



ISBN 92-9034-053-3

COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

**METHODS OF CHARACTERIZING THE
PERFORMANCE OF RADIOMETERS AND
PHOTOMETERS**

Publ. No. CIE 53 - 1982

This report has been prepared by CIE Technical Committee 2.2 Detectors. It has been approved by the majority of the Technical Committee and is recommended for study and application. This report is not an Officially Agreed CIE Recommendation approved by the National Committees of the Member Countries of the CIE. It should be noted that any recommendation in this report are advisory and not mandatory. The latest CIE Proceedings or CIE Bulletin should be consulted regarding the current status of this report and possible subsequent amendments.

Ce rapport a été préparé par le Comité Technique 2.2. Detecteurs de la CIE. Il a été approuvé par la majorité du Comité Technique et il est recommandé pour étude et application. Ce rapport n'est pas une Recommandation officielle de la CIE, approuvée par les Comités Nationaux des Pays Membres de la CIE. Il doit être noté que toute recommandation y figurant est donnée à titre de conseil et non d'obligation. En ce qui concerne la situation présente de ce Rapport et d'éventuelles modifications, il faut consulter le plus récent Compte Rendu de Session ou Bulletin de la CIE.

Dieser Bericht wurde vom Technischen Komitee 2.2 Detektoren der CIE ausgearbeitet. Er wurde durch die Mehrheit des Technischen Komitees gebilligt und wird zum Studium und zur Anwendung empfohlen. Dieser Bericht ist keine offiziell anerkannte CIE-Empfehlung, der die Nationalen Komitees der Mitgliedsländer der CIE zugestimmt haben. Es sei darauf hingewiesen, dass jede Empfehlung in diesem Bericht als Anleitung dient und nicht verbindlich ist. Was den gegenwärtigen Status dieses Berichtes und mögliche Nachfolge-Ausgaben angeht, ziehe man die neuesten CIE-Tagungsberichte oder das CIE-Bulletin zu Rate.

ISBN 92-9034-053-3

The following members of Committee TC-2.2 took part in the preparation of the technical report:

Les membres suivant du comité TC-2.2 ont participés a la préparation du rapport technique:

Die folgenden Mitarbeiter des Komitees TC-2.2 haben sich an der Ausarbeitung des Technischen Berichtes beteiligt:

Chairman of Subcommittee	C.L. SANDERS (till 77) J. SCHANDA (from 78)	Canada Hungary
Members Membres Mitglieder	R. ANDREJCHIN M. ARTOM J.J. BALDER W. BUDDE A. CORRONS F. DESVIGNES A.J.D. FARMER A.A. GAERTNER (from 79) G. GEUTLER E.J. GILLHAM F. HENGSTBERGER (Chairman from 80) B. HISDAL V.G. IGNATJEV V. KOP (from 77) J. KRTIL (from 78) M. LIPOWSKI F. MAEDER G. MUSA M. NONAKA A. OTTOSON (from 78) R. PASTIELS H. REITER J. SCHANDA (Chairman till 80) T. TIMONEN E.F. ZALEWSKI	Bulgaria Italy Netherlands Canada Spain France Australia Canada F.R.G. Great Britain South Africa Norway U.S.S.R. Denmark Czechoslovakia Poland Switzerland Romania Japan Sweden Belgium Austria Hungary Finland U.S.A.
Consultants Consultants Berater	J. BASTIE G. BAUER P. BLAISE W. BLEVIN F.J.J. CLARKE H.P. Field J. GEIST F. GRUM M. HALSTEAD O.C. JONES R. KALADGIEVA C.J. KOK J. KROCHMANN	France F.R.G. France Australia U.K. U.S.A. U.S.A. U.S.A. U.K. U.K. U.K. Bulgaria South Africa F.R.G.

R.D. LOZANO
L. MIDDENDORF
J. MOORE
L. MORREN
J.V. NICHOLS
M. POPPE
W. STANIOCH
E. STEEB
R.A. WALKER

Argentina
U.S.A.
U.K.
Belgium
N.Z.
Hungary
Poland
U.S.A.
U.S.A.

Editorial Committee:

F. HENGSTBERGER
J. KROCHMANN
J.R. MOORE
C.L. SANDERS
J. SCHANDA (chairman)

South Africa
F.R.G.
U.K.
Canada
Hungary

SUMMARY

The technical report outlines procedures for characterizing the performance of radiometers with special attention to photometers.

