (as illustrated in Fig. 2). The iris is then adjusted to a diameter slightly smaller (typically 10 %) than the expected target diameter.

NOTE 9—The iris should be kept cool enough so that its thermal emission does not contribute significantly to the output signal. Uncovering the iris quickly can minimize heating, but this requires care. Evaluation of the error from this source requires computational procedures beyond the scope of this test method; a discussion of such procedures can be found in footnote 2. In most cases, however, the error is insignificant if the iris is maintained near room temperature (20°C) and the reference temperature source temperature is at or above 200°C.

8.3.3 The position of the radiation thermometer is then adjusted vertically and horizontally and focused to produce maximum output while also maintaining the line of sight perpendicular to the iris.

8.3.4 The iris is then opened to the point where the temperature indicated by the radiation thermometer stops increasing, but its diameter is still smaller than the reference temperature source opening.

8.3.5 The temperature indicated by the radiation thermometer (in degrees) is recorded.

8.3.6 The iris diameter is then decreased until the temperature indicated by the radiation thermometer decreases by the amount appearing in Table 1. The following example illustrates the use of Table 1:

8.3.6.1 *Example*—Assume that the temperature of the reference temperature source is 500°C and the radiation thermometer operates at a center wavelength of 6.1 μm. When the iris is closed to the diameter for which the temperature indicated by the radiation thermometer has been reduced by 2.06°C, the maximum radiant power collected from the source has been reduced by 1 %.

NOTE 10—This same test method can also be applied to a test instrument equipped with an output signal that is proportional to the target

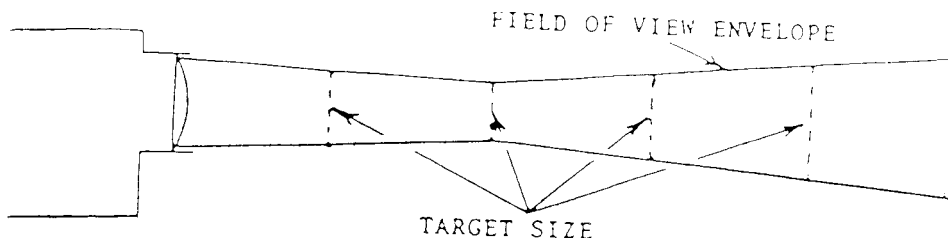


FIG. 4 Target Diameter versus Target Distance from Instrument

TABLE 1 The Change in Indicated Temperature Corresponding to a 1 % Reduction in the Maximum Radiant Power Received by a Radiation Thermometer

Center Wavelength, μm	0.65 ^A	0.85 ^A	1.0 ^A	1.6 ^A	2.2 ^A	3.0 ^A	3.43 ^A	4.0 ^A	5.1 ^A	7.95 ^A	11.0 ^A	Total Radiation ^B	
Temperature ^C C	Temperature Change, °C												
						1 % ^C		5 % ^C					
50	...	...	...	...	...	...	...	...	...	...	...	...
100	...	...	...	...	...	-0.21	-0.29	-0.33	-0.39	...	...	...
150	...	...	...	-0.20	-0.27	-0.37	-0.43	-0.50	-0.63	...	...	...
200	...	...	...	-0.25	-0.34	-0.47	-0.53	-0.62	-0.79	-1.21	...	...
250	...	...	...	-0.30	-0.42	-0.57	-0.65	-0.76	-0.97	-1.46	...	-1.31	
300	...	...	-0.23	-0.37	-0.50	-0.68	-0.78	-0.91	-1.16	-1.74	...	-1.44	5 %
400	-0.20	-0.27	-0.32	-0.50	-0.69	-0.94	-1.08	-1.25	-1.58	-2.33	-2.97	-1.69	
500	-0.27	-0.35	-0.42	-0.66	-0.91	-1.24	-1.42	-1.65	-2.06	-2.98	-3.73	-1.94	
600	-0.34	-0.45	-0.53	-0.85	-1.17	-1.58	-1.80	-2.09	-2.60	-3.68	-4.53	-2.19	1 %
700	-0.43	-0.56	-0.66	-1.05	-1.45	-1.96	-2.23	-2.57	-3.17	-4.42	-5.35	-2.44	
800	-0.52	-0.68	-0.80	-1.28	-1.76	-2.37	-2.69	-3.09	-3.79	-5.19	-6.20	-2.69	
900	-0.62	-0.81	-0.96	-1.53	-2.10	-2.82	-3.19	-3.65	-4.44	-5.98	-7.07	-2.94	
1000	-0.73	-0.96	-1.13	-1.80	-2.46	-3.30	-3.72	-4.24	-5.12	-6.79	-7.96	-3.19	
1200	-0.98	-1.28	-1.51	-2.41	-3.28	-4.35	-4.87	-5.51	-6.56	-8.48	-9.76	-3.70	
1400	-1.26	-1.65	-1.95	-3.10	-4.19	-5.50	-6.13	-6.88	-8.08	-10.2	-11.6	-4.20	
1600	-1.59	-2.07	-2.45	-3.87	-5.20	-6.75	-7.47	-8.32	-9.68	-12.0	-13.5	-4.70	
1800	-1.94	-2.54	-2.99	-4.72	-6.29	-8.08	-8.89	-9.84	-11.3	-13.8	-15.4	-5.20	
2000	-2.33	-3.05	-3.60	-5.64	-7.46	-9.47	-10.4	-11.4	-13.0	-15.7	-17.3	-5.70	
2500	-3.47	-4.53	-5.33	-8.22	-10.6	-13.2	-14.3	-15.5	-17.4	-20.4	-22.1	-6.96	
3000	-4.83	-6.29	-7.38	-11.2	-14.2	-17.2	-18.5	-19.9	-21.9	-25.1	-27.0	-8.21	
3500	-6.41	-8.32	-9.70	-14.4	-17.9	-21.4	-22.8	-24.3	-26.6	-30.0	-31.9	-9.47	
4000	-8.20	-10.6	-12.3	-17.8	-21.9	-25.7	-27.2	-28.9	-31.3	-34.8	-36.8	-10.7	

