

Nuclear energy — Radiation protection — Individual thermoluminescence dosemeters for extremities and eyes

ICS 13.280; 17.240

National foreword

This British Standard reproduces verbatim ISO 12794:2000 and implements it as the UK national standard.

The UK participation in its preparation was entrusted to Technical Committee NCE/2, Health physics instrumentation, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled “International Standards Correspondence Index”, or by using the “Find” facility of the BSI Standards Electronic Catalogue.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, the ISO title page, pages ii to v, a blank page, pages 1 to 20, an inside back cover and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

This British Standard, having been prepared under the direction of the Engineering Sector Committee, was published under the authority of the Standards Committee and comes into effect on 15 April 2000

© BSI 04-2000

Amendments issued since publication

Amd. No.	Date	Comments

INTERNATIONAL
STANDARD

ISO
12794

First edition
2000-02-15

**Nuclear energy — Radiation protection —
Individual thermoluminescence dosimeters
for extremities and eyes**

*Énergie nucléaire — Radioprotection — Dosimètres individuels
thermoluminescents pour yeux et extrémités*



Reference number
ISO 12794:2000(E)

Contents

Page

Foreword.....	iv
Introduction.....	v
1 Scope	1
2 Normative references	1
3 Terms and definitions	2
4 Units	5
5 General test conditions	5
6 Classification.....	5
7 Performance requirements	6
8 Test methods.....	6
9 Certification	6
Annex A (normative) Reference conditions and standard test conditions.....	8
Annex B (normative) Confidence limits.....	9
Annex C (normative) Performance tests.....	12
Annex D (informative) Determination of evaluated value (<i>E</i>) from readout values	17
Annex E (normative) Conversion tables	18
Bibliography	20

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 12794 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

Annexes A, B, C and E form integral parts of this International Standard. Annex D is for information only.

Introduction

This International Standard covers dosimeters for the eyes and extremities.

This International Standard should be used in conjunction with IEC 1066:1991, which provides performance criteria and tests for thermoluminescence dosimetry systems comprising dosimeters, readers, ancillary equipment and procedures for converting light output into dose, for the assessment of personal or environmental doses, excluding extremities. It also includes some performance criteria and tests for thermoluminescent detectors and thermoluminescence dosimeters where these criteria are dependent on the characteristics of the detectors or dosimeters, rather than on the reader or ancillary equipment.

This document was prepared and discussed by Working Group WG 7 of ISO/TC85/SC2 following meetings in Paris in August 1988, Moscow in May 1990, Rome in November 1991, Paris in September 1992 and London in October 1993. It was not possible to hold a WG meeting in Orlando in October 1994. The draft was agreed at the Paris meeting by the working group and circulated by the Secretariat as a CD. A further meeting of the WG was held in London in October but the results of the voting were not available until later in October 1995. A final draft, dated February 1996, incorporating comments included with the results of the voting on ISO/CD (WI 7-2.07.1), circulated as ISO/TC85/SC2 N 475 in October 1993, was agreed by WG 7 in Albuquerque in February 1996. The comments following circulation as a DIS were considered by the WG in July 1997 and this International Standard incorporates those that were agreed upon.

Nuclear energy — Radiation protection — Individual thermoluminescence dosimeters for extremities and eyes

1 Scope

This International Standard provides performance criteria and tests for determining the performance of thermoluminescence dosimeters intended to be used for the measurement of radiation doses to the eyes and extremities (fingers, and limbs defined as hands, feet, forearms including the elbow, and leg including the patella), for photons from 15 keV to 3 MeV and beta radiation from 0,5 MeV to 3 MeV. It is conditional upon the use of an appropriate reader, procedures and ancillary equipment. It does not cover information access and data processing.

This International Standard provides performance criteria and tests for dosimeters intended to measure dose equivalent at depths of $7 \text{ mg}\cdot\text{cm}^{-2}$ in tissue for fingers and limbs and $300 \text{ mg}\cdot\text{cm}^{-2}$ in tissue for the eyes, including provision for the use of dosimeters only intended to be used once. Appropriate phantoms and dose conversion coefficients are recommended but others are not precluded.

In all cases, performance is assessed under laboratory conditions which may not adequately simulate conditions actually experienced in personal dosimetry. For example, it may be necessary to sterilize dosimeters for medical applications. Therefore, caution is necessary in applying the results of these performance tests in real situations.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 31-0, *Quantities and units — Part 0: General principles*.

ISO 4037-3:1999, *X and gamma reference radiation for calibrating dosimeters and dose-rate meters and for determining their response as a function of photon energy — Part 3: Calibration of area and personal dosimeters and the measurement of their response as a function of energy and angle of incidence*.

ISO 6980, *Reference beta radiations for calibrating dosimeters and dose-rate meters and for determining their response as a function of beta-radiation energy*.

3 Terms and definitions

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

3.1

thermoluminescence

radiothermoluminescence

TL

property exhibited by certain substances, namely the emission of light, which is induced by irradiation when the substance is heated following exposure to ionizing radiation or UV

NOTE Strictly speaking, the property should be referred to as radiothermoluminescence but the abbreviated form thermoluminescence is usually adequate.