Quantitative methods are given for evaluating the most important errors. These include: the systematic errors in the calibration; the errors caused by non-standard spectral response; the non-standard spatial evaluation of irradiance (illuminance), spherical irradiance (illuminance), cylindrical irradiance (illuminance) or radiance (luminance); non-linearity; fatigue; and temperature coefficient.

Ways of judging the significance of less important aspects are suggested. These include: reading error; influence of modulated radiation; influence of polarization; non-uniform responsivity; instability of responsivity; zero drift; etc.

This report deals with the general problems of evaluation of photometric and radiometric instruments. Numerical requirements will be presented for the single types of instruments in later reports.

Tables are given of relative spectral distributions of 5 special sources which can be used to make an estimate of the quality of the $V(\lambda)$ -correction of measuring heads.

RÉSUMÉ

METHODES POUR CHARACTERISER LES PROPRIÉTÉS DES RADIOMÈTRES ET PHOTOMÈTRES

Le rapport technique décrit brièvement les procédures à suivre afin de caractériser les propriétés caractéristiques des radiomètres, tout en accordant une attention spéciale aux photomètres.

Des méthodes quantitatives sont décrites pour l'évaluation des erreurs les plus importantes. Celles-ci incluent: les erreurs systématiques dans l'étalonnage; les erreurs causées par une réponse spectrale nonnormalisée; l'évaluation spatiale nonnormalisée de la luminance énergétique (lumineuse) ou de l'éclairement énergétique (lumineux) sur une surface plane, sphérique ou cylindrique; le défaut de linéarité; la fatigue des détecteurs; et le coefficient de température.

Des suggestions sont faites quant à la façon de juger de l'importance des facteurs secondaires. Ceux-ci incluent: l'erreur de lecture; l'influence de la modulation du rayonnement; l'influence de la polarisation; une sensibilité nonuniforme; une sensibilité instable; la dérive du zéro; etc.

On trouvera dans des tableaux les répartitions spectrales relatives de 5 sources typiques pour estimer la qualité d'ajustement $V(\lambda)$ de la tête de mesure.

ZUSAMMENFASSUNG

METHODEN ZUR KENNZEICHNUNG VON RADIOMETERN UND PHOTOMETERN

Dieser technische Bericht beschreibt Methoden für die Charakterisierung der Eigenschaften von Radiometern mit spezieller Anwendung auf Photometer.

Quantitative Methoden für die Bewertung der wichtigsten Fehlerquellen werden angegeben. Diese sind: systematische Fehler bei der Kalibrierung, Unterschiede zwischen der idealen und der tatsächlichen spektralen Empfindlichkeitsverteilung, Fehler der räumlichen Bewertung bei der Messung der Bestrahlungsstärke (Beleuchtungsstärke), Raumbestrahlungsstärke (Raumbeleuchtungsstärke) oder zylindrischer Bestrahlungsstärke (zylindrischer Beleuchtungsstärke), Linearitätsfehler, Ermüdung, Temperaturkoeffizient. Methoden zur Abschätzung des Einflusses der weniger wichtigen Fehlerquellen werden vorgeschlagen. Diese sind: Ablesefehler, Effekte bei modulierter Strahlung, Polarisierungseffekte, ungleichmässige Empfindlichkeit über die Empfängerfläche, zeitliche Änderungen der Empfindlichkeit, Nullpunktswanderung, usw.

Dieser Bericht beschreibt die allgemeinen Fragen der Bewertung photometrischer und radiometrischer Instrumente. Numerische Anforderungen bezüglich der einzelnen Instrumententypen werden in weiteren Berichten beschrieben.

Tabellen der Strahlungsfunktionen von 5 besonderen Strahlungsquellen, die für die Abschätzung der Güte der $V(\lambda)$ -Anpassung von Messköpfen benutzt werden können, sind beigefügt.

