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BSI Standards Publication

Space systems — Measurements of thermo-optical properties of thermal control materials

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National foreword

This British Standard is the UK implementation of ISO 16378:2013.

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Space systems — Measurements of thermo-optical properties of thermal control materials

Systèmes spatiaux — Mesures des propriétés thermo-optiques des matériaux de thermorégulation

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Contents

Page

Foreword ..... **iv**

Introduction ..... **v**

1 Scope **1**

2 Normative references **1**

3 Terms and definitions **1**

4 Abbreviated terms **4**

5 Preparatory conditions **4**
5.1 Hazards, health, and safety precautions 4
5.2 Preparation of samples 5
5.3 Facilities 5
5.4 Standard Materials 6

6 Solar absorptance (α_s) test methods **7**

7 Hemispherical infrared emittance (ε_h) test method **7**

8 Normal infrared emittance (ε_n) test methods **7**

9 Test report **8**
9.1 Standard tests 8
9.2 Non-standard tests 9

10 Quality assurance **9**
10.1 Precision 9
10.2 Non-conformance 10
10.3 Calibration 10
10.4 Traceability 10

11 Audit of measurement equipment **10**
11.1 General 10
11.2 Initial audit of the system (acceptance) 10
11.3 Annual regular review (maintenance) of the system 10
11.4 Special review 11

Annex A (normative) **Solar absorptance using a spectrophotometer (α_s)** **12**

Annex B (normative) **Solar absorptance using the comparative test method (α_p)** **17**

Annex C (normative) **Hemispherical infrared emittance using the thermal test method ($\varepsilon_{h\text{-}t}$)** **19**

Annex D (normative) **Normal infrared emittance using an IR spectrometer ($\varepsilon_{n\text{-}s}$)** **23**

Annex E (normative) **Normal infrared emittance using ellipsoid collector optics ($\varepsilon_{n\text{-}e}$)** **26**

Annex F (normative) **Normal infrared emittance using two rotating cavities ($\varepsilon_{n\text{-}c}$)** **31**

Annex G (informative) **Key parameters for measurement** **34**

Annex H (informative) **Theoretical directional emittance** **35**

Bibliography **36**

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

Throughout this International Standard, the minimum essential criteria are identified by the use of the imperative or the keyword "shall". Recommended criteria are identified by the use of the keyword "should" and, while not mandatory, are considered to be of primary importance in providing serviceable, economical, and practical designs. Deviations from the recommended criteria can be made only after careful consideration, extensive testing, and thorough service evaluation have shown an alternative method to be satisfactory.

Solar absorptance and infrared emittance are the key parameters of materials for both active and passive thermal design of space systems.

This International Standard describes the methodology, instruments, equipment, and samples used to calculate the key parameters of thermal-control materials, i.e. solar absorptance [α_s or α_p] and the infrared emittance [ε_h or ε_n].

Attention is drawn to the possibility that some of the elements of this document can be the subject of patent rights other than those identified. ISO shall not be held responsible for identifying any or all such patent rights.

INTERNATIONAL STANDARD ISO 16378:2013(E)

Space systems — Measurements of thermo-optical properties of thermal control materials

1 Scope

This International Standard specifies the multiple measurement methods, instruments, equipment, and samples used to calculate the thermo-optical properties of thermal control materials. This International Standard compares their features, indicates their limitations and biases, and guides the applications. These measurements will be performed at ground test facilities with the purpose of obtaining material properties. The measured properties will be used for material selection, thermal design of spacecraft, process control, quality control, etc. Also, on-orbit temperature data in the beginning of life can be assessed using the data obtained by ground measurement. Requirements for calibration and reference materials to ensure data quality are also defined.

The following test methods are detailed in the Annexes of this International Standard including the configuration of samples and calculations.

a) Solar absorptance using a spectrophotometer: (α_s) — Annex A

b) Solar absorptance using the comparative test method: (α_p) — Annex B

c) Hemispherical infrared emittance using the thermal test method: ($\varepsilon_{h\text{-}t}$) — Annex C

d) Normal infrared emittance using an IR spectrometer: ($\varepsilon_{n\text{-}s}$) — Annex D

e) Normal infrared emittance using ellipsoid collector optics ($\varepsilon_{n\text{-}e}$) — Annex E

f) Normal infrared emittance using two rotating cavities: ($\varepsilon_{n\text{-}c}$) — Annex F

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9288:1989, *Thermal insulation — Heat transfer by radiation — Physical quantities and definitions*

ISO 21348:2007, *Space environment (natural and artificial) — Process for determining solar irradiances*

ASTM E490-00a:2006, *Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
absorptance *(α)*
$\alpha = \Phi a/\Phi m$
where Φa is the absorbed radiant flux or the absorbed luminous flux and Φm is the radiant flux or luminous flux of the incident radiation

[SOURCE: ISO 80000-7]

3.2
emissivity, emittance *(ε)*
$\varepsilon = M/Mb$
where M is the radiant exitance of a thermal radiator and Mb is the radiant exitance of a blackbody at the same temperature

[SOURCE: ISO 80000-7]

Note 1 to entry: The following adjectives should be added to define the conditions.

— **Total:** If they are related to the entire spectrum of thermal radiation (this designation can be considered as implicit) [ISO 9288:1989]

— **Spectral or monochromatic:** If they are related to a spectral interval centered on the wavelength λ [ISO 9288:1989]

— **Hemispherical:** If they are related to all directions along which a surface element can emit or receive radiation [ISO 9288:1989]

— **Directional:** If they are related to the directions of propagation defined by a solid angle around the defined direction [ISO 9288:1989]

— **Normal:** If they are related to the normal direction of propagation or incidence to the surface

EXAMPLE Total hemispherical emittance/emissivity.

Total hemispherical exitance M of the considered surface divided by the total hemispherical exitance $M0$ of the blackbody at the same temperature.

[SOURCE: ISO 9288:1989]

Note 2 to entry: When there is a certain need to distinguish a property of a material from a property of a real object, the word "emissivity" could be used. Emissivity is a property of a material measured as the emittance of an ideal material that is completely opaque and has an optically smooth surface.

Emissivity depends on the temperature at which it is determined and wavelength range.

Emittance is a property of a particular object. It is determined by material emissivity, surface roughness, oxidation, the sample's thermal and mechanical history, surface finish, and measured wavelength range. Although emissivity is a major component in determining emittance, the emissivity determined under laboratory conditions seldom agrees with actual emittance of a certain sample.

$$\varepsilon = \int_0^\infty L_b(\lambda,T)\varepsilon(\lambda)d\lambda \,/\, \int_0^\infty L_b(\lambda,T)d\lambda$$

where

$L_b(\lambda,T)$ Spectral Planck distribution of blackbody radiation, $c_1\lambda^{-5}(e^{(c2/\lambda T)}-1)^{-1}$;

C_1 $3{,}741\,77 \times 10^{-16}$ W·m^2;

C_2 $1{,}438\,8 \times 10^{-2}$ m·K;

T absolute temperature, K;

λ wavelength, m;

$\int_0^\infty L_b(\lambda,T)d\lambda$ $\sigma\pi^{-1}T^4$;

σ Stefan-Boltzmann constant, $5{,}670\,400\,(40) \times 10^{-8}$ [W·m^{-2}·K^{-4}].

3.3
diffuse
indicates that flux propagates in many directions, as opposed to direct beam, which refers to collimated flux. When referring to reflectance, it is the directional-hemispherical reflectance less the specular reflectance

3.4
infrared emittance
emittance in the infrared range at least from 5 µm to 25 µm

3.5
integrating sphere
an optical device used to either collect flux reflected or transmitted from a sample into a hemisphere or to provide isotropic irradiation of a sample from a complete hemisphere. It consists of a cavity that is approximately spherical in shape with apertures for admitting and detecting flux and usually having additional apertures over which sample and reference specimens are placed

3.6
irradiance
at a point on a surface, $E = d\Phi/dA$ [$W \cdot m^{-2}$], where $d\Phi$ is the radiant flux incident on an element of the surface with area dA

[SOURCE: ISO 80000-7]

3.7
near-normal-hemispherical
indicates irradiance to be directional near-normal to the specimen surface and the flux leaving the surface or medium is collected over an entire hemisphere for detection

3.8
radiant flux
$\Phi = dQ/dt$ [W]
where dQ is the radiant energy emitted, transferred, or received during a time interval of the duration dt

[SOURCE: ISO 80000-7]

3.9
reflectance (ρ)
$\rho = \Phi r/\Phi m$
where Φr is the reflected radiant flux or the reflected luminous flux and Φm is the radiant flux or luminous flux of the incident radiation

[SOURCE: ISO 80000-7]

3.10
solar
<radiometric> indicating that the radiant flux involved has the sun as its source or has the relative spectral distribution of solar flux

3.11
solar
<optical> indicating a weighted average of the spectral property, with a standard solar spectral irradiance distribution as the weighting function

3.12
solar absorptance (α_S)
ratio of the solar radiant flux absorbed by a material (or body) to the radiant flux of the incident radiation

Note 1 to entry: Differentiation is made between two methods:

a) Method of spectral measurements using a spectrophotometer covering the range from 250 nm to 2 500 nm for the determination of α_S.

b) Portable equipment using a xenon flash for relative measurements (α_p).