3.2

thermoluminescent material

TL material

substance exhibiting the property of thermoluminescence

3.3

thermoluminescent detector

TL detector

detector

specified quantity of TL material, or such material incorporated with other non-luminescent material into a matrix, defined by mass, shape or size or the mass of material incorporated in the matrix

3.4

thermoluminescence dosimeter

TL dosimeter

dosimeter

passive device consisting of one or more TL detectors, which may be mounted in a holder (appropriate for the application), intended to be worn on a person's body or placed in an environment for the purpose of assessing the appropriate dose equivalent at or near the position where it is placed

3.5

thermoluminescence dosimeter reader

TL dosimeter reader

reader

instrument used to measure the light emitted from the detectors in thermoluminescence dosimeters; consisting essentially of a heating device, a light measuring device and the associated electronics

3.6

extremity dosimeter

dosimeter intended to be worn on the finger or limb [hands, feet, forearms (including the elbow), and lower leg (including the patella)]

3.7

eye dosimeter

dosimeter intended to be worn near the eyes

3.8

reusable dosimeter

dosimeter intended to be reused, as opposed to one which is discarded after one use

NOTE When used in medical applications, appropriate sterilization may be necessary.

3.9**batch**

collection of detectors or dosimeters made to a specific design or specification and intended to have the same performance characteristics consistent with the appropriate requirements of this International Standard

3.10**annealing**

controlled thermal treatment of a TL detector or dosimeter during or after readout

3.11**prepare****reprepare**

normal treatment of annealing, cleaning, etc. which the dosimeters or detectors are intended to be subjected to in routine use

3.12**readout**

process of measuring the light emitted when a TL detector or dosimeter is heated in a reader

3.13**readout value**

m

value indicated by a TL reader after readout of a detector or dosimeter expressed in units appropriate to the output of the reader

3.14**absorbed dose**

D

quotient of $d\bar{\epsilon}$ by dm , where $d\bar{\epsilon}$ is the mean energy imparted by ionizing radiation to matter of mass dm .

NOTE 1 The special name for the unit of absorbed dose is gray (Gy) ($1 \text{ Gy} = 1 \text{ J}\cdot\text{kg}^{-1}$). In this International Standard, absorbed doses are specified in grays.

NOTE 2 Where no ambiguity could be involved, the term "absorbed dose" is abbreviated to "dose".

3.15**kerma**

K

quotient of $d\bar{\epsilon}_{\text{tr}}$ by dm , where $d\bar{\epsilon}_{\text{tr}}$ is the sum of the initial kinetic energies of all the charged ionising particles liberated by uncharged ionising particles in a matter of mass dm :

$$K = \frac{d\bar{\epsilon}_{\text{tr}}}{dm} \quad (1)$$

3.16**dose equivalent**

H

product of D and Q at the point of interest in tissue where D is the absorbed dose and Q is the quality factor:

$$H = DQ \quad (2)$$

NOTE The SI unit for both D and H is joule per kilogram. The special name for the unit of dose equivalent is the sievert (Sv): ($1 \text{ Sv} = 1 \text{ J}\cdot\text{kg}^{-1}$).

3.17**personal dose equivalent**

$H_p(d)$

dose equivalent in soft tissue below a specified point at an appropriate depth, d

NOTE The SI unit for $H_p(d)$ is joule per kilogram. The special name is sievert (Sv) ($1 \text{ Sv} = 1 \text{ J}\cdot\text{kg}^{-1}$).

**3.18
evaluated value**

E
value of the quantity of interest, e.g. dose equivalent (H), air kerma (K_a), free-air absorbed dose (D_a), obtained by applying the appropriate evaluation coefficient (F_e) to the readout value or values (m)

**3.19
conventional true value**

C
best estimate of the quantity of interest at the point of measurement, e.g. dose equivalent (H), air kerma (K_a), free air absorbed dose (D_a)

NOTE This is a widely used standardized term. The grammatically correct synonymous term is Conventionally True Value.

**3.20
evaluation coefficient**

F_e
factor or collection of factors, used to convert the readout value or values, (m), to the evaluated value of interest (E)

NOTE See annex D.

**3.21
residue**

readout signal obtained on second readout following normal readout and annealing procedures

**3.22
conversion coefficient**

F_e
factor used to convert from air kerma or free-air absorbed dose to the corresponding dose equivalent

NOTE See annex E.

**3.23
response**

R
quotient of the evaluated value and the conventional true value

**3.24
self-irradiation**

irradiation of the detector due to radioactive impurities contained in the dosimeter holder or detector itself

**3.25
phantom**

specified object used to simulate the human body or parts thereof in terms of its scattering and absorption of gamma and beta radiation

**3.26
zero point**

evaluated value of an unirradiated prepared dosimeter or detector

**3.27
reader background**

evaluated value corresponding to the readout value obtained when the reader is operated without a dosimeter or detector

3.28**detection threshold**

minimum evaluated value for which the readout value of a dosimeter or detector is significantly different (at the 95 % confidence level) from the readout value of an unirradiated dosimeter or detector

3.29**coefficient of variation**

ratio of the standard deviation s , to the arithmetic mean \bar{x} of a set of n measurements x_i ; is given by the following formula:

$$V = \frac{s}{\bar{x}} = \frac{1}{\bar{x}} \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} \quad (3)$$

NOTE The coefficient of variation is generally expressed as a percentage.