TABLE OF CONTENTS

1. INTRODUCTION	1
1.1. Purpose	1
1.2. Errors	1
1.3. Scope	2
1.4. Procedures for determining and stating errors	2
1.4.1. Possible procedures	2
1.4.2. Suggested procedures	2
2. DEFINITIONS	2
2.1. Detector (of optical radiation)	2
2.2. Radiometer [photometer] head	2
2.3. Influence quantity	3
2.4. Responsivity (sensitivity)	3
2.5. Spectral responsivity	3
2.5.1. Absolute spectral responsivity	3
2.5.2. Relative spectral responsivity	4
2.6. Relative responsivity	4
2.7. Linearity	5
2.8. Further terms and definitions	5
2.8.1. Radiance	5
2.8.2. Irradiance	6
2.8.3. Spherical irradiance	6
2.8.4. Cylindrical irradiance	6
3. SPECIFIC ERRORS FOR WHICH A RECOMMENDED QUANTITATIVE ASSESSMENT IS AVAILABLE	7
3.1. Errors in calibration of the instrument	7
3.2. Non-standard relative spectral responsivity of photometer head	8
3.2.1. Introduction	8
3.2.2. Presentation of $s(\lambda)_{rel}$	8
3.2.3. Calculation of error	10
3.2.4. Test sources for use in estimating possible errors	11
3.2.5. IR-responsivity of photometers	11
3.2.6. $s(\lambda)_{rel}$ independent of t , ε and φ	11
3.3. Directional evaluation	12
3.3.1. Irradiance meters [illuminance meters]	12
3.3.2. Spherical irradiance [illuminance] meters	13
3.3.3. Cylindrical irradiance [illuminance] meters	13
3.3.4. Radiance [luminance] meters	14
3.4. Non-linearity	15
3.5. Reading error	16
3.6. Fatigue	16
3.7. Temperature coefficient	17
3.8. Influence of frequency of modulated radiation	18
3.9. Influence of polarization	18
3.10. Influence of non-uniform irradiation of the detector	19
4. SPECIFIC ERRORS FOR WHICH A QUANTITATIVE ASSESSMENT IS NOT YET RECOMMENDED	20
4.1. Instability of spectral and absolute responsivity	20
4.2. Zero setting drift	20

4.3. Susceptibility to damage from shock, vibration, temperature, altitude, humidity and optical radiation	20
4.4. Influence of magnetic fields	21
4.5. Errors arising from range change	21
4.6. Instability of radiometer to mains or battery voltage change	21
4.7. Specification of effective measurement area and plane	22
4.8. Response time	22
4.9. Shading by the observer	22
4.10. Ease and frequency of calibration	22
5. OTHER CONSIDERATIONS (NOT ERROR CAUSING)	22
5.1. Ease of use	22
5.2. Versatility	23
6. BIBLIOGRAPHY	23

1. INTRODUCTION

1.1. PURPOSE

The purpose of this report is to put forward as far as possible an objective means by which users may evaluate specific properties of radiometers and photometers which are under consideration for a given application. The factors, which constitute this evaluation system and which are considered by members of TC-2.2 to be important in the use of a radiometer or photometer, may serve also as a guide to manufacturers in developing improved radiometric and photometric instruments. By radiometric instrument is meant any device for measuring optical radiation which thus includes a photometer, since this would just have a certain spectral response.

The rating of a radiometer involves numerous properties which may be considered individually. Some properties cause definite related errors which can be assigned quantitative values and the instruments can be ranked for each of those properties. Other properties cannot, at present, be assigned a quantitative value and any ranking for each of these is a subjective or qualitative one. It has been decided by the committee that assigning an overall rating based on all properties is not possible, although some general guidance can be given to the user.

1.2. ERRORS

The errors in radiometry, which are caused by poor calibration procedures, improper maintenance, stray light resulting from poor techniques, inaccurate lamp orientation, inaccurate distance measurement, etc., are not considered here. They would be present even if the instruments were perfect.

Error tolerances for each of the items in Section 3 can be established only by the user. The total of the individual errors f_i must never add to more than the maximum permissible error. It is not appropriate to calculate the accumulated error by using

$$[\sum_i (f_i)^2]^{1/2}$$

when the errors are mostly systematic with a definite size and direction rather than random errors of indeterminate size and direction. Where errors are stable and well established and amount to (or exceed) a significant fraction of the maximum error permitted in the measurement, the user should (must) correct for these errors as well as he can.

The error for a single measurement resulting from a certain cause should therefore be specified as a systematic error plus a standard deviation in the evaluation of the error. With that procedure the systematic errors could be eliminated by corrections and the square root of the sum of the individual standard deviations squared could be used as an indication of the uncertainty. Correction for the expected systematic errors can be made but no correction can be applied for the standard deviation in the instrument reading which results from this particular error.

Most of the properties are dependent on several influence quantities. Therefore, when the dependency of the device output on one of the variables is being determined, it is very important to fix the other parameters at representative or average values. For example, if the spectral responsivity is being determined, the radiation should be unpolarized and incident normally (or uniformly in a specified solid angle if that is more appropriate); the irradiance should be uniform and cover all of the detector or a specific part; the ambient temperature should be 25 °C*; the radiation should be steady.

*ISO Publ.: No 3205-1976 recommends 23°C, but CIE and IEC publications contain, for the time being 25°C.

