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Dosimetry with solid thermoluminescence detectors for photon and electron radiations in radiotherapy

Dosimétrie avec détecteurs de thermolumiscence solides pour le photon et rayonnements d'électron en radiothérapie

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Foreword

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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. www.iso.org/directives

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The committee responsible for this document is ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

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: http://www.iso.org/iso/home/standards_development/resources-for-technical-work/foreword.htm

Introduction

The thermoluminescence dosimetry (TLD) with lithium fluoride (LiF) detectors has several advantages, in particular:

— small volumes of the detectors;

— applicability to continuous and pulsed radiation;

— fair water equivalency of the detector material;

— few correction factors needed for absorbed dose determinations.

The main disadvantage of thermoluminescence (TL) detectors is, however, that they have to be regenerated by a pre-irradiation annealing procedure. Unfortunately, it is not possible to restore the former response of the detectors perfectly by this annealing. Provided, however, that all detectors of a production batch always undergo the same thermal treatment, one can at least determine the mean alteration of the response of these detectors, with sufficiently small fluctuations of the individual values. From this mean alteration, a correction factor can be derived.

The essential aim of this International Standard is to specify the procedures and to carry out corrections which allow one to achieve (1) a repeatability of the indicated value within a fraction of a percent[17] and thus, (2) a total uncertainty of measurement (including the calibration steps tracing to the primary standards) of a few percent, as in ionization chamber dosimetry.[18][31][25][61][62]

The specifications in this International Standard comprise special terms used in TLD, rules for the measurement technique, and requirements for the measurement system. The defined requirements and the testing techniques can, in whole or in part, serve as a basis for stability checks and acceptance tests. The TLD procedures described in this International Standard can be used for photon radiation within the energy range from 20 keV to 50 MeV, including photon brachytherapy, and for electron radiation within the energy range from 4 MeV to 25 MeV, excluding beta radiation brachytherapy. In order to achieve the repeatability and total uncertainty stated above, this International Standard is applicable in the dose range above 1 mGy. The upper limit of the minimum measuring range is in the order of magnitude of 10 Gy to 100 Gy. In clinical dosimetry, TL detectors are applied taking into account the requirements of high spatial resolution, i.e. in the study of the dose distributions with high gradients occurring in small stereotactic radiation fields and around brachytherapy sources. The other common application is the measurement of dose distributions in large absorbers, e.g. geometrical or tissue equivalent phantoms, either within the radiation field or in its periphery. A further usage is the quality assurance of clinical dosimetry by postal dose intercomparison.[1][2][10][12][20][22][26][27][55]

The role of this International Standard is not to anticipate national or international codes of practice in clinical dosimetry, neither for external beam therapy, brachytherapy, whole-body irradiation, mammography, nor dose measurements outside the treatment field or radiation protection of the staff. The authors of this International Standard are well aware of the wide spectrum of the methods of clinical dosimetry, in which TL dosimetry is merely occupying a small sector. But within this framework, this International Standard provides reliable concepts and rules for good practice for the application of TLD methods. The items covered include the terms and definitions, the rules for TLD measurement procedures, and the requirements for the TLD system; this International Standard also addresses medical physicists and instrument producers. Notably, the numerical examples given are valid for the TL detector materials and products stated in the publications referred to, and tests may be necessary to check whether they apply to TLD materials of other producers. The practical examples given, e.g. for the TL probe calibration conditions and for the numerical values of correction factor, k_Q, accounting for the dependence of the detector response on radiation quality, Q, are not conceived to be preemptive in relation to more general standards of the methods of clinical dosimetry or of dose intercomparisons. Rather, this International Standard provides access to the reliable application of TLD methods based upon the published results of worldwide development. The long-standing experience in the clinical usage of TLD, expressed in a set of valuable textbooks, protocols, and recommendations,[6][13][25][28][29][42][43][61][62][54] has been accounted for.