3.13
solar irradiance
radiation of the sun integrated over the full disk and expressed in SI units of power through a unit of area, $W \cdot m^{-2}$

[SOURCE: ISO 21348 (Notes in the original standard is omitted)]

3.14
spectral
<optical> indicating that the property was evaluated at a specific wavelength, λ, within a small wavelength interval, $\Delta\lambda$ about λ, symbol wavelength in parentheses as L(350 nm), or as a function of wavelength, symbol $L(\lambda)$

Note 1 to entry: The parameters of frequency, ν, wave-number, κ, or photon energy can be substituted for wavelength, λ, in this definition.

3.15
spectral
<radiometric> the concentration of the quantity per unit wavelength (or frequency), indicated by the subscript lambda, as $L\lambda = dL/d\lambda$

Note 1 to entry: The parameters of frequency, ν, wave-number, κ, or photon energy can be substituted for wavelength, λ, in this definition.

Note 2 to entry: At a specific wavelength, the wavelength at which the spectral concentration was evaluated can be indicated by the wavelength in parentheses following the symbol, $L\lambda$ (350 nm).

3.16
specular
indicates that the flux leaves a surface or medium at an angle that is numerically equal to the angle of incidence, lies in the same plane as the incident ray and the perpendicular, but is on the opposite side of the perpendicular to the surface

Note 1 to entry: Reversing the order of terms in an adjective reverses the geometry of the incident and collected flux, respectively.

3.17
transmittance *(τ)*
$\tau = \Phi t / \Phi m$
where Φt is the transmitted radiant flux or luminous flux and Φm is the radiant flux or luminous flux of the incident radiation

[SOURCE: ISO 80000-7]

4 Abbreviated terms

For the purposes of this document, the following abbreviations are used.

RT Room Temperature

5 Preparatory conditions

5.1 Hazards, health, and safety precautions

Attention shall be given to health and safety precautions. Hazards to personnel, equipment, and materials shall be controlled and minimized.

5.2 Preparation of samples

5.2.1 Sample property

This International Standard is applicable to materials having both specular and diffuse optical properties.

5.2.2 Configuration

The material samples shall be prepared according to the relevant process specification or manufacturer's data and shall be representative of batch variance.

The samples shall represent the work piece as exactly as possible. Expected changes in thermo-optical properties from the measured sample to the flight equipment shall be considered in thermal design.

For instance, the application procedure for paint can result in different thermo-optical properties depending on the painter and the type of spray gun used; therefore, the samples should be coated or made at the same time as the work piece.

The surface roughness strongly affects on the measurement results. Bare (uncoated) samples shall be finished to the same surface condition as the work piece.

5.2.3 Cleaning

The cleaning method and other treatment of the sample shall always be the same as for the flight hardware. Further cleaning or treatment of the sample is not allowed.

In particular, solar absorptance properties are very sensitive to contamination and if the sample or the flight hardware is contaminated (even by hand grease), the test results can be significantly in error.

5.2.4 Handling and storage

Samples shall only be handled with clean nylon or lint-free gloves and shall be stored in a cleanliness-controlled area, with a room temperature of 15 °C to 30 °C and a relative humidity of 20 % to 65 %.

a) Coated surfaces shall be shielded from contact by using soft and inert material such as polyethylene or polypropylene bags or sheets.

b) Mechanical damage shall be avoided in the standard way by packing the wrapped samples in clean and dust and lint-free material.

c) Limited-life materials shall be labelled with their relative shelf lives and dates of manufacture.

5.2.5 Identification

a) Samples submitted for testing shall be accompanied by a completed "Material identification card".

b) Hazardous samples shall be accompanied by a completed "Safety data sheet".

c) The surface of the samples which is to be measured shall be clearly indicated unless the samples have completely even properties on both surfaces.

5.3 Facilities

5.3.1 Cleanliness

a) The work area shall be clean and free of dust.

b) Air used for ventilation should be filtered to prevent contamination of the sample.

5.3.2 Environmental conditions

The ambient conditions for the process and work areas shall be from 15 °C to 30 °C with a relative humidity of 20 % to 65 % unless otherwise stated.

5.3.3 Equipment

The equipment is specific for each test and defined in the Annexes.

5.4 Standard Materials

5.4.1 General

Both reference and working (comparison) standards are required. Highly durable materials are preferred. Standard materials shall be handled and stored in accordance with the associated specification. Avoid touching the optical surfaces even with gloves.

5.4.2 Reference standard material

Reference standards are the primary standard material for the calibration of instruments and working standards. Reference standards shall be traceable to a national or an international authority having jurisdiction.

5.4.3 Working standard material

Working standards are used in the daily operation of the instrument to provide comparison curves for data reduction. A working standard shall be calibrated annually by measuring its thermo-optical properties relative to the properties of the appropriate reference standard. If degradation is noticeable, the working standard shall be cleaned, renewed, or replaced.

5.4.4 Solar absorptance

For transmitting samples, incident radiation shall be used as the standard relative to which the transmitted light is evaluated. For some applications, calibrated transmittance standards are available.

For diffuse high-reflectance samples, a working standard that has high reflectance and is highly diffusing over the range of the solar spectrum is required.

NOTE 1 White diffuser is commonly used as a diffuse high-reflectance standard material. Various white diffusers are provided by a national or an international authority such as NIST. Spectralon®[1)] is a commercially available material that provides high-diffuse reflectance for 250 nm to 2 500 nm. $BaSO_4$ and magnesium oxide have been widely utilized but are no longer recommended for use as a standard since they are not stable for longer periods.

For specularly reflecting samples, a working standard that is highly specular is required. Identified suitable working standards are vacuum-deposited thin opaque films of metals. All front surface metalized working standards shall be calibrated frequently with an absolute reflectometer or relative to a national or an international standard reference material before being acceptable in this test method.

NOTE 2 Aluminium-coated glass mirror is widely used because of its high reflectance and ease of deposition. Although bare aluminium surface is highly vulnerable, protective coating could maintain the optical property.

For absorber materials, a working standard that has low reflectance over the range of the solar spectrum is required in order to obtain an accurate zero line correction.

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1) This information is given for the convenience of users of this document and does not constitute an endorsement by ISO TC 20/SC 14 of the product named. Equivalent products may be used if they can be shown to lead to the same results.

5.4.5 Infrared Emittance

A set of high- and low-emittance materials are often provided by the instrument manufacturer as standard materials. Typical high- and low-emittance standards can consist of black paint (or preferably a blackbody cavity) and polished high-purity aluminium, respectively.

6 Solar absorptance (α_S) test methods

Two test methods are described in this clause.

Though α_p have slightly bigger standard deviations than α_S, both two methods provide well-repeatable data to use in thermal design. Solar absorptance obtained by these two methods shall be clearly distinguished by the terms α_s and α_p.

a) Solar absorptance using a spectrophotometer (α_s)

This method covers the measurement of spectral absorptance (α_S), reflectance, and transmittance of materials using spectrophotometers equipped with integrating spheres.

b) Solar absorptance using the comparative test method (α_p)

The comparative method (α_p) compares the reflection of a Xenon flash by a known reference material to the reflection of an unknown sample. This method has limitations due to the difference between a Xenon flash spectrum and the solar spectrum.

7 Hemispherical infrared emittance (ε_h) test method

A test method is described in this clause.

Hemispherical infrared emittance obtained by the thermal test method shall be clearly defined by the term $\varepsilon_{h\text{-}t}$.

a) Hemispherical infrared emittance using the thermal test method ($\varepsilon_{h\text{-}t}$)

Only the thermal test method enables direct measurement. Although the thermal method requires more time and effort, it is the fundamentally correct method to obtain total hemispherical infrared emittance. ε_h of wider temperature samples are obtained solely by the thermal method.

NOTE The method that measures total hemispherical reflectance as absorptance of materials using infrared spectrophotometers equipped with integrating spheres is still under study. ASTM E1392–96 could be referred to for the measurement method development.

8 Normal infrared emittance (ε_n) test methods

Three test methods are described in this clause.

a) Normal infrared emittance using an IR spectrometer ($\varepsilon_{n\text{-}s}$)

The IR spectrometer method measures the normal reflectance as residue from unity minus emittance of materials using infrared spectrophotometers equipped with integrating spheres. Normal infrared emittance obtained using an IR spectrometer shall be identified by the term $\varepsilon_{n\text{-}s}$.

b) Normal infrared emittance using ellipsoid collector optics ($\varepsilon_{n\text{-}e}$)

The test method using ellipsoid collector enables direct measurement without knowing the exact sample temperature. The source beam is provided to the sample with a near-normal incident angle. The ellipsoid collector focuses over 99 % of the hemispherical reflected energy onto the detector. Normal infrared emittance obtained using an ellipsoid collector shall be identified by the term $\varepsilon_{n\text{-}e}$.

c) Normal infrared emittance using two rotating cavities ($\varepsilon_{n\text{-}c}$)

This method measures reflected energy of the sample using two rotating cavities that are maintained at different temperatures. Sample temperature is not necessarily measured. Suitable calibration with known reflectance standards is required to obtain reflectance values on samples. Total normal emittance is calculated by subtracting the calibrated reflectance from unity.