3.30**quality control test****QT**

test performed on a number of TL dosimeter systems, dosimeters, detectors or readers of a given batch or production designed to assure quality control

3.31**type test****TT**

test performed on a small number of TL dosimeter systems, dosimeters, detectors or readers of a given type to determine performance characteristics of that type

4 Units

This International Standard uses SI units. However, the following units of practical importance for time are used where necessary: days (d), hours (h). The symbols of the units for time are provided by International Standard ISO 31-0.

5 General test conditions**5.1 Test conditions**

All tests shall be performed under standard test conditions (see annex A), except where otherwise stated. Dosimeters shall be subjected to the annealing, cleaning and handling procedures which are recommended by the manufacturer.

5.2 Reference radiations

The radiation sources specified in ISO 4037-3 and ISO 6980 shall be used in the manner specified in these International Standards. Photon reference radiations used for spectral response checks shall be chosen from the first column of table 1 in 4 of ISO 4037-3:1999. Sources for beta spectral response shall be ^{90}Sr (in equilibrium with ^{90}Y), ^{106}Ru , and ^{204}Tl . Calibration of radiation sources shall be traceable to the appropriate primary or secondary standards.

6 Classification

Dosimeters shall be classified in accordance with body part and the depth of intended measurement, and method of intended use viz:

F(7)D	Finger, depth 7 mg·cm ⁻² , disposable;
F(7)R	Finger, depth 7 mg·cm ⁻² , re-usable;

L(7)D	Limb, depth 7 mg·cm ⁻² , disposable;
L(7)R	Limb, depth 7 mg·cm ⁻² , re-usable;
E(300)D	Eye, depth 300 mg·cm ⁻² , disposable;
E(300)R	Eye, depth 300 mg·cm ⁻² , re-usable.

7 Performance requirements

The performance criteria are listed in Table 1. All dose values listed in the criteria are in terms of dose equivalent to tissue at the intended depth of measurement. The conventional true value of the dose equivalent, C , for any specific tests may be obtained by using the conversion coefficients specified in annex E, for each type of intended measurement (finger, limb or eyes). In this International Standard, conversion coefficients are only provided for tissue depths of 7 mg·cm⁻² and 300 mg·cm⁻².

Annex E includes conversion coefficients for selected phantoms for photons and beta radiation. The selected phantoms are a solid 19 mm diameter cylinder of PMMA (ISO PMMA rod) for the finger, a 73 mm diameter water-filled cylinder of PMMA (ISO water pillar) for the limb, both of length 300 mm, and the ICRU sphere or 30 cm × 30 cm × 15 cm water-filled PMMA slab (ISO water slab) for the eyes. The use of other coefficients or phantoms is not precluded and shall be agreed between the manufacturer and the purchaser. The evaluated value of the dose equivalent, (E), shall be determined from the readout value in accordance with annex E. However, in the case of purely comparative tests (i.e. all except energy response and isotropy), the readout values may be used instead of evaluated values.

The performance requirements are identified in Table 1 as type tests (T) or quality control tests (Q). Type tests are intended to demonstrate the basic performance of the type of dosimeter and quality control tests are intended to verify the performance of a specific production or delivery batch of dosimeters.

The number of dosimeters used for each test or repeated tests shall be such that the performance requirements are demonstrated to be met to 95 % confidence. The number, n , of dosimeters (or irradiations) used for any test need not be the same for each test but may be determined using annex B. However, it may be convenient to use, arbitrarily, 5, 10 or 20 dosimeters (or irradiations), in which case the Student's t -value, obtained from annex B, Table B.1, would be 2,78, 2,26 or 2,09 respectively.

Where the response to neutrons is greater than 1 % of the response to photons, in terms of dose equivalent, the manufacturer shall draw the attention of the user to this fact and provide appropriate quantitative information.

Performance requirements are specified in terms of the dose equivalent at appropriate tissue depths, the conventional true value in testing being determined using conversion coefficients for appropriate phantoms. One school of thought suggests that this quantity should be called $H_p(d)$, analogous with measurements on the body. However, neither the International Commission on Radiological Protection (ICRP) nor the International Commission on Radiation Units and Measurements ICRU have specifically addressed the question of a name for the measurement quantity for extremities. The measurement quantity is therefore specified in this International Standard in the way described but is not named.

8 Test methods

Suggested tests to demonstrate compliance with the specified performance requirements are specified in annex C. Alternative tests which equally demonstrate compliance are not precluded.

9 Certification

Manufacturers claiming compliance (or part compliance) with the performance requirements of this International Standard should provide a signed certificate including the following details:

- a) names and addresses of the manufacturer and test laboratories;
- b) description/specification of the dosimeters under consideration, including dosimeter classification;
- c) description of reader, procedures and ancillary equipment used for the tests (Model, No., etc.);
- d) statements certifying the results of each test, and dates undertaken (test reports should be available for inspection by the purchaser);
- e) statement giving the quantitative response to neutrons, if required;
- f) details of conversion coefficients and phantoms agreed between the manufacturer and the purchaser, where those specified in this International Standard are not used.