Dosimetry with solid thermoluminescence detectors for photon and electron radiations in radiotherapy

1 Scope

This International Standard describes rules for the procedures, applications, and systems of thermoluminescence dosimetry (TLD) for dose measurements according to the probe method. It is particularly applicable to solid "TL detectors", i.e. rods, chips, and microcubes, made from LiF:Mg,Ti or LiF:Mg,Cu,P in crystalline or polycrystalline form. It is not applicable to LiF powders because their use requires special procedures. The probe method encompasses the arrangement, particularly in a water phantom or in a tissue-equivalent phantom, of single TL detectors or of "TL probes", i.e. sets of TL detectors arranged in thin-walled polymethyl methacrylate (PMMA) casings.

The purpose of these rules is to guarantee the reliability and the accuracy indispensable in clinical dosimetry when applied on or in the patient or phantom. This International Standard applies to dosimetry in teletherapy with both photon radiation from 20 keV to 50 MeV and electron radiation from 4 MeV to 25 MeV, as well as in brachytherapy with photon-emitting radionuclides. These applications are complementary to the use of ionization chambers.

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.

ICRU 60, *Fundamental Quantities and Units for Ionizing Radiation (1998)*

ICRU 62, *Prescribing, recording and reporting photon beam therapy. International Commission on Radiation Units and Measurements (1999)*

IEC 60050-88, *IEV: International Electrotechnical Vocabulary. Radiology and radiological physics.*

IEC 60601-1, *Electromedical equipment — Part 1: General instructions pertaining to safety*

IEC 61000-4-2, *Electromagnetic compatibility (EMV) — Part 4-2: Test and measurement procedure; Test of immunity against static electric discharges*

IEC 61000-4-3, *Electromagnetic compatibility (EMC) — Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-4, *Electromagnetic compatibility (EMC) - Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test*

IEC 61000-4-5, *Electromagnetic compatibility (EMC) — Part 4-5: Testing and measurement techniques - Surge immunity test*

IEC 61000-4-6, *Electromagnetic compatibility (EMC) — Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields*

IEC 61000-4-8, *Electromagnetic compatibility (EMC) — Testing and measurement techniques - Power frequency magnetic field immunity test*

IEC 61000-4-11, *Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) — Part 6-2: Generic standards - Immunity for industrial environments*

IEC 61187, *Electrical and electronic measuring equipment — Documentation*

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

3 Terms and definitions

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

3.1
absorbed dose
energy imparted to matter in a suitably small element of volume by ionizing radiation, divided by the mass of that element of volume

3.2
background value
M_0
<clinical TL dosimetry> *indicated value* (3.16) of a *TLD system* (3.46) during evaluation of a non-irradiated *TL detector* (3.45) according to the operating instructions

Note 1 to entry: A change in the *background value* (3.2) can be caused by a change in the *TL-indicating instrument* (3.47), by an insufficient *pre-irradiation annealing* (3.28), or by contamination of the *detector* (3.45).

3.3
batch
<clinical TL dosimetry> number of *TL detectors* (3.45) of the same type originating from the same manufacturing process and corresponding in their entirety both to the requirements defined in this International Standard and to the quality properties guaranteed by the manufacturer with regard to their *response* (3.39), their *individual variation* (3.17), and their *nonlinearity* (3.24)

3.4
calibration
<clinical TL dosimetry> determination of the correlation between the *indicated value* (3.16) of a *TL detector* (3.45) and the conventional true value of the *measured quantity* (3.20), *absorbed dose* (3.1) to water, under *reference conditions* (3.32)

Note 1 to entry: Calibration serves to determine or check the *calibration coefficient* (3.5). The conventional true value of the *measured quantity* (3.20) is given by the *measured value* (3.21) determined directly or indirectly with a primary standard.

3.5
calibration coefficient
N_i
<clinical TL dosimetry> relation valid under *reference conditions* (3.32)

$$N_i = \frac{D}{M_i - M_0}$$

in this formula, D is the conventional true value of the *measured quantity* (3.20), $M_i - M_0$ is the difference resulting from the *indicated value* (3.16) of a single *TL detector* (3.45)*i* and the *background value* (3.2)

Note 1 to entry: Thus, the *calibration coefficient* (3.5) is the reciprocal value of the *response* (3.39) under *reference conditions* (3.32).