Measured data with two rotating cavities is limited in accuracy by the degree to which the emittance properties of calibrating standards are known and by the angular emittance characteristics of the surfaces being measured. At the round-robin test performed in 2007, the two rotating cavities provided relatively low emittance compared to the direct measurements. The maximum difference of ε_n measured by the two method was greater than 0,1. Normal infrared emittance obtained using two rotating cavities shall be identified by the term $\varepsilon_{n\text{-}c}$. Although many historical data have been obtained by this method, it is recommended to use the other two methods instead.

9 Test report

9.1 Standard tests

9.1.1 Complete identification of the material tested

The test report shall contain as a minimum the following:

a) trade names and batch numbers of the materials under test;

b) name of the manufacturer or supplier through whom the purchase was made;

c) summary of the preparation and conditioning schedule (e.g. mixing proportions, coating thickness, cure time and temperature, post-cure, cleaning procedure);

d) sample size and thickness, coating thickness of layers if available, surface contour if any, description of optical properties such as diffuse or specularly reflecting, clear or translucent transmitting, etc.;

e) properties of the substrate when the material is applied on (e.g. trade name, material, thickness, etc.).

9.1.2 Complete identification of the measurement condition

The test report shall contain as a minimum the following:

a) utilized measurement method;

b) date and time the measurements were taken;

c) identification of the instrument used (Manufacturer's name and model number including modifications and accessories is sufficient for a commercial instrument. Other instruments shall be described in detail including wavelength range and estimations of their accuracy. Key accessories information such as integrating sphere coating material and diameter, filter's path band, etc., shall be included.);

d) identification of the working standard materials used for calibration;

e) thermo-optical properties assumed for the working standard materials;

f) ambient temperature and related humidity;

g) sample temperature (RT or controlled certain temperature);

h) locations on the surface area at which measurements were performed (not applicable for small individual test samples);

i) estimate precision (repeatability) and estimated accuracy reported as uncertainty due to bias. The accuracy and precision shall be reported in the same units as the optical property itself;

j) any noticeable incident observed during the measurement which shall be recorded;

k) the quality records (e.g. log sheets) shall be retained for at least 10 years or in accordance with project contract requirements.

9.1.3 Measurement results

9.1.3.1 Solar optical properties

The test report shall contain as a minimum the following:

a) solar transmittance, absorptance, or reflectance, or all three, determined to the nearest 0,01 unit or 1 %;

b) solar spectral irradiance source document or source data and weighting method used for computation of the solar optical property.

9.1.3.2 Infrared optical properties

The test report shall contain as a minimum the following:

a) infrared emittance, absorptance, or transmittance, or all three, determined to the nearest 0,01 unit or 1 %;

b) indicated meter reading (reflectance) for three successive measurements with their standard deviation (not applicable for $\varepsilon_{h\text{-}t}$);

c) infrared emittance determined to the nearest 0,01 unit or 1 % obtained by subtracting an average of the three reflectance values from one (not applicable for $\varepsilon_{h\text{-}t}$);

d) for samples with rough surface and/or inhomogeneous property, appropriate number of tests shall be performed on multiple samples considering the sample condition (an average of the measured values shall be reported with its standard deviation).

9.2 Non-standard tests

Measurement performed with any deviation from standard test conditions is considered as a non-standard test. The test report shall clearly indicate all the deviation. Measured data shall be distinguished from standard test data. It is recommended to note the assumed bias on the measurement results caused by the deviations.

10 Quality assurance

10.1 Precision

The measurement precision for the key parameters shall be as follows:

a) Solar absorptance measurement repeatability on the same point of a sample ±0,01 (non-dimension) in repeated measurement data or 5 % of the mean measured value;

NOTE 1 0,1 % for spectrophotometer without integrating sphere; 0,5 % for spectrophotometer with integrating sphere.

b) Infrared emittance measurement repeatability on the same point of a sample ±0,01 (non-dimension) in repeated measurement data or 5 % of the mean measured value;

NOTE 2 Random uncertainty of reflectance measurements performed by Labsphere, Inc. is 0,005 for the spectral range (300 nm to 2 200 nm) and is equal to 0,02 over the spectral range (250 nm to 2 500nm). (See calibration certificate for Spectralon® reference.)

c) Sample thickness: 10^{-2} mm (bulk material);

d) Sample thickness: 10^{-3} mm (thin films, paints, and coatings);

e) Temperature: ±5K.

10.2 Non-conformance

Any non-conformance that is observed in respect of the measurement procedure shall be resolved in accordance with the quality assurance requirements.

10.3 Calibration

a) Each reference standard and piece of measuring equipment shall be calibrated according to the equipment specific procedure.

b) Any suspected or actual equipment failure shall be recorded as a project non-conformance report so that previous results can be examined to ascertain whether or not reinspection and retesting is required.

c) The customer shall be notified of the non-conformance details.

10.4 Traceability

Traceability shall be maintained throughout the process from incoming inspection to final measurements and calculations, including details of the test equipment and personnel employed in performing the task.

11 Audit of measurement equipment

11.1 General

The thermo-optical property data from test houses for the projects of the customer, obtained in the manner laid down in this International Standard, are only accepted for the projects of the customer if the test house is certified to perform the relevant procedure in this International Standard.

11.2 Initial audit of the system (acceptance)

a) Once a system has been built or purchased, it shall be audited by the customer's product assurance department before it can be accepted for running qualification or quality control tests on materials for use in customer projects.

b) This initial audit shall, at least, consist of (but not necessarily be restricted to) an inspection of the apparatus and associated equipment, the performance of a test on a defined set of materials, the reporting of the non-conformance, and the audit findings.

11.3 Annual regular review (maintenance) of the system

a) Inspection of apparatus and associated equipment

b) Mutual comparability evaluation (testing)

c) Non-conformance:

If the inspection of the system or the "round-robin test" shows a non-conformance with the applicable audit specification of the customer or the acceptable limits of the test results, actions shall be undertaken

by the test house in order to determine the reasons for the non-conformance and a further test shall be performed in accordance with 10.2 before a certificate of conformance is renewed.

d) Reporting of findings:

   1) A detailed written report of the result of the regular review shall be delivered to all participants within six weeks after the end of the regular review or evaluation testing;

   2) The certificate of conformance shall be renewed annually after a successful review.

11.4 Special review

a) All modifications of the apparatus or associated equipment shall be reported and, if deemed necessary, be audited by the customer before utilization of the modified system for the customer's project.

b) Major modifications shall result in the retesting of apparatus as described in 10.2.

Annex A
(normative)

Solar absorptance using a spectrophotometer (α_S)

A.1 General

Solar absorptance is calculated using the absorption spectrum of the material over the region from 250 nm to 2 500 nm and this spectrum is then multiplied with the solar spectrum.

a) The absorption spectrum shall be measured using an integrating sphere.

b) Absolute measurements are available using a sphere with central sample mounting.

c) Opaque samples shall be mounted on the wall of the integrating sphere.

d) Two measurements are required for transparent samples. Transmittance shall be measured mounting the sample on the wall of the integrating sphere. Reflectance shall be measured with central sample mounting.

e) For transmitting samples, incident radiation shall be used as the standard relative to which the transmitted light is evaluated. For some applications, calibrated transmittance standards are available.

NOTE A sphere with a sample holder on the sidewall can also be used. In this case, the reflectivity is compared to a known standard (e.g. calibrated Al-mirror or calibrated Spectralon® standard).

Measurements of spectral near-normal-hemispherical transmittance (or reflectance) are made over the spectral range from approximately 250 nm to 2 500 nm with an integrating sphere spectrophotometer.

The solar transmittance, reflectance, or absorptance is obtained by calculating a weighted average with a standard solar spectral irradiance as the weighting function by either the weighted or selected ordinate method.

A.2 Configuration of samples

The size of test specimens required depends on the dimensions of the integrating sphere. For wall-mounted spheres, the specimen shall be large enough to fully cover the aperture of the sphere. If large enough sample is not available, the test requester shall coordinate with test facility.

EXAMPLE When the aperture of the sphere was 15 mm × 15 mm, the sample must be larger than the 15 mm square regardless of its shape. Depending on the method and equipment used, these dimensions can vary. For patterned samples, either the specimen shall be large enough to make a number of measurements over different areas or several specimens representing the different areas of the material shall be used.

Flexible samples shall be mounted on a rigid surface. The sample shall be flat. For spherical curved samples, its radius of curvature shall be larger than 300 mm.

Special care shall be taken on alignments of optical systems. The sample shall be closely fit on the sample port in the right angle. Deviations in the incident angle of the probe beam and optical systems inside could produce error in results.

This test method is applicable to materials having both specular and diffuse optical properties.

Opaque specimens shall have at least one surface that is essentially plane over an area large enough to cover the aperture of the sphere.

Transparent and slightly translucent specimens shall have two surfaces that are essentially plane and parallel. In order to reduce light scattered out the edges of translucent specimen, the minimum distance between the edge of the beam and the edge of the aperture shall be 10 times the thickness of the specimen.