NOTE In the situation where all tests are not done in the same establishment, the certificate should clearly identify the individual test laboratories for each test.

Table 1 — Performance requirements for extremity and eye dosimeters

No.	Performance characteristic	Class of dosimeter	Performance requirements	Test required ^a
1	Batch homogeneity	R/D	The coefficient of variation of the evaluated value for n dosimeters shall not exceed 15 % for a dose of 10 mSv or less	Q
2	Reproducibility	R D	The coefficient of variation of the evaluated value for n dosimeters shall not exceed 10 % for each dosimeter separately for a dose of 10 mSv or less No requirement	Q
3	Linearity	R/D	The response shall not vary by more than 10 % over the dose equivalent range 1 mSv to 1 Sv	T
4	Stability of dosimeters under various climatic conditions	R/D	The evaluated values of dosimeters irradiated either at the beginning or at the end of a storage period shall not differ from the conventional true value by more than 5 % for 30 d storage under standard test conditions, or 10 % for 48 h storage at 40 °C and 90 % relative humidity	T
5	Detection threshold	R/D	The detection threshold shall not exceed 1 mSv	T
6	Self- irradiation	R/D	After a storage period of 60 days, the zero point shall not exceed 2mSv	T
7	Residue	R	After irradiation with a conventional true value of 100 mSv, the detection threshold limit shall not be exceeded and the response shall remain within the requirement for linearity at a dose level of 2 mSv	T
8	Effect of light exposure on the dosimeter	R/D	As a result of exposure to 1 000 W·m ⁻² equivalent to bright sunlight (295 nm to 769 nm) for 1 d, the zero point shall not change by more than 1 mSv and, for exposure during one week, the evaluated value shall not differ from the evaluated value of a dosimeter kept in the dark by more than 10 %	T
9	Isotropy (photons)	R/D	When irradiated with photons of (60 ± 5) keV, the mean value of the response at angles of incidence of 0°, 20°, 40° and 60° from normal shall not differ from the corresponding response for normal incidence by more than 15 %	T
10	Energy response (photons)	R/D	When irradiated with photons in the energy range 15 keV to 3 MeV, response shall not vary by more than ± 50 %	T
11	Energy response (beta radiation)	R/D	When irradiated with beta radiation in the energy range (E_{\max}) 0,5 MeV to 3 MeV, the response shall not vary by more than ± 50 %	T
^a T: Type. Q: Quality control.				

Annex A (normative)

Reference conditions and standard test conditions

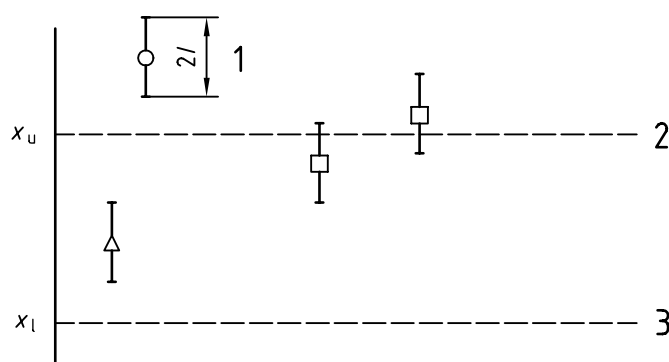
Influence quantity	Reference conditions (unless otherwise stated by the manufacturer)	Standard test conditions (unless otherwise stated by the manufacturer)
Reference photon radiation	To conform to ISO 4037-3	To conform to ISO 4037-3
Reference beta radiation	To conform to ISO 6980	To conform to ISO 6980
Ambient temperature	20 °C	18 °C to 22 °C
Relative humidity	65 %	55 % to 75 %
Gamma radiation background	$\leq 0,2 \mu\text{Gy}\cdot\text{h}^{-1}$	$\leq 0.2 \mu\text{Gy}\cdot\text{h}^{-1}$
Contamination by radioactive elements	Negligible	Negligible
Light intensity	$50 \text{ W}\cdot\text{m}^{-2}$	$< 100 \text{ W}\cdot\text{m}^{-2}$

Annex B (normative)

Confidence limits

B.1 General

If the magnitude of the random uncertainty of a measured value is a significant fraction of the permitted tolerances of this measured value, the random uncertainty has to be considered by taking more than one measurement. The number of measurements or the sample size has to be chosen in such a way that the confidence interval obtained for each mean, \bar{x} , for a confidence level of 95 % lies either within the limits of variation of the measured value permitted in the test (test passed, points Δ in Figure B.1) or outside of these limits (test failed, points \circ in Figure B.1). If one of the permitted limits of variation, x_u or x_l , lies within the confidence interval of the mean (points \square in Figure B.1) the number of measurements or the sample size can be increased to reduce the width $2I$ of the confidence interval of the mean \bar{x} , in order to reach one of the two cases mentioned above, which are necessary for an unequivocal decision of passing the test or not.