3.6
casing
capsule, usually made from PMMA of 1 mm front wall thickness and shaped as a flat circular cylinder, in which a small set of *TL detectors* (3.45) can be placed in the same plane

Note 1 to entry: The setup consisting of the *detectors* (3.45) and the *casing* (3.6) is the *TL probe* (3.48).

3.7
conditioning of a batch
conditioning
multiple irradiation and *pre-irradiation annealing* (3.28) of a *batch* (3.3) of *TL detectors* (3.45)

Note 1 to entry: Whether *conditioning* (3.7) is sufficient is examined by the *reusability* (3.40) test according to 5.3.3.

3.8
correction factor
<clinical TL dosimetry> factor applied to the *indicated value* (3.16) in order to compensate for the measurement deviation caused by an *influence quantity* (3.18) or by the *measured quantity* (3.20)

Note 1 to entry: Examples for using a *correction factor* (3.8) are the corrections for *fading* (3.13), *energy dependence* (3.12), and *nonlinearity* (3.24) (see 4.4.5).

3.9
correction summand
summand added to the *indicated value* (3.16) in order to compensate for the measurement deviation caused by an *influence quantity* (3.18)

Note 1 to entry: The *background value* (3.2) is an example for corrections using a *correction summand* (3.9) (see 4.4.2).

3.10
directional dependence of response
directional dependence
<clinical TL dosimetry> dependence of the *response* (3.39) of a *TL detector* (3.45) on the direction of radiation incidence

3.11
direction of preference
direction referring to the *TL detector* (3.45) or *TL probe* (3.48) that is considered as a reference value for the direction of radiation incidence as an *influence quantity* (3.18)

3.12
energy dependence of response
energy dependence
dependence of the *response* (3.39) of a *TL detector* (3.45) on *radiation quality* (3.30)

3.13
fading
F
quotient of the alteration of the *measured value* (3.21) of the *absorbed dose* (3.1) during the time interval between the end of irradiation and evaluation, e.g. caused by the influence of ambient temperature, and the value of the *absorbed dose* (3.1) measured immediately after irradiation

Note 1 to entry: *Fading* (3.13) is expressed as a percentage.

Note 2 to entry: The alteration of the measured *absorbed dose* (3.1) may be positive (increment) or negative (decrement).

3.14
fading rate

$\dot{F}$
fading (3.13) per time interval

3.15
glow curve
<clinical TL dosimetry> *measured value* (3.21) of the light emission of the *TL detector* (3.45) as a function of the temperature or time during the evaluation process

3.16
indicated value
M
<clinical TL dosimetry> numerical value of a parameter displayed by a *TL-indicating instrument* (3.47)

Note 1 to entry: The *indicated value* (3.16), M, for a *TL detector* (3.45) is assessed from the *glow curve* (3.15) by the *TL-indicating instrument* (3.47) (see 4.3.8.3). The *measured value* (3.21) of the dose is determined from the *indicated value* (3.16) by applying the *calibration coefficient* (3.5), the correction factors (3.8), and the *correction summands* (3.9) (see 4.4).

Note 2 to entry: The *indicated value* (3.16) is also termed the reading of the *TL-indicating instrument* (3.47).

3.17
individual variation of the response
individual variation
deviation of the *response* (3.39) of single *TL detectors* (3.45) from the mean *response* (3.39) of a *batch* (3.3) of *TL detectors* (3.45) under identical irradiation and evaluation conditions

3.18
influence quantity
<clinical TL dosimetry> a quantity which is not a *measured quantity* (3.20) but nevertheless influences the result of a measurement

Note 1 to entry: *Influence quantities* (3.18) can develop influences as external disturbances (temperature, humidity, line voltage, etc.), as properties inherent to the instrument, i.e. caused by the instrument itself (zero drift, aging of the system components, post-irradiation stabilization, etc.), or as adjustable quantities affecting the result of the measurement [e.g. *radiation quality* (3.30) or direction of radiation incidence during dose measurement].

Note 2 to entry: The correction of the impact of an *influence quantity* (3.18) may require the application to the *indicated value* (3.16) of a *correction factor* (3.8) [multiplicative *influence quantity* (3.18), e.g. *fading* (3.13)] or of a *correction summand* (3.9) [additive *influence quantity* (3.18), e.g. *background value* (3.2)].