The transmittance of highly scattering translucent samples is not easily measured with an integrating sphere instrument because a significant portion of the incident flux will be scattered outside the aperture from the side of the sample. The test report shall describe when the measured samples had such characters.

A.3 Test equipment and setting up

The test equipment consists of a spectrometer, covering at least the range over 250 nm to 2 500 nm. An apparatus which covers wider wavelength range is encouraged for better replication. Figure A.1 and A.2 show the test equipment configurations.

a) The wavelength resolution of the spectrometer shall be compatible with the resolution used for the solar spectrum.

b) The signal-to-noise ratio shall be better than the following:

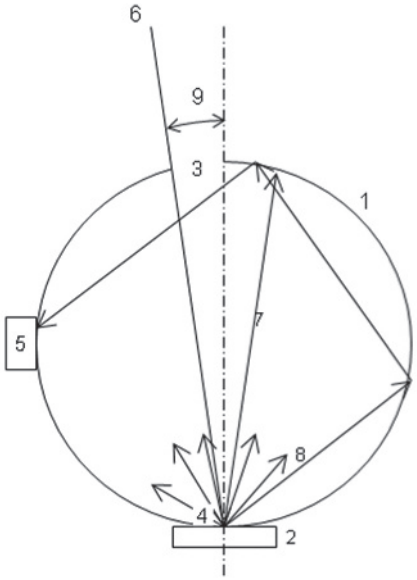
   1) ±1 % full scale in the region between 250 nm and 2 000 nm;

   2) 5 % full scale in the region between 2 000 nm and 2 500 nm.

c) If the sample is mounted on the side wall, the associated sphere shall have a maximum port to total surface ratio of 5 %. A smaller ratio of the port area to the total internal surface area can be achieved using large spheres. Small spheres can give rise to large errors.

NOTE 1 If the test equipment is used in a central sample mode, i.e. an “Edwards”-type integrating sphere, the measurement is called “absolute”.

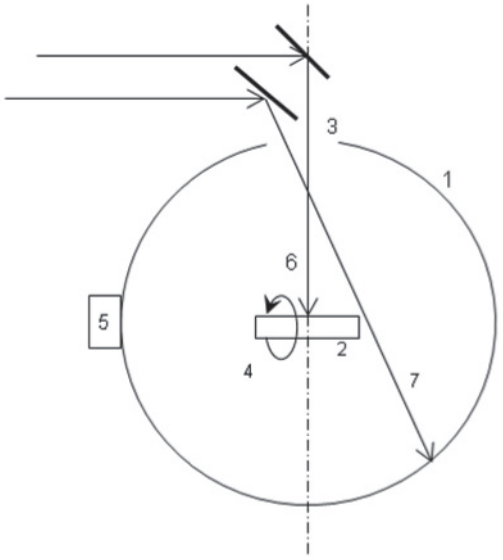
NOTE 2 If the sample is mounted on the sidewall, the measurement is done towards a calibrated standard that can be specular (e.g. Al-mirror) or diffuse (e.g. Spectralon®). In the case of relative measurements, change in the optical property of the standard materials affects the measured value.



Key

1 integrating sphere
2 test specimen
3 entrance port
4 sample port
5 detector
6 incident radiation
7 specular reflection
8 diffuse reflection
9 incident angle

Figure A.1 — Integrating sphere (wall mount type)



Key

1 integrating sphere
2 test specimen
3 entrance port
4 sample rotation
5 detector
6 incident radiation
7 reference radiation

Figure A.2 — Integrating sphere (central mount type)

d) The responsible test officer shall make the choice of a standard based on the visual aspect of the sample.

e) For materials having, in the visible region, a large specular component, a standard mirror shall be used.

f) When the diffuse component is predominant in the visible region, a diffuse sample such as Spectralon® shall be used.

g) The standard used for the measurement shall be indicated in the report.

ISO 9505 requests that the wavelength resolution shall be

— less than 5 nm (wavelength is shorter than 380 nm),

— less than 10 nm (wavelength is 380 nm to 780 nm),

— less than 50 nm (wavelength is longer than 780 nm).

ISO 9505 requests that the photometric accuracy shall be

— less than 1 % of full scale (wavelength is shorter than 780 nm),

— less than 2 % of full scale (wavelength is longer than 780 nm).

ISO 9505 requests that the photometric reproducibility shall be

— less than 0,5 % of full scale (wavelength is shorter than 780 nm),

— less than 1 % of full scale (wavelength is longer than 780 nm).

ISO 9505 requests that the wavelength accuracy shall be

— less than ±1 nm (wavelength is shorter than 780 nm),

— less than ±5nm (wavelength is longer than 780 nm).

A.4 Test process and measurement

Before starting a measurement sequence, the 100 % and 0 % baseline shall be taken (using the standard reference as applicable). The baseline shall be measured at least once a day when equipment is switched on.

A.5 Calculation of solar absorptance

The spectrum is taken over 250 nm and 2 500 nm and covers 95,6 % of the total energy.

$$\alpha_s = 1 - \rho_s$$

$$\rho_s = \frac{\int_{\lambda_1}^{\lambda_2} \rho(\lambda) S(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} S(\lambda) d\lambda} \tag{A.1}$$

where

$\rho(\lambda)$ is the spectral reflectance after 100 % reference correction;

$S(\lambda)$ is the spectral solar irradiance;

$d\lambda$ is typically 1 nm and shall be defined considering the sample properties;

λ_1 is smaller than 250 nm;

λ_2 is larger than 2 500 nm.

Solar irradiance spectrum is available in several sources. ASTM E490-00a should be primarily applied. When other spectrum is used, the data source shall be described in the test report.

For transparent test pieces, it is possible to calculate the absorptance by the same method because

$$\alpha(\lambda) = 1 - [\rho(\lambda) + \tau(\lambda)] \tag{A.2}$$

It is also possible to calculate absorptance for a spectrum other than the solar spectrum, e.g. for solar simulators.

Annex B
(normative)

Solar absorptance using the comparative test method (α_p)

B.1 General

This method is based on comparing the reflection of a Xenon flash by a known appropriate standard material to the reflection of an unknown sample. The nature of the standard material (chemical composition and surface morphology) shall be representative for the unknown. The solar absorptance of the standard surface shall be measured using the method described in Annex A.

This method has limitations due to the fact that the flasher spectrum is not identical to the solar spectrum.

Special precautions shall be taken when using portable reflectometer equipment.

This equipment shall only be used for comparative measurements. It shall be used in conjunction with known standard or calibrated materials, identical to or at least having similar optical behaviour to the material to be measured. If such an approach is followed, the equipment shall give a direct and correct result within the linearity limitation. If the standard material used is not identical to the material under test, the result of the reading not only depends on the linearity of the equipment but also on the spectral reflectivity of the material. Any reporting of results shall include the detailed test conditions.

B.2 Configuration of samples

The minimal sample dimensions are dictated by the diameter of the aperture on the portable equipment. This diameter is typically between 15 mm and 20 mm.

Flexible samples shall be mounted on a rigid surface. The sample shall be flat. For spherical curved samples, its radius of curvature shall be larger than 300 mm.

B.3 Test equipment and setting up

The equipment consists of a flasher, able to produce a flash with a reproducible spectrum. The total intensity, as well as the reflected intensity of the flasher, is measured both with the standard material surface and the sample surfaces.

B.4 Test process and measurement

a) Before any measurement is performed, the equipment shall be stabilized following the instructions given by the manufacturer.

b) The equipment shall be calibrated following the instructions given by the manufacturer.

c) The calibration shall, as a minimum, include a “zero” or baseline measurement, as well as the measurement of the standard material.

d) After calibration with the appropriate standard material, the unknown sample shall be measured.

e) If several materials have to be measured, calibration shall be repeated at regular time intervals, depending on the known stability of the equipment.

f) For statistical reasons, each measurement shall be repeated at least five times; the average and standard deviation of the measurements shall be calculated and reported.

g) Some equipment makes these calculations automatically through integrated software. The standard deviation between measurements shall be 0,02 or better.

B.5 Calculations

Reflectance reference surface (ρ_r):

$$\rho r = I_r / I_{tr} \quad \text{(B.1)}$$

where

I_r is the intensity of flash reflected on standard material surface;

I_{tr} is the total intensity of flash during standard material flashing.

Reflectance sample surface (ρ_s):

$$\rho_s = I_s / I_{tr} \quad \text{(B.2)}$$

where

I_s is the intensity of flash reflected on sample surface;

I_{tr} is the total intensity of flash during sample flashing.

$$\rho = I_s / I_r \times \rho_r \quad \text{(B.3)}$$

where

ρ_r is the measured standard material reflectance (using method in Annex A);

ρ is the calculated sample reflectance.

$$\alpha_p = 1 - \rho \quad \text{(B.4)}$$

Annex C
(normative)

Hemispherical infrared emittance using the thermal test method ($\varepsilon_{h\text{-}t}$)

C.1 General

By means of the dynamic thermal method, one can determine the total hemispherical emittance from the decrease in temperature of a test item with well-defined thermal characteristics.