Key

- 1 Confidence interval of the mean width $2I$
- 2 Permitted upper limit of variation, x_u
- 3 Permitted lower limit of variation, x_l

Figure B.1 — Test for confidence interval

The test is passed if the confidence interval of width $2I$ around \bar{x} lies between the permitted upper and lower limit of variation, x_u and x_l :

$$x_l + I < \bar{x} < x_u - I \quad (\text{B.1})$$

In each test, it is recommended to start with 10 measurements for each dosimeter. If it turns out to be necessary to reduce the width $2I$ of the confidence interval of the experimental standard deviation, the number of measurements should be increased (see B.2).

Occasionally, it is more convenient to carry out a test (including, for example, an irradiation) with a certain number of different dosimeters withdrawn at random from the batch instead of repeating a number of measurements with the same dosimeter. There are no objections to such a procedure but the random uncertainties of the test results may be increased.

B.2 Confidence interval for the standard deviation, s

The confidence interval for the standard deviation of the means s is:

$$(s - I_s, s + I_s) \quad (\text{B.2})$$

where I_s is the half-width of the confidence interval of s . If s is calculated from n_s measurements, the upper limit of I_s at a confidence level of 95 % is given by:

$$I_s(n_s) = t_{ns} \cdot s \sqrt{\frac{1}{2(n_s - 1)}} \quad (\text{B.3})$$

where t_{ns} is taken from table B.1 for n_s measurements. By way of example, $I_s(10) = 0,53s$ is obtained for 10 dosimeters.

B.3 Confidence interval for the mean, \bar{x}

The confidence interval for the mean \bar{x} is:

$$(\bar{x} - I_i, \bar{x} + I_i) \quad (\text{B.4})$$

where I_i is the half-width of the confidence interval of x relative to the i th set of measurements. When calculating \bar{x} from n_i measurements, the half-width of the confidence interval is given by:

$$I_i = \frac{t_n s_i}{\sqrt{n_i}} \quad (\text{B.5})$$

where s_i is the standard deviation for the i th group of measurements, and t_n is taken from Table B.1 for n_i measurements.

For example, for $n_i = 10$, $I_i = \frac{2,26s_i}{\sqrt{10}} = 0,71s_i$

Table B.1 — Student's t -values for 95 % confidence interval

n_i	t_n	n_i	t_n
2	12,71	15	2,15
3	4,30	20	2,09
4	3,18	25	2,06
5	2,78	30	2,05
6	2,57	40	2,02
7	2,45	60	2,00
8	2,37	120	1,98
9	2,31	∞	1,96
10	2,26		

B.4 Confidence interval for a combined quantity

If the limits of variation are stated for a quantity x , the mean value calculated from k means, $\bar{x}_1, \bar{x}_2, \bar{x}_3, \dots, \bar{x}_k$, is:

$$\bar{x} = f(\bar{x}_1, \bar{x}_2, \bar{x}_3, \dots, \bar{x}_k) \quad (\text{B.6})$$

and the half-width of the confidence interval of the i th mean is I_i , the half-width, I , of the confidence interval for \bar{x} is given by :

$$I = \sqrt{\sum_{i=1}^k \left(\frac{\delta \bar{x}}{\delta x_i} \right)^2 I_i^2} \quad (\text{B.7})$$

EXAMPLE 1 $\bar{x} = \bar{x}_1 \pm \bar{x}_2$ hence $I = \sqrt{I_1^2 + I_2^2}$.

in general $\bar{x} = \sum_{i=1}^n \bar{x}_i$ hence $I = \sqrt{\sum_{i=1}^n I_i^2}$

EXAMPLE 2 $\bar{x} = \frac{\bar{x}_1}{\bar{x}_2}$ hence $I = \frac{\bar{x}_1}{\bar{x}_2} \sqrt{\left(\frac{I_1}{x_1} \right)^2 + \left(\frac{I_2}{x_2} \right)^2}$

EXAMPLE 3 $\bar{x} = \frac{x_1 / x_2}{x_1 + x_2}$ hence $I = \frac{2}{(\bar{x}_1 + \bar{x}_2)^2} \sqrt{(\bar{x}_2 I_1)^2 + (\bar{x}_1 I_2)^2}$

Annex C (normative)

Performance tests

C.1 Batch homogeneity (Types R and D)

Prepare and irradiate n dosimeters to the same conventionally true value (C) of 10 mSv or less. Determine the evaluated value (E) for each dosimeter and show that the coefficient of variation for the n dosimeters does not exceed 15 %.

C.2 Reproducibility (Type R)

Prepare, irradiate and read out n dosimeters. Repeat this 10 times. The conventional true value shall be exactly the same each time and about 10 mSv or less.

For each of the n dosimeters, determine the mean evaluated value, \bar{E}_j , and the standard deviation, s_{Ej} .

Show that for each of the n dosimeters:

$$\frac{100 (s_{Ej} + I_s)}{\bar{E}_j} \leq 10 \quad (\text{C.1})$$

Where I_s is given in expression (B.2).