^A The entries for wavelengths 0.65 μm through 11.0 μm were calculated using the reciprocal of the temperature derivative of the Planck blackbody spectral radiance distribution function.

$$\Delta T = [\Delta L_{bb}(\lambda, T) / L_{bb}(\lambda, T)] [1 - \exp(-c_2 / \lambda T)] [\lambda^2 / c_2]$$

where:

- $L_{bb}(\lambda, T)$ = the Planck function,
- c_2 = the second radiation constant (14388 $\mu\text{m}\cdot\text{K}$),
- λ = the wavelength (μm),
- T = the temperature of the reference temperature source (K), and the quantity $[\Delta L_{bb}(\lambda, T) / L_{bb}(\lambda, T)]$ has the value 0.01.

^B The entries for total radiation were calculated using the Stefan-Boltzmann Law.

$$\Delta T = T - (0.99T^4)^{1/4}$$

where:

- T = the temperature of the reference temperature source (K).

^C Below the 1 % boundary line, the error in a tabular entry, due to the background contribution from the iris, is estimated to be not greater than 1 % of the value itself. Between the 1 % and 5 % boundary lines, the error ranges from 1 % to 5 % of the tabular entry. Above the 5 % boundary line, the error ranges from 5 % to 10 % of the tabular entry.

radiance. Provided that the test is restricted to the wavelengths and temperatures for which there are entries in Table 1, all that is then required is to reduce the iris opening from its maximum diameter until the output signal is reduced by 1 %.

8.4 Test Result—The value for the target size at the target distance chosen is taken to be the diameter of the iris opening for which the radiant power received by the radiation thermometer has been reduced by 1 % from its maximum value.

NOTE 11—The target size is generally expressed in terms of target diameter versus target distance from the radiation thermometer. See Fig. 4.

NOTE 12—This procedure may be repeated for other target distances for which the opening of the reference temperature source remains sufficiently large.

9. Response Time Test Method

9.1 Summary—This test method outlines the procedure to be used to evaluate the time interval required for the output

signal of a radiation thermometer to reach 95 % of full scale in response to a corresponding step change of input radiant power.

9.2 Test Conditions:

9.2.1 Rated supply of voltage and frequency.

9.2.2 Laboratory ambient temperature range (20 to 25°C).

9.2.3 Reference temperature source stabilized at the maximum temperature the radiation thermometer can indicate.

9.2.4 Radiation thermometer output terminals, as specified by the manufacturer, are to be connected to input of the data acquisition system.

9.3 Test Method:

9.3.1 The radiation thermometer is sighted at the reference temperature source.

9.3.2 The sight path between the radiation thermometer and the reference temperature source is interrupted by a shutter

mechanism and the output of the radiation thermometer is allowed to stabilize.

9.3.3 The data acquisition system is triggered and the shutter is opened such that the signal from the test instrument in response to the full-scale step change in input radiant power can be measured and recorded.

9.3.4 Instruments that contain digital processors may have a variation in the measured value for response time when successive measurements are performed. The test performed in 9.3.1 should be repeated on a single unit a sufficient number of times until the maximum and average values of response time are uniquely determined.

9.3.5 Instruments that contain digital processors may also be programmed to perform other functions besides temperature measurement, for example, the instrument may periodically perform a calibration function. The response time test procedure does not apply during these non-operating intervals.

9.4 *Test Result*—The value for the response time of the test instrument is taken to be the time interval required for the output signal to reach 95 % of full scale in response to a corresponding step change in input radiant power from the reference temperature source.