C.2 Configuration of samples

A "standard sample substrate" as detailed in Figure C.1 should be used in favour of any other geometrical shape.

In particular, the sample shall be made by machining and not by cutting out with shears since this flattens the edges and does not produce a very accurate square shape. Sample material is bonded on the sample substrate. Sample material shall be opaque over the infrared range to eliminate the transmitted heat from the substrate.

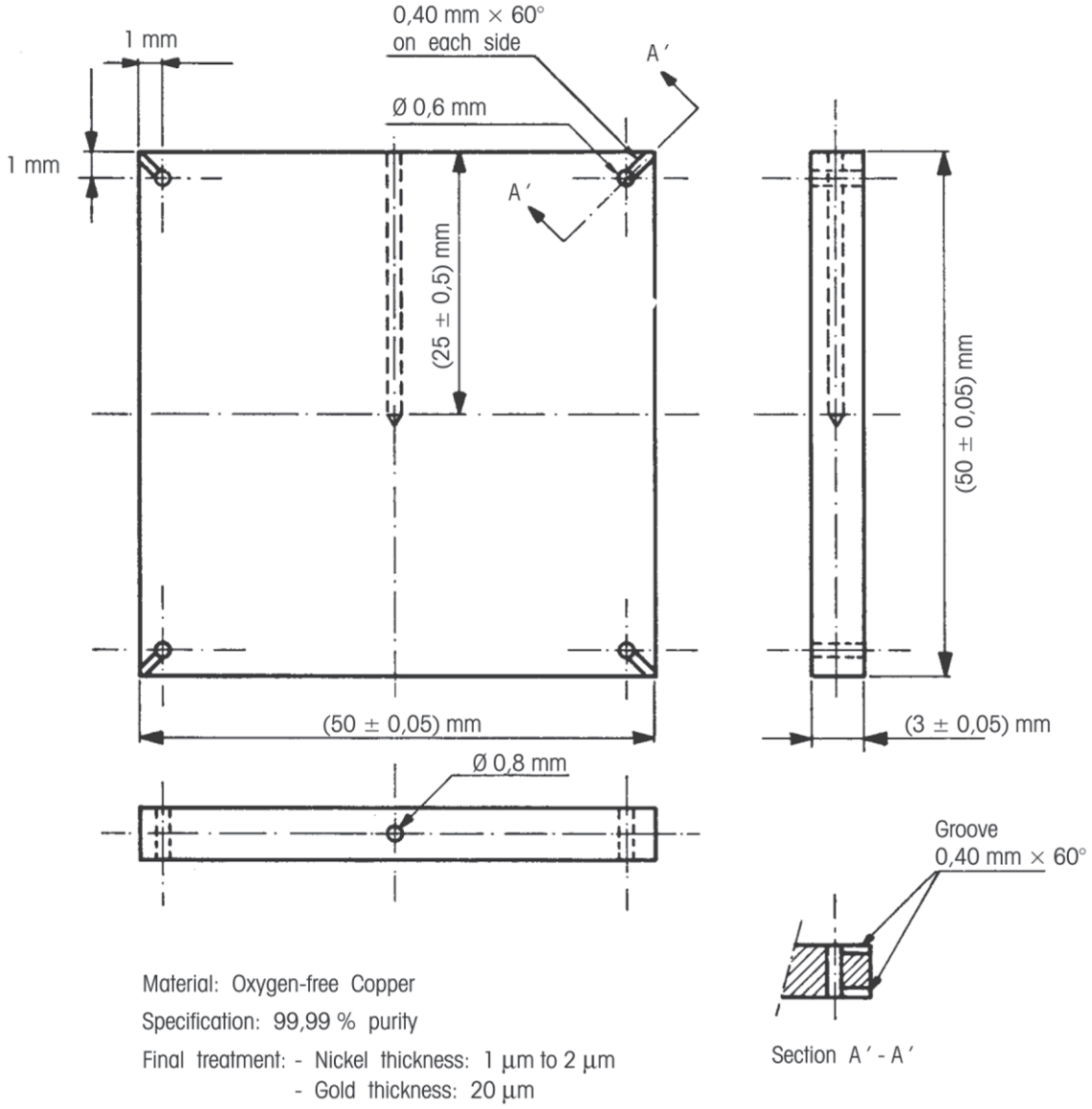


Figure C.1 — Standard sample substrate

C.3 Test equipment and setting up

For the dynamic thermal method, it is assumed that the specific heat of the test piece is known. A lightweight test piece (i.e. one with a low-heat capacity) is bonded by means of double-sided adhesive tape to a gold-plated substrate (standard sample substrate), the heat capacity of which is high enough to keep a uniform surface temperature of the test piece.

Initially, the gold-plated substrate's emittance is measured. A copper, Constantan®[2)], thermocouple is fixed in the centre of the gold-plated substrate. Four nylon threads (e.g. φ = 0,16 mm) secure the substrate and test piece to the centre of a sample holder which is fixed on the axis.

This is then lowered to the centre of the cryogenic shroud which is coated in black and cooled with liquid nitrogen.

2) This information is given for the convenience of users of this document and does not constitute an endorsement by ISO TC 20/SC 14 of the product named. Equivalent products may be used if they can be shown to lead to the same results.

The dimensions are such that the shroud area is more than 100 times the total area of the test piece.

A window made of high-purity synthetic fused silica (working diameter: 90 mm) enables this test piece to be illuminated by an external heat source.

C.4 Test process and measurement

After a sufficient vacuum is attained (<10^{-4} Pa), and the temperatures of the shroud and sample holder are stabilized, the test piece is heated up to 30 °C. The decreasing temperature is then recorded down to 20 °C. The total hemispherical emittance is then calculated for a temperature of 25 °C. It is possible to do this for any temperature between –100 °C and +100 °C by using a similar method.

NOTE 1 The sample temperature should be determined according to the material's operational temperature range.

NOTE 2 The errors of measurement depend mainly on the following quantities:

— specific heat of the test piece: C_e;

— temperature: T;

— time: t.

The first quantity, C_e, can be measured from the test piece by means of thermal analyses such as with a differential scanning calorimeter or is taken from the literature for clearly defined materials.

C.5 Calculations of total hemispherical emittance

Calculation of the emittance is performed using the following formulae:

$$\varepsilon = \frac{(M_r C_r)_0 + (M_e C_e)_{Tmoy}}{4\sigma S T_0^3 (t_2 - t_1)} \left[(\alpha T_0) \ln A + \ln B + 2C \right] \tag{C.1}$$

$$A = \frac{(T_2^2 + T_0^2)(T_1^2 - T_0^2)}{(T_2^2 - T_0^2)(T_1^2 + T_0^2)} \tag{C.2}$$

$$B = \frac{(T_2 + T_0)(T_1 - T_0)}{(T_2 - T_0)(T_1 + T_0)} \tag{C.3}$$

$$C = (1 - \beta T_0^2) \left(\arctan \frac{T_2}{T_1} - \arctan \frac{T_2}{T_0} \right) \tag{C.4}$$

and

$$\varepsilon_e = \frac{\varepsilon S - \varepsilon_r S_r}{S_e} \tag{C.5}$$

where

(t_1, T_1) and (t_2, T_2) are two points on a cooling curve at times t_1 and t_2 for which the corresponding temperatures are T_1 and T_2;

(MC) is the total heat capacity of a test piece with gold-plated substrate.

If the variation of specific heat is assumed to be parabolic with the temperature, then

$$(MC)_T = (M_r C_r + M_e C_e) \tag{C.6}$$

and

$$(M_r C_r)_T = (M_r C_r)_0 (1 + \alpha T + \beta T^2) \tag{C.7}$$

where

ε is the total hemispherical emittance of test piece plus substrate;

ε_r is the total hemispherical emittance of the gold-plated substrate;

ε_e is the total hemispherical emittance of the test piece;

$(M_r C_r)_0$ is the thermal mass of the substrate at 0 °C (JK^{-1});

M_r is the weight of gold-plated piece (kg);

C_r is the specific heat of gold-plated piece ($J\ kg\ K^{-1}$);

M_e is the weight of the test piece (kg);

C_e is the specific heat of the test piece ($J\ kg\ K^{-1}$);

S_r is the gold-plated surface area (m^2);

S_e is the surface area of the test piece (m^2);

S is the total emitting surface area, i.e. $S = S_e + S_r\ (m^2)$;

T_0 is the temperature of the cryogenic shroud (K);

t is time (s);

σ is the Stefan-Boltzmann constant = 5,670 400 (40) × 10^{-8} $Wm^{-2}\ K^{-4}$.

Annex D
(normative)

Normal infrared emittance using an IR spectrometer ($\varepsilon_{n\text{-}s}$)

D.1 General

This method is based on optical measurements of emittance of materials in the infrared range from 5 µm to 25 µm. This emittance is determined by measuring the total hemispherical reflectance of these materials using an integrating sphere coupled with an infrared spectrometer. The wavelength of the maximum emission from a material shifts toward a longer wavelength when its temperature goes down. Due to the wavelength range limitation, this method is not applicable to cryogenic sample measurement.