C.3 Linearity (Types R and D)

Prepare, irradiate and read out four groups of dosimeters. Let n_i be the number of dosimeters in the i th group. The conventional true values (C_i) given to each group shall be 0,001 Sv, 0,01 Sv, 0,1 Sv and 1 Sv.

Calculate the mean evaluated value (\bar{E}_i) at each irradiation level and its standard deviation $S_{\bar{E}}$.

Show that:

$$0,90 \leq \frac{\bar{E}_i \pm I_i}{C_i} \leq 1,10 \quad (\text{C.2})$$

Where I_i is obtained from equation (B.5) for n dosimeters. The uncertainties in C_i are considered negligible.

C.4 Stability of dosimeters under various climatic conditions (Types R and D)

Prepare two groups of n dosimeters each. Store both groups for 24 h under standard conditions.

Irradiate group 1 to a known conventional true value (C) of about 10 mSv.

Store both groups of dosimeters in a climatic chamber in which standard test conditions prevail.

After a continuous period of 30 d, remove both groups of dosimeters from the climatic chamber. Irradiate group 2 to the same conventional true value as group 1.

Store both groups for 1 d under standard test conditions. Determine the evaluated values (E) for each dosimeter and calculate the mean of the evaluated values (\bar{E}) for each of the two groups and the respective standard deviations, s .

Show that for each group:

$$0,95 \leq \frac{\bar{E} \pm I_i}{C} \leq 1,05 \quad (\text{C.3})$$

where I_i is calculated according to equation (B.5).

Repeat the test for a storage period of 2 d but in a climatic chamber in which the temperature is $40 \text{ }^\circ\text{C} \pm 2 \text{ }^\circ\text{C}$ and the relative humidity is at least 90 %.

Show that for each group :

$$0,90 \leq \frac{\bar{E} \pm I_i}{C} \leq 1,10 \quad (\text{C.4})$$

where I_i is calculated according to equation (B.5).

C.5 Detection threshold (Types R and D)

Prepare and read out n dosimeters.

Determine the evaluated value (E) for each (unirradiated) dosimeter and calculate the standard deviation ($s_{\bar{E}}$) for all n dosimeters.

Show that:

$$E + 1 \leq 10 \text{ mSv} \quad (\text{C.5})$$

C.6 Self irradiation (Types R and D)

Prepare n dosimeters. Store them for 60 d under standard test conditions in a location where the background dose rate is known.

Read out the dosimeters and determine the evaluated value (E). Calculate the mean of the evaluated values (\bar{E}) for all n dosimeters and the standard deviation. Determine the conventional true value, C_B (background), due to the background irradiation during storage.

Show that:

$$(\bar{E} + I_i) - C_B \leq 2 \text{ mSv} \quad (\text{C.6})$$

where I_i is the half-width of the confidence interval, determined as in equation (B.5).

C.7 Residue (Type R)

C.7.1 Effect on detection threshold

Prepare, irradiate and read out the n dosimeters used for the detection-threshold test. The conventional true value (C) shall be about 100 mSv.

Using the same dosimeters, repeat the test for detection threshold.

C.7.2 Effect on response

Prepare, irradiate and read out the same n dosimeters used above. The conventional true value, (C) shall be about 2 mSv.

Determine the evaluated value (E) for each dosimeter and calculate the mean of the evaluated values (\bar{E}) and the standard deviation, s_E .

Show that:

$$0,90 \leq \frac{\bar{E} \pm I_i}{C} \leq 1,10 \quad (\text{C.7})$$

where I_i is determined according to equation (B.5).

C.8 Effect of exposure to light (Types R and D)

C.8.1 Effect on zero point

Prepare two groups of 20 dosimeters each.

Expose group 1 to $1\,000 \text{ W}\cdot\text{m}^{-2}$ of light for 1 d. Ensure that the temperature of the dosimeters is maintained at less than 40° .

To produce $1\,000 \text{ W}\cdot\text{m}^{-2}$ of light, use apparatus which produces light whose spectrum corresponds to that of bright sunlight (295 nm to 769 nm), (for example with a xenon lamp equipped if necessary with appropriate filters), or use a daylight fluorescent lamp.

NOTE $1\,000 \text{ W}\cdot\text{m}^{-2}$ bright sunlight includes $60 \text{ W}\cdot\text{m}^{-2}$ of UV.

Store the group 2 dosimeters in the dark in an otherwise identical environment. Ensure that the temperature of group 2 dosimeters is within $\pm 5^\circ\text{C}$ of the group 1 dosimeters.

After 1 d, read out all dosimeters.

Determine the evaluated value (E) for each group and calculate the mean of the evaluated values (\bar{E}) for each of the two groups and their respective standard deviations.

Show that:

$$\left| \left(\bar{E}_{\text{group 1}} - \bar{E}_{\text{group 2}} \right) \right| + I \leq 1,0 \text{ mSv} \quad (\text{C.8})$$

where I is calculated according to equation (B.7) for the difference of two means.

C.8.2 Effect on response

Prepare and irradiate two groups of 20 dosimeters each. The conventional true value (C) shall be about 10 mSv.

Expose and store groups 1 and 2 respectively as above.

After one week, read out all dosimeters.