NOTE 13—Smaller step changes in radiant power and changes in direction may be tested in the same manner, but they may yield different values for the response time.

10. Warm-Up Time Test Method

10.1 *Summary*—This test method outlines the procedure to be used to evaluate the time interval, after switching the power on, that is required for the output signal or temperature reading of a radiation thermometer to stabilize to within the manufacturer’s repeatability specification (See Fig. 5).

10.2 *Test Conditions:*

10.2.1 Rated supply voltage and frequency.

10.2.2 Laboratory ambient temperature range (20 to 25°C).

10.2.3 Reference temperature source stabilized at a temperature within the calibrated range of the radiation thermometer.

10.3 *Test Method:*

10.3.1 The radiation thermometer is turned off and allowed to stand and stabilize at the specified ambient temperature for a period of approximately 8 h.

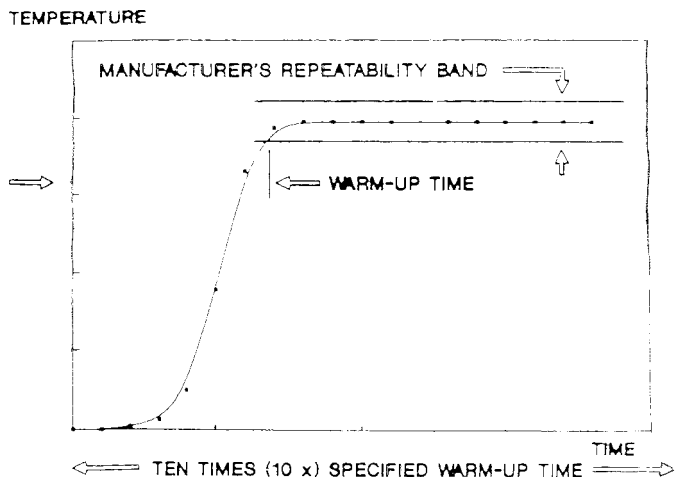


FIG. 5 Example of Warm-Up Time

10.3.2 The radiation thermometer is then sighted at the reference temperature source and switched on. The output signal is periodically recorded as the radiation thermometer warms to its operating temperature. The minimum total test time shall be ten times (10 ×) the time it takes to stabilize to within the manufacturer’s repeatability specification.

NOTE 14—The total test time shall not be less than 15 min.

10.4 *Test Result*—The value for the warm-up time is taken to be the elapsed time required for the output signal to equal the output signal recorded near the end of the test minus one-half the manufacturer’s repeatability band.

NOTE 15—The value applies across the entire calibration range.

11. Long-Term Drift Test Method

11.1 *Summary*—This test method outlines the procedure to be used to evaluate the change in output indication of a radiation thermometer, occurring over a long period of time, but not caused by external influences on the device.

11.2 *Test Conditions:*

11.2.1 Rated supply of voltage and frequency to be set within manufacturer’s range and held to a 1 % tolerance.

11.2.2 Prescribed warm-up period.

11.2.3 After execution of internal standardization check (if applicable).

11.2.4 Laboratory ambient temperature range (20 to 25°C) and held to within 1°C.

11.2.5 Reference temperature source should be stabilized at a temperature within the calibrated range of the radiation thermometer and regularly monitored to ensure that test results are not distorted by source drift.

11.3 *Test Method:*

11.3.1 The radiation thermometer is to be continuously powered up and sighted at the reference temperature source.

11.3.2 Temperature readings are taken at least once a month. The test duration is to be the manufacturer’s recommended recalibration interval or warranty period, whichever is less.

NOTE 16—Portable radiation thermometers are tested in the same fashion, except that the unit under test need not be powered up or sighted on a reference temperature source continuously.

11.4 *Test Result*—The long-term drift of a radiation thermometer is taken to be the difference between the maximum and minimum temperature readings obtained over the test interval.

NOTE 17—The value for the long-term drift is generally expressed as a temperature difference or a percent of full scale value per unit of time, or both.

NOTE 18—The value applies at one or more points across the measurement range of the radiation thermometer.

12. Precision and Bias

12.1 No statement can be made about the precision or bias of the test methods described until sufficient experience is obtained by users and manufacturers.

12.2 On a provisional basis, the following guidelines are suggested:

12.2.1 Duplicate tests by the same operator should be considered suspect if any two results for the same parameter differ by more than 0.5 % of radiation thermometer full scale

reading or 2°C (3°F), whichever is greater.

12.2.2 End user should consult the manufacturer if calibration results differ from manufacturer's results by more than 1 % of radiation thermometer full scale reading or 3°C (5°F), whichever is greater.

13. Keywords

13.1 blackbody; calibration; long-term drift; radiation thermometer; radiometer; repeatability; response time; target size; temperature; warm-up time; waveband

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