Note 3 to entry: If an *influence quantity* (3.18) is not taken into account by applying a *correction factor* (3.8) or a *correction summand* (3.9), the *correction factor* (3.8) is set equal to one or the *correction summand* (3.9) is set equal to zero, respectively.

3.19
linear energy transfer
LET
average energy locally imparted to a medium by a charged particle of a specified energy along a suitably small element of its path, divided by that element

Note 1 to entry: The value of LET (in keV/μm) is usually stated for water as the medium traversed by the charged particle.

[SOURCE: ICRU 60]

3.20
measured quantity
<clinical TL dosimetry> physical quantity to be determined by the measuring system

Note 1 to entry: According to ICRU 62, the measured quantity in clinical dosimetry is the *absorbed dose* (3.1) to water at the *point of measurement* (3.26).

3.21
measured value of a TLD system
measured value
<clinical TL dosimetry> value of the *measured quantity* (3.20), *absorbed dose* (3.1) to water, determined with a *TLD system* (3.46) at the *point of measurement* (3.26)

Note 1 to entry: The *measured value* (3.21) is determined as the product of the *correction factors* (3.8) and the mean of the *indicated values* (3.16) of the single *TL detectors* (3.45), located at and irradiated together at the same time in the *TL probe* (3.48), corrected for the *background value* (3.2), and multiplied by the individual *calibration coefficient* (3.5).

3.22
measurement cycle
sequence of working steps in TL dosimetry consisting of *pre-irradiation annealing* (3.28), irradiation, *post-irradiation annealing* (3.27), and evaluation of *TL detectors* (3.45)

3.23
measuring range
<clinical TL dosimetry> range of dose values in which the *TLD system* (3.46) meets the requirements for the operation characteristics

Note 1 to entry: The limits of the measuring range of a *TLD system* (3.46) are within the interval spanned by the smallest and the highest *measured value* (3.21).

3.24
nonlinearity of response
nonlinearity
<clinical TL dosimetry> change in *response* (3.39) to dependence on dose

Note 1 to entry: Linearity means constant *response* (3.39), supralinearity denotes an increase in *response* (3.39), and sublinearity denotes a decrease in *response* (3.39) with increasing dose.

3.25
parameters for tests
values of *influence quantities* (3.18) agreed upon for testing the impact of other *influence quantities* (3.18)

3.26
point of measurement
<clinical TL dosimetry> the point on or in the patient's body or water phantom at which the *absorbed dose* (3.1) to water is measured

Note 1 to entry: See also References,[13],[39] and,[40] and ICRU 35.

3.27
post-irradiation annealing
<clinical TL dosimetry> controlled heat treatment (annealing) of a *TL detector* (3.45) after irradiation and before evaluation

Note 1 to entry: Post-irradiation annealing serves to reduce the *fading* (3.13).

3.28
pre-irradiation annealing
<clinical TL dosimetry> controlled heat treatment of already evaluated *TL detectors* (3.45) before reuse

Note 1 to entry: Pre-irradiation annealing serves to delete the radiation-induced TL signal remaining after evaluation and approximately restores the original response.

3.29
radiation damage
<clinical TL dosimetry> permanent alteration of the *response* (3.39) of a *TL detector* (3.45) due to pre-irradiation beyond a detector-specific dose

Note 1 to entry: The value of this dose may depend on the temporal pattern of pre-irradiations (dose fractionation, dose protraction).

3.30
radiation quality
parameter for the classification of the relative spectral particle fluence of a radiation type at a specified location

Note 1 to entry: In clinical dosimetry, simply measurable parameters such as the quality index of a photon radiation or the 50 % range of an electron radiation are used for the characterization of radiation quality (see ICRU 35, ICRU 62, and Reference[25]).