Determine the evaluated value (E) for each and calculate the mean of the evaluated values (\bar{E}) for each of the two groups, and their respective standard deviations.

Show that:

$$0,90 \leq \frac{\bar{E}_{\text{group 1}}}{\bar{E}_{\text{group 2}}} \pm I \leq 1,10 \quad (\text{C.9})$$

where I is calculated from equation (B.7) for the quotient of two means.

C.9 Isotropy (photons) (Types R and D)

Prepare, irradiate on a phantom and read out four groups of n dosimeters. Let n_i be the number of dosimeters of the i th group. The conventional true value C shall be about 10 mSv using photons of energy (60 ± 5) keV (X-radiation or ^{241}Am) and for the following conditions:

- group 1: normal incidence;
- group 2: 20° off normal;
- group 3: 40° off normal;
- group 4: 60° off normal.

For each group, the angle of incidence for the n irradiations is varied in a positive and negative direction in two planes perpendicular to each other and to the plane of the dosimeter.

Determine the evaluated value (E) for each dosimeter (see Table E.1) and calculate the mean of the evaluated values (\bar{E}_i) for each of the four groups and the respective standard deviations.

Show that:

$$0,85 \leq \frac{\sum \bar{E}_i}{4\bar{E}_1} \pm I \leq 1,15 \quad (\text{C.10})$$

where I is determined according to equation (B.7).

C.10 Energy response (photons) (Types R and D)

Prepare, irradiate on a phantom and read out four groups of n dosimeters each. The conventional true value (C) shall be about 10 mSv using the following reference radiations:

- group 1: 15,8 keV;
- group 2: in the range 30 to 40 keV;
- group 3: in the range 80 to 100 keV;
- group 4: ^{137}Cs or ^{60}Co .

NOTE These are the minimum requirements to fully comply with this International Standard. Additional reference radiations may be used.

Determine the evaluated value (E) for each dosimeter (see Table E.2) and calculate the mean of the evaluated values, (\bar{E}) for each of the four groups and the respective standard deviations.

For each group show that:

$$0,5 \leq \frac{\bar{E}_i \pm I_i}{C} \leq 1,5 \quad (\text{for } i = 1, 2, 3, 4) \quad (\text{C.11})$$

where I_i is determined according to equation (B.5).

C.11 Energy response (beta radiation) (Types R and D)

Prepare, irradiate on a phantom and read out two groups of n dosimeters each. The conventional true value (C) shall be about 10 mSv using the following reference radiations:

- group 1: $^{90}\text{Sr}/^{90}\text{Y}$;
- group 2: ^{204}Tl .

Determine the evaluated value (E) for each dosimeter (see Table E.3) and calculate the mean of the evaluated values (\bar{E}) for each of the two groups.

For each group show that:

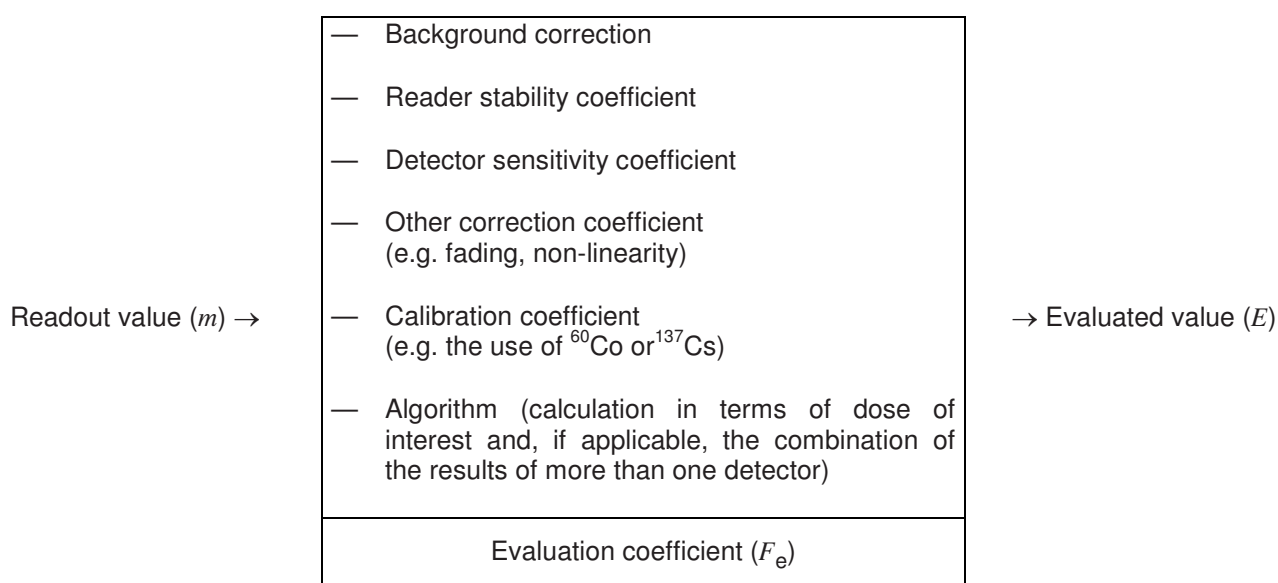
$$0,5 \leq \frac{\bar{E}_i \pm I_i}{C} \leq 1,5 \quad (\text{C.12})$$

where I_i is determined according to equation (B.5).