As for emittance measurements, one can make absolute measurements with a central sample holder, but another solution is to measure the reflectivity of the sample on the wall comparing the reflectivity of the sample with a calibrated standard (mirror or Infragold®[3)]). The spectrum obtained is weighted by blackbody spectrum and integrated.

D.2 Configuration of samples

The size of the samples depends on the configuration adopted (either central or tangential) and the sizes of the sphere, beam, sample holder, and measurement port. The sample shall be large enough to receive the complete incident beam but small enough to disturb, at the minimum, the sphere integrity.

A common size is 20 mm × 20 mm or 20 mm diameter for an integrating sphere of 150 mm in diameter with a central sample mounting, with a maximum thickness of 5 mm.

The samples shall be rigid.

Reflectance measurements with transparent and semi-transparent samples have errors due to transmittance losses.

D.3 Test equipment and setting up

The test equipment consists of an IR reflectometer covering the range at least from 5 µm to 25 µm equipped with an integrating sphere. The range of measurement is limited by the material used for the sphere walls.

a) The spectrometer should be purged with a permanent N_2 flux in order to eliminate CO_2 and H_2O absorption bands. When N_2 purge is not available, it shall be purged with dry air.

b) The signal-to-noise ratio over the whole interval from 5 µm to 20 µm shall be better than 1 % full scale.

D.4 Test process and measurement

The measurement on the sample is made after a baseline measurement is obtained either on the standard sample for a tangential sample or on the wall sphere if the sample is centrally mounted.

The baseline and the sample measurement shall be made in the same conditions of the purge of the spectrometer.

3) This information is given for the convenience of users of this document and does not constitute an endorsement by ISO TC 20/SC 14 of the product named. Equivalent products may be used if they can be shown to lead to the same results.

This method can measure reflectance on samples that are opaque in the wavelength region of interest. The infrared emittance of semi-transparent samples is determined from approximate total transmittance and reflectance of the samples, the backside of which is covered with the substrates. To see if a sample is partially transmitting, the substrates with high and low reflectance shall be alternately placed on the sample as backing. Do not use the standard materials as they could become damaged. If the sample is transmitting, the reflectance values will be different.

The sample shall be measured with backing of the high-reflectance (gold) substrate and the low-reflectance (black) substrate. The total reflectance of each substrate shall also be measured. The approximate transmittance and reflectance of the semi-transparent samples were calculated with Formulae (D.1) and (D.2). Then, the infrared emittance is determined by subtracting the reflectance and transmittance from unity. It should be noted that higher uncertainty is expected in data obtained using backing.

$$\tau = \frac{\rho_b G - \rho_g B}{\rho_b \rho_g (G - B) + \rho_b - \rho_g} \tag{D.1}$$

$$\rho_s = \sqrt{\frac{(G-B)(\rho_g B - 1)(\rho_g - \rho_b)(\rho_b G - 1)}{(\rho_b \rho_g (G-B) + \rho_b - \rho_g)^2}} \tag{D.2}$$

where

τ is the transmittance of the sample;

ρ_s is the reflectance of the sample;

ρ_b is the reflectance of the substrate with low reflectance (black);

ρ_g is the reflectance of the substrate with high reflectance (gold);

B is the reflectance of the sample, the back side of which is covered by the substrate with low reflectance (black);

G is the reflectance of the sample, the back side of which is covered by the substrate with high reflectance (gold).

D.5 Calculation of emittance

The spectrum obtained by the above test method is then weighted and integrating following the formula:

$$\varepsilon = \frac{\int_{5\mu m}^{25\mu m} \alpha(\lambda) E(\lambda) d(\lambda)}{\int_{5\mu m}^{25\mu m} E(\lambda) d(\lambda)} \tag{D.3}$$

where

ε is the infrared emittance of sample;

$\alpha(\lambda)$ is the spectral absorptance of the sample after 100 % reference correction ($\alpha(\lambda) = 1 - \rho(\lambda)$ or $\alpha(\lambda) = 1 - [\rho(\lambda) + \tau(\lambda)]$ if the sample is transparent);

$E(\lambda)$ is the blackbody emittance spectrum at 300 K and can be calculated with the Planck law:

$$E(\lambda) = \frac{2\pi hc^2 \lambda^{-5}}{e^{hc/\lambda\kappa T} - 1} \left(\mathrm{W/m^2 \frac{1}{4} m} \right) ; \tag{D.4}$$

h = 6,626 069 57 (29) × 10^{-34} [J·s] and k = 1,380 648 8 × 10^{-23} [J·K^{-1}].

The emittance at other temperatures can also be determined with measurements in another wavelength range. In this case, the blackbody spectrum shall be calculated at this new temperature.

Annex E
(normative)

Normal infrared emittance using ellipsoid collector optics ($\varepsilon_{n\text{-}e}$)

E.1 General

The measurements are performed by illuminating the sample at a near-normal angle, with respect to the surface. An ellipsoidal collection cavity collects a virtually full hemisphere of the reflected/scattered energy from the surface and directs this energy onto a detector. A calibration mirror alternately directs the incident beam either to the detector or to the sample. The incident energy, in terms of the detector output voltage, provides a calibration of the 100 % scale. By comparing incident energy to the reflected energy, the weighted reflectance of the sample is measured. This reflectance is subtracted from 1 in order to obtain the infrared emittance.

This method is based on an expired US Patent 5659397 Method and apparatus for measuring total specular and diffuse optical properties from the surface of an object.

E.2 Configuration of samples

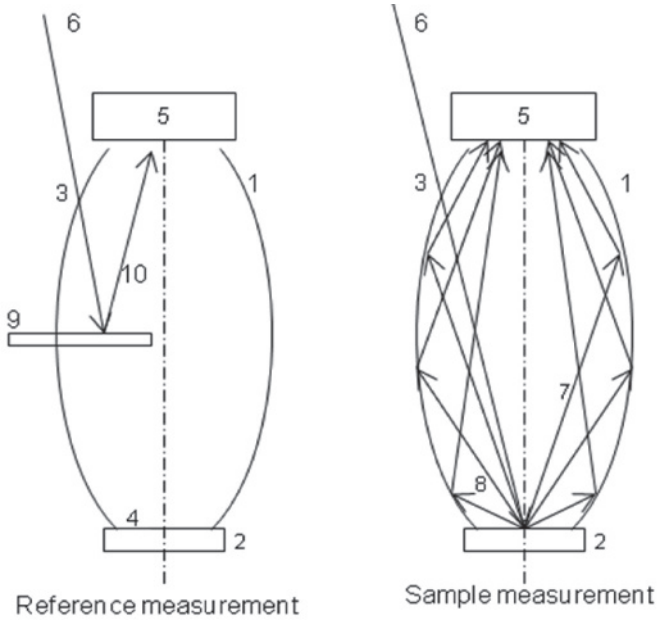
The minimal sample dimensions are dictated by the diameter of the aperture on the portable equipment. This diameter is typically between 15 mm and 20 mm.

Samples of about 10 mm or larger are easily measured. Smaller sizes to about 5 mm can be accommodated with special care in placing the sample in the centre of the aperture. Samples with concave surfaces shall have 166 mm radius or larger. Convex surfaces shall be 12,5 mm radius or larger.

Very diffuse samples should be within 1,2 mm normal to the aperture, specular samples within 2,5 mm. Sample temperature shall be in the range from dew point to 66 °C.

E.3 Test equipment and setting up

Figure E.1 shows the measurement configuration of this method. The infrared source with a corrective coating provides radiation with a colour temperature that very closely matches that of a 300 K blackbody from 2,5 µm to over 50 µm. The source beam intensity is modulated via a rotating chopper blade. The chopped beam is then collected by a mirror, which images the source on the centre of the sample aperture at an incident angle of 15°. The total incident energy does not affect the sample temperature even when thin foils are measured. Of the energy reflected from the sample, over 99 % is collected in a 2 π steradian hemisphere and then re-imaged on a windowless pyroelectric detector. The detector is coated for flat response through the far infrared.



Key

1 ellipsoid collector
2 test specimen
3 entrance port
4 sample port
5 detector
6 incident radiation
7 specular reflection
8 diffuse reflection
9 mirror
10 reflected radiation

Figure E.1 — Measurement procedure with an ellipsoid collector

Wavelength range: 2,5 µm to 35 µm

Measurement accuracy (for specular and diffuse samples): ±1 % of full scale for gray samples and ±1 % of full scale for non-gray samples

E.4 Test process and measurement

Place the sample on the measurement aperture such that the aperture is held firmly against the measurement surface. With a true hemispheric collector, it is important to place diffuse samples as closely as possible to the measurement aperture in order to prevent scattered light from escaping. With more specular samples, this scattered light becomes less and the measurement is less sensitive to sample placement. Foil or wrinkled material shall be flattened over the measurement aperture with an appropriate heavier flat weight.

The beam deflector, a polished mirror, is moved into the path of the beam, reflecting it onto the detector. After the signal has settled, a number of reference readings are made and averaged. The infrared beam is then reflected onto the sample. After the signal has settled, a number of sample readings are made and averaged. Reflectance is calculated as the ratio of the sample measurement to the reference measurement.

