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Dosimetry with radiophotoluminescent glass dosimeters for dosimetry audit in MV X-ray radiotherapy

Dosimétrie avec dosimètres radiophotoluminescents de type verre utilisée pour l'audit dosimétrique en radiothérapie à rayons X de haute énergie

Contents

Page

Foreword

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This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection,* Subcommittee SC 2, *Radiological protection*.

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Introduction

A radiophotoluminescent glass dosimeter (RPLD) is a cumulative radiation dosimeter usually made of silver-activated phosphate glass. The silver atoms act as radiophotoluminescence (RPL) centres excited by ionizing radiation. The number of RPL centres excited is proportional to the absorbed dose to the RPLD. Since the first RPLD was produced in 1949, improvements have been made to the reading precision and reliability[1]. The latest products, rod-like dosimeters of a few millimetres in size, measure the absorbed dose that can be evaluated with an uncertainty of about 1 % to 2 % (k = 1) in certain conditions[2] to [5]. The RPL centres do not disappear after readout. Therefore, repeated readouts for a single exposure is possible. The results are stable and good accuracy of the signal readouts is possible. In addition, since the RPL centres once formed are hardly affected by fading, it is suitable in long-term dose measurement with retention capacity. RPLDs can be reused by annealing at high temperature.

RPLDs have been widely used for personal dosimetry and environmental radiation measurements[6] to [7].They are also used for radiation dose assessment of patients and staff in the field of radiation medicine, including interventional radiology, external radiotherapy, and brachytherapy[8] to [21]. Due to their advantages of compactness, repeatable readout, good precision, and small fading, RPLDs have been recently used as a dosimeter for dosimetric external audits in external radiotherapy with high-energy X-rays[22] to [27]. Thermoluminescent Dosimeter (TLD) and optically stimulated luminescent dosimeter (OSLD) have also been used for the audits. The three dosimeters, RPLD, TLD, and OSLD, are passive solid-state dosimeters