3.31
rated range of use
variation range of an *influence quantity* (3.18) causing a change in *response* (3.39) that does not lead to a transgression of agreed upon values of the measurement deviation or to a transgression of defined values of the correction of its influence

3.32
reference conditions
<clinical TL dosimetry> set of reference values of all *influence quantities* (3.18) and of the *measured quantity* (3.20)

Note 1 to entry: If one or more *influence quantities* (3.18) or the *measured quantity* (3.20) deviate from their *reference values* (3.35, 3.36) (Table 2), the conditions of measurement are denoted as non-reference conditions. The correction for use of *detectors* (3.45) under non-reference conditions is dealt with in the context of Table 4.

3.33
reference detector
<clinical TL dosimetry> *TL detector* (3.45) used to determine the *correction factor* (3.8) for the change in *response* (3.39) during successive *measurement cycles* (3.22)

Note 1 to entry: See 4.4.5.3.

3.34
reference point of a TL probe
point located within or on the surface of the *TL probe* (3.48) whose spatial coordinates serve to specify the position of the *TL probe* (3.48) in its surroundings

Note 1 to entry: The position of the reference point within or on the *TL probe* (3.48) is defined by the manufacturer. In clinical dose measurements, the reference point of a *TL probe* (3.48) is placed at the *point of measurement* (3.26) either on or in the phantom or the patient's body. For *calibration* (3.4), the reference point of a *TL probe* (3.48) is placed at the point at which the *absorbed dose* (3.1) to water under *reference conditions* (3.32) is known.

3.35
reference value for tests
initial value for the variation of an *influence quantity* (3.18) when testing its effect on the *response* (3.39)

3.36
reference value for calibrations
value of an *influence quantity* (3.18) or of the *measured quantity* (3.20), to which the *calibration coefficient* (3.5) refers and for which it is valid without further corrections

Note 1 to entry: Due to *nonlinearity* (3.24), a reference value has also been set for the *measured quantity* (3.20).

3.37
repeatability
<clinical TL dosimetry> degree of compliance of the *measured values* (3.21) of a given quantity that have been successively obtained in the same laboratory under the same conditions or *repetition conditions* (3.38)

Note 1 to entry: Repeatability is marked by the empirical standard deviation of the single *measured value* (3.21) and may be expressed as a percentage of the *measured value* (3.21). In this case, it makes a difference as to whether the repeated measurements have been performed with one *TL detector* (3.45) or a group of *detectors* (3.45).

Note 2 to entry: By contrast, comparability marks the degree of compliance when a given quantity is measured in different laboratories by using different measuring instruments of the same type.

Note 3 to entry: Repeatability is synonymous with "precision".

3.38
repetition conditions
<clinical TL dosimetry> conditions under which measurements are repeated in the same laboratory under similar measurement conditions according to a defined measurement procedure with short time intervals between repetitions

3.39
response
$R_{D,i}$

<clinical TL dosimetry> difference between the *indicated value* (3.16), M_i, for a single *TL detector* (3.45) i and the *background value* (3.2), M_0, divided by the conventional true value of the causing *absorbed dose* (3.1) to water, D_w

$$R_{D,i} = \frac{M_i - M_0}{D_w}$$

Note 1 to entry: This definition of response as the quotient of the background-corrected *indicated value* (3.16) and the conventional true value of the *measured quantity* (3.20) complies with IEC 60050-88. It is different from less strict terminology where "response" means *indicated value* (3.16).

Note 2 to entry: The response of a *TL detector* (3.45) does not only depend on the *absorbed dose* (3.1), but also on the *radiation quality* (3.30), the direction of radiation incidence, the material and size of the *detector* (3.45), the type of the *detector* (3.45), the *casing* (3.6), and the TL-reading instrument.

Note 3 to entry: In clinical dosimetry, each *TL detector* (3.45) or *TL probe* (3.48) is placed with its reference point (3.34) at the *point of measurement* (3.26) (see 4.4.1). The *reference points* (3.34) are specified in Tables 4 to 8 of this International Standard.

Note 4 to entry: If air kerma, K_a, instead of *absorbed dose* (3.1) to water, D_w, is used as the reference quantity, i.e. as the denominator of the formula for response, this modification of the definition of response has to be clearly stated.

Note 5 to entry: If the term response is used in the sense of a relative response, i.e. as the quotient $R_{D,i}/R_{D,j}$ of two radiation qualities i and j, this has to be clearly stated.