This method can measure reflectance on samples that are opaque in the wavelength region of interest. The infrared emittance of semi-transparent samples is determined from the approximate total

transmittance and reflectance of the samples, the backside of which is covered with the substrates. To see if a sample is partially transmitting, the substrates with high and low reflectance shall be alternately placed on the sample as backing. Do not use the standard materials as they could become damaged. If the sample is transmitting, the reflectance values will be different.

The sample shall be measured with backing of the high-reflectance (gold) substrate and the low-reflectance (black) substrate. The total reflectance of the each substrate shall also be measured. The approximate transmittance and reflectance of the semi-transparent samples were calculated with Formulae (E.1) and (E.2). Then, the infrared emittance is determined by subtracting the reflectance and transmittance from unity. It should be noted that higher uncertainty is expected in data obtained using backing.

$$\tau = \frac{\rho_b G - \rho_g B}{\rho_b \rho_g (G - B) + \rho_b - \rho_g} \tag{E.1}$$

$$\rho_s = \sqrt{\frac{(G-B)(\rho_g B - 1)(\rho_g - \rho_b)(\rho_b G - 1)}{(\rho_b \rho_g (G-B) + \rho_b - \rho_g)^2}} \tag{E.2}$$

where

τ is the transmittance of sample;

ρ_s is the reflectance of the sample;

ρ_b is the reflectance of the substrate with low reflectance (black);

ρ_g is the reflectance of the substrate with high reflectance (gold);

B is the reflectance of the sample, the back side of which is covered by the substrate with low reflectance (black);

G is the reflectance of sample, the back side of which is covered by the substrate with high reflectance (gold).

E.5 Calculation of the normal emittance

In this method, near-normal total emittance is determined by measuring near-normal total hemispheric infrared reflectance. The emittance is obtained by subtracting the reflectance from unity;

$$\varepsilon_S \sigma T_S^4 + \rho_S \sigma T_{IR}^4 = I_D \tag{E.3}$$

where

ε_S is the sample emittance;

σ is the Stefan-Boltzmann constant;

T_S is the sample temperature (K);

ρ_S is the sample reflectance;

T_{IR} is the infrared source temperature;

I_D is the energy to the collector/detector system.

The first term represents unchopped energy from the sample at ambient temperature. This term drops out for two reasons. First, the detector will only respond to a change in intensity. Second, the detector electronics

perform a synchronous detection at the frequency and phase of the chopper blade modulation. In the second term, T_{IR} is kept at a fixed value so that σT_{IR}^4 becomes constant. I_D is now only a function of ρ_S.

Energy emitted from the sample and reflected by the sample are focused on the detector. Ellipsoid collector optics collects 99 % of the total energy. The total energy obtained by the detector is explained by the following formulae:

$$I_D = \rho_{ellipsoid} (\varepsilon_h \sigma T_s^4 + \rho_N \sigma T_{IR}^4) \quad \text{(E.4)}$$

where

$\rho_{ellipsoid}$ is the ellipsoid collector reflectance;

T_s is the sample temperature (K);

ε_h is the sample hemispherical emittance;

σ is the Stefan-Boltzmann constant;

ρ_N is the sample normal reflectance;

T_{IR} is the infrared source temperature;

I_D is the energy to the collector/detector system.

A rotating chopper alternately stops and lets the energy from the infrared source irradiate the sample. When the source beam is introduced to the sample, emitted and reflected energy go to the detector. When the chopper prevents the source energy, only the energy emitted by the sample is detected. Delta of the two output energies is reflected energy, explained by the following formula:

$$I_D = \rho_{ellipsoid} \rho_N \sigma T_{IR}^4 \quad \text{(E.5)}$$

Infrared source beam energy ($I_{reference}$) is measured as the left of Figure F.1. The reference arm directly reflects the source beam to the detector. After the reference arm is retracted (the right of Figure F.1), the

source beam irradiates the sample. Total energy reflected by and emitted from the sample ($I_{measurement}$) is focused on the detector. When the reference arm has reflectance ρ_{arm},

$$\frac{I_{measurement}}{I_{reference}} = \frac{\rho_{ellipsoid}\rho_N\sigma{T_{IR}}^4}{\rho_{arm}\sigma{T_{IR}}^4} \tag{E.6}$$

The same coating is applied on both the reference arm and the ellipsoid collector. Therefore, the reference arm and the ellipsoid collector have the same reflectance.

$$\rho_{arm} = \rho_{ellipsoid}$$

The sample normal reflectance ρ_N is calculated by the following formula:

$$\frac{I_{measurement}}{I_{reference}} = \frac{\rho_{ellipsoid}\rho_N\sigma{T_{IR}}^4}{\rho_{arm}\sigma{T_{IR}}^4} = \frac{\rho_N\sigma{T_{IR}}^4}{\sigma{T_{IR}}^4} = \rho_N \tag{E.7}$$

Emittance of an semitransparent sample (transmittance: τ) is:

$$\varepsilon_N = 1 - \rho_N - \tau \tag{E.8}$$

Emittance of an opaque sample (τ = 0) is:

$$\varepsilon_N = 1 - \rho_N \tag{E.9}$$

Annex F
(normative)

Normal infrared emittance using two rotating cavities ($\varepsilon_{n\text{-}c}$)

F.1 General

This method is used to cover the determination of the total normal emittance of opaque surfaces when using portable reflectometer instruments which measure radiant energy reflected from the specimen.

This test method is suitable for measuring over large surfaces where a non-destructive test is desired.

Depending on the equipment, the signal obtained is integrated over a defined spectral range (e.g. the "Gier Dunkle" DB-100 equipment is an infrared reflectometer and has an integration of 5 µm to 25 µm).

F.2 Configuration of samples

The minimal sample dimensions are dictated by the diameter of the aperture on the portable equipment. This diameter is typically between 15 mm and 20 mm.

Measurements are only valid on flat samples. However, it is possible to perform measurements on spherical curved samples, provided the radius of curvature exceeds 300 mm.

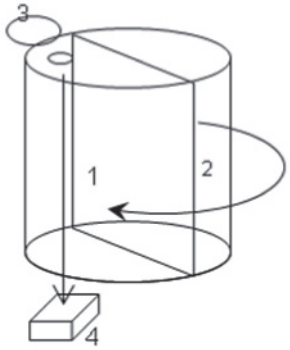
When curved specular surfaces of less than about 300 mm radius are measured, calibrating standards that have the same radius of curvature as the test surface should be used to minimize error.

F.3 Test equipment and setting up

Figure F.1 shows the measurement configuration. The surface to be measured is placed against an aperture on the portable sensing component. Inside the sensing component are two semi-cylindrical cavities that are maintained at different temperatures, one at near ambient and the other at a slightly elevated temperature. A suitable drive mechanism is employed to rotate the cavities alternately across the aperture. As the cavities rotate past the specimen aperture, the specimen is alternately irradiated with infrared radiation from two heat sources, one at near ambient and the other at a slightly elevated temperature (see Figure F.2).

The detector receives both the radiation emitted from the test specimen and a constant radiation of all other surfaces inside the optical path. Only the reflected energy from the test specimen varies with the alternating irradiation and the detection amplifying system is made to respond only to this modulated signal.

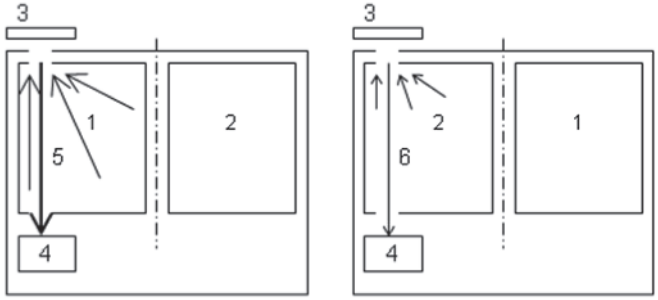
The instrument shall be calibrated with standards of known emittance.



Key

1 hot semi-cylinder
2 cold semi-cylinder
3 test specimen
4 detector

Figure F.1 — Two rotating cavities



Key

1 hot semi-cylinder
2 cold semi-cylinder
3 test specimen
4 detector
5 emitted radiation plus reflected energy with irradiation of a hot semi-cylinder
6 emitted radiation plus reflected energy with irradiation of a cold semi-cylinder

Figure F.2 — Measurement when a hot semi-cylinder (left) and a cold semi-cylinder (right) comes under a sample

F.4 Test process and measurement

Following an appropriate warm-up time, calibrate the readout meter. Adjust the meter to give the correct reading when measuring both high- and low-emittance (or reflectance) working standards. Repeat calibration of the meter several times at short time intervals until the correct readings can be obtained near each end of the scale.

The measurement on the sample is made after the calibration. Place the sample surface over the aperture of the measuring instrument. The resulting meter reading is then the infrared reflectance for blackbody radiant energy at near room temperature.

For semi-transparent samples, a correction shall be made for transmittance losses. Another possibility is to cover the semi-transparent sample with an opaque material from behind. In this case, the reflectance of this combination can be measured.

It is recommended that the instrument be recalibrated as soon as possible after measuring the sample. If the meter calibration has changed, repeat the entire calibration and readout procedure.