1.3. SCOPE

The document is intended for all photometric and radiometric instruments which include instruments for measuring luminance, luminous flux, illuminance (spherical and cylindrical illuminance), luminous intensity, luminous exposure (quantity of light) and the radiometric equivalents of these with any specified target spectral response.

1.4. PROCEDURES FOR DETERMINING AND STATING ERRORS

1.4.1. *Possible procedures*

One could provide with each instrument the detailed measurements from which the error for a particular measurement situation could be calculated. One could instead calculate the error expected for several selected measurement situations and give this expected error for each case. The user would then need to judge which situation approximated his present measurement situation most closely in order to decide what error he should expect. Some users might prefer only to know the maximum expected error in order to be sure that their measurement error was below a predetermined level.

1.4.2. *Suggested procedures*

Methods for determining different types of errors and mathematical descriptions for their quantitative assessment are given as far as possible. Some of these error expressions can be used as correction factors as well, and manufacturers are encouraged to make use of these, especially for instruments of higher quality.

Some other error expressions are average values and can serve only to estimate probable errors of measurements. These might serve, however, as guides for users in selecting instruments for different measuring situations, therefore manufacturers are urged to make use of these error descriptions, if possible stating errors for their individual instrument, as well as the estimated uncertainty in these values, or for lower grade devices as specified tolerance limits for the given type of instrument.

2. DEFINITIONS

In the following definitions a subscript "e" is used to indicate energetic quantities, similar definitions apply to the luminous and photon quantities where the subscripts "v" and "p" are used.

2.1. DETECTOR (of optical radiation)

Device in which incident optical radiation produces a measurable physical effect.

2.2. RADIOMETER [PHOTOMETER] HEAD

The part of a physical photometer containing the detector and means for spectral and spatial corrections of the detector.

2.3. INFLUENCE QUANTITY

A quantity (other than the measured quantity) which is liable to cause unwanted variation in the indications of an instrument.

Note: Generally, it covers such quantities as temperature, rate of change of temperature, supply voltage, humidity, etc.

2.4. RESPONSIVITY (sensitivity)

Quotient of the detector output (quantity Y) by the detector input (quantity X).

$$\text{Symb.: } s = \frac{Y}{X} \quad (2.1.)$$

Note 1: If there exists a detector output (quantity Y_w) without irradiation and the measured total detector output is Y_t , the detector output (quantity Y) caused by a detector input (quantity X) is $Y = Y_t - Y_w$.

Note 2: If X stands for radiation quantities, the term radiant responsivity s_e is used; if X stands for light quantities, the term luminous responsivity s_v is used. Using the terms spectral responsivity $s(\lambda)$, spectral concentration of the radiant input quantity $X_{e\lambda}$ and relative spectral distribution $S(\lambda)$ one obtains:

$$\text{radiant responsivity } s_e = \frac{\int_0^{\infty} X_{e\lambda} s(\lambda) d\lambda}{\int_0^{\infty} X_{e\lambda} d\lambda} = \frac{\int_0^{\infty} S(\lambda) s(\lambda) d\lambda}{\int_0^{\infty} S(\lambda) d\lambda} \quad (2.2.)$$

$$\text{luminous responsivity } s_v = \frac{\int_0^{\infty} X_{e\lambda} s(\lambda) d\lambda}{K_m \int_0^{\infty} X_{e\lambda} V(\lambda) d\lambda} = \frac{\int_0^{\infty} S(\lambda) s(\lambda) d\lambda}{K_m \int_0^{\infty} S(\lambda) V(\lambda) d\lambda} \quad (2.3.)*$$

where K_m is the maximum spectral luminous efficacy
and $V(\lambda)$ is the spectral luminous efficiency for photopic vision.

Note 3: The responsivity depends on the relative spectral distribution, moreover it may depend on the polarization and the direction of the incident radiation, on the homogeneity of irradiation and the temperature of the detector as well as on the electrical circuit. If the detector output quantity and the detector input quantity are not proportional, the responsivity also depends on the value of the detector input quantity.

2.5. SPECTRAL RESPONSIVITY

2.5.1. Absolute spectral responsivity

Quotient of the detector output (quantity $dY(\lambda)$) by the detector input (quantity $dX_e(\lambda) = X_{e\lambda} \cdot d\lambda$ at wavelength λ).

*As limits of integration for luminous quantities 0 and ∞ were chosen: In case of integrals involving $s(\lambda)$, one stops integrating when the function reaches zero. For integrals containing $V(\lambda)$ practical limits - for the time being - are 360 and 830 nm.