Annex D (informative)

Determination of evaluated value (E) from readout values

To determine the evaluated value of dose that a TL dosimeter is expected to measure, at least one and sometimes more TL detectors are read in the TL reader, leading to one or more readout values. In order to convert the results of these readout values (m) into the final answer, a number of steps have to be made, depending on the TLD system being used and how it is used. The following diagram indicates, as an example, what steps may be involved.



In any particular situation, some of these coefficients may not be necessary and other coefficients may have to be introduced. For this reason, in this International Standard one single coefficient is assumed to replace the entire process, namely the evaluation coefficient (F_e), which converts the readout value (m) into the evaluated value (E).

Annex E (normative)

Conversion tables

Table E.1 — Conversion coefficients — Air kerma to dose equivalent to tissue for (60 ± 5) keV monoenergetic photons or mean energy ISO narrow-spectrum X-radiation (Sv/Gy)

Depth in tissue	7 mg·cm ⁻²	7 mg·cm ⁻²	300 mg·cm ⁻²
Angle of incidence ^a	Finger ^b	Limb ^b	Eye ^c
0°	1,14	1,39	1,81
20°	1,14	1,39	1,78
40°	1,14	1,38	1,74
60°	1,14	1,33	1,54

^a Oblique incidence relative to the cylinder axis.

^b B. Grosswendt, *Radiat. Prot. Dosim.* **59**, (3), pp. 195-203 (1995), Tables 1 and 2.

^c B. Grosswendt, *Radiat. Prot. Dosim.* **35**, (4), pp. 221-235 (1991), Table 1. (ICRU tissue slab, by interpolation).

Table E.2 — Conversion coefficients — Air kerma to dose equivalent to tissue for normal incidence photons (Sv/Gy)

Depth in tissue	7 mg·cm ⁻²	7 mg·cm ⁻²	300 mg·cm ⁻²
Photon energy	Finger ^a	Limb ^a	Eye ^b
15 keV	0,98	0,98	0,683
30 keV	1,06	1,18	1,223
40 keV	1,09	1,29	1,496
80 keV	1,16	1,38	1,809
100 keV	1,17	1,35	1,743
¹³⁷ Cs	1,12	1,15	1,226
⁶⁰ Co	1,11	1,12	1,182

^a B. Grosswendt, *Radiat. Prot. Dosim.* **59**, (3), pp. 165-179 (1995), Table 1 (ICRU tissue).

^b B. Grosswendt, *Radiat. Prot. Dosim.* **35**, (4), pp. 221-235 (1991), Table 1 (ICRU tissue slab).

Table E.3 — Conversion coefficients — Free-air absorbed dose to dose equivalent to tissue for normal incidence betas

Depth in tissue	7 mg·cm ⁻²	7 mg·cm ⁻²	300 mg·cm ⁻²
Beta Energy	Finger ^a	Limb ^a	Eye ^b
⁹⁰ Sr/ ⁹⁰ Y	1,25	1,25	0,6
²⁰⁴ Tl	1,22	1,22	n/a
<p>^a British Committee on Radiation Units (BCRU), <i>Radiat. Prot. Dosim.</i> 14, (4), pp. 337-343, (1986), Table 3, for the ICRU sphere but assumed to be valid for smaller phantoms.</p> <p>^b The transmission of ²⁴⁰Tl beta particles through 300 mg·cm⁻² is zero.</p>			

Bibliography

- [1] IEC 1066:1991, *Thermoluminescence dosimetry systems for personal and environmental monitoring*.
- [2] ICRP¹⁾ Publication 60:1991, *1990 Recommendations of the International Commission on Radiological Protection*.
- [3] ICRU²⁾ Report 33:1980, *Radiation quantities and units*.
- [4] ICRU Report 39:1985, *Determination of dose equivalent resulting from external radiation sources*.
- [5] ICRU Report 43:1988, *Determination of Dose Equivalents from External Radiation Sources — Part 2*.
- [6] ICRU Report 47:1992, *Measurement of Dose Equivalents from External Photon and Electron Radiations*.
- [7] ICRU Report 51:1993, *Quantities and Units in Radiation Protection Dosimetry*.

1) ICRP is the acronym for International Commission on Radiological Protection.

2) ICRU is the acronym for International Commission on Radiation Units and Measurements.

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: 020 8996 9000. Fax: 020 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: 020 8996 9001. Fax: 020 8996 7001.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: 020 8996 7111. Fax: 020 8996 7048.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: 020 8996 7002. Fax: 020 8996 7001.

Copyright

Copyright subsists in all BSI publications. BSI also holds the copyright, in the UK, of the publications of the international standardization bodies. Except as permitted under the Copyright, Designs and Patents Act 1988 no extract may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior written permission from BSI.

This does not preclude the free use, in the course of implementing the standard, of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained.

If permission is granted, the terms may include royalty payments or a licensing agreement. Details and advice can be obtained from the Copyright Manager. Tel: 020 8996 7070.