F.5 Calculation of the normal emittance

The normal emittance for opaque material is defined as:

$$\varepsilon_N = 1 - \rho_S \tag{F.1}$$

$$I_D = \rho_S \sigma T_{IR}^4 \tag{F.2}$$

where

ε_N is the normal emittance;

ρ_S is the sample reflectance;

σ is the Stefan-Boltzmann constant;

T_{IR} is the infrared source temperature;

I_D is the energy seen by the detector.

By keeping the infrared source at a fixed temperature, the terms σ and T_{IR} become constant

$$K = \sigma T_{IR}^4 \tag{F.3}$$

with Formulae (F.2) and (F.3)

$$I_D = \rho_S K \tag{F.4}$$

The sample reflectance ρ_S is proportional to the measured signal I_D. The normal emittance can be obtained by subtracting the measured reflectance from unity.

Annex G
(informative)

Key parameters for measurement

The parameters which affect the combined uncertainty are shown in Figure G.1. When uncertainty assessment is needed, uncertainty should be assessed and explained according to the following documents in the Bibliography:

ISO/IEC Guide 98-3: *Uncertainty of measurement — Part 3, Guide to the expression of uncertainty in measurement (GUM)*

ISO/IEC Guide 99: *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

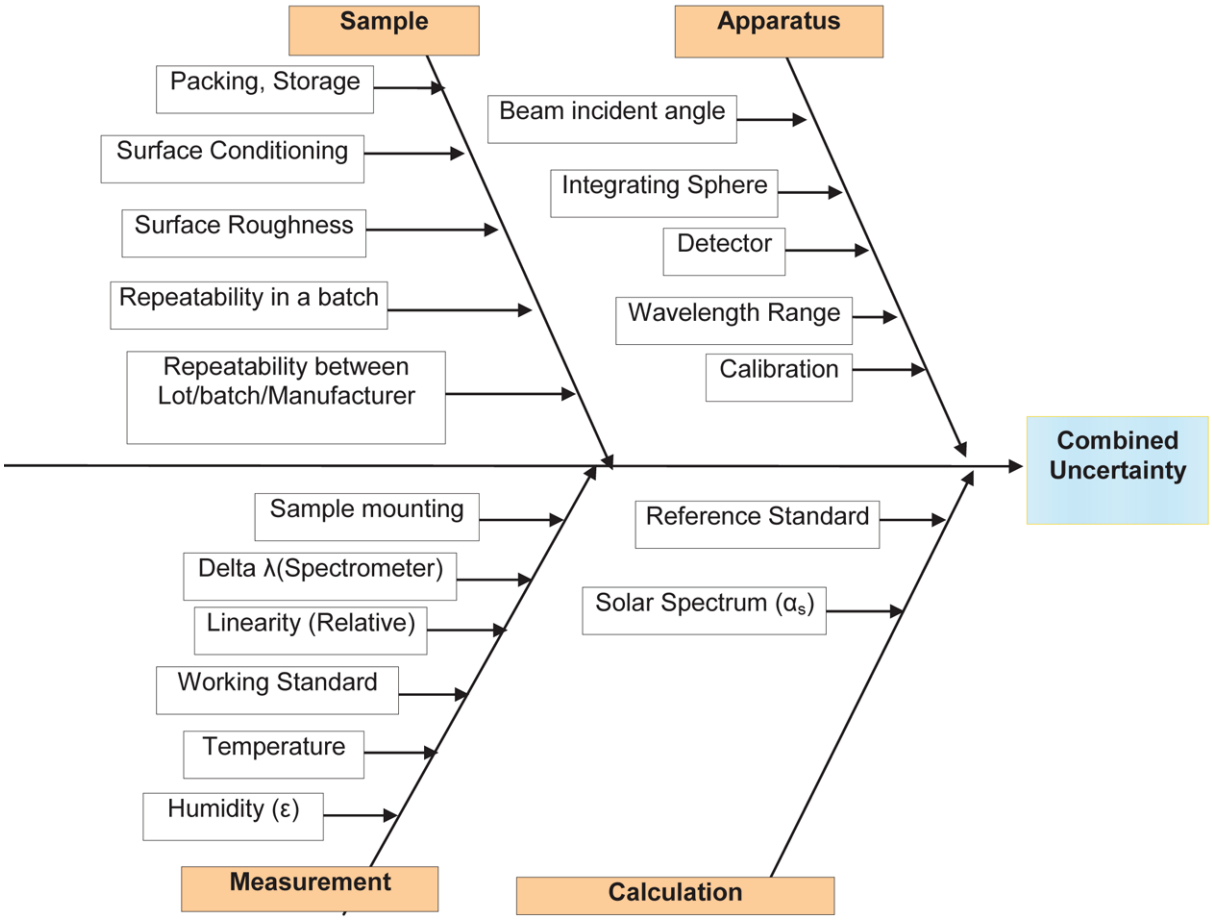


Figure G.1 — Key parameters for measurement

Annex H
(informative)

Theoretical directional emittance

Thermal design based on the radiation heat transfer utilizes hemispherical infrared emittance. However, hemispherical emittance measurement data are not always available. In these cases, normal infrared emittance data need to be used for thermal design in lieu of hemispherical emittance.

Electromagnetic wave theory could provide a prediction of monochromatic directional emissivity of the ideal surface. Directional emissivity can be explained using Fresnel relations. Figure H.1 indicates the example of monochromatic directional emissivity calculations of an opaque material with slight absorption. When the complex refractive index of the material is available for whole wavelength range, hemispherical emissivity could be obtained by integrating the equation for whole wavelength range and over hemisphere.

Theoretically predicted emissivity agrees well with experiments in cases of optically smooth surfaces such as bare metals or glasses that are free from contamination. However, emittance of practical engineering surfaces scarcely meets the theoretical relations. Emittance of real surfaces is strongly affected by surface roughness, oxide layers, and contaminations.

Therefore, it is not recommended to convert normal emittances to hemispherical emittances based on theoretical relations. The directional emittance characteristics based on measurements of real surfaces are also available. Normal to hemispherical conversion using empirical relations shall be performed with special care on the agreement of their optical properties.

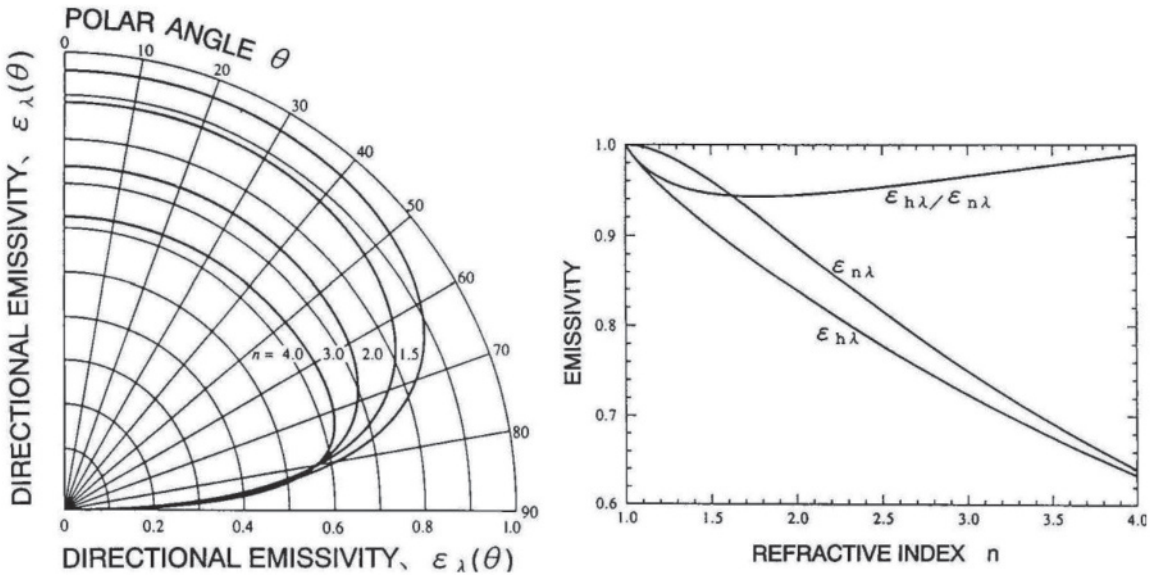


Figure H.1 — Directional monochromatic emissivities of an opaque material with slight absorption as predicted by electromagnetic wave theory [Modest, M.F. "Radiative Heat Transfer", 1993]

Bibliography

[1] ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

[2] ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

[3] ISO 80000-7, *Quantities and units — Part 7: Light*

[4] ASTM E408-71 (2008) *Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques*

[5] ASTM E903-96, *Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres (Withdrawn 2005 NO REPLACEMENT)*

[6] ASTM E1392-96, *Standard Practice for Angle Resolved Optical Scatter Measurements on Specular of Diffuse Surfaces*

[7] ECSS-Q-ST-70-09C Measurements of thermo-optical properties of thermal control materials

[8] U. S. Patent 5659397 (Expired)

[9] Bevans J.T., Luedke E.E., Nelson K.E. A device for the rapid measurement of total emmitance. *J. Spacecr. Rockets*. 1996, **3** pp. 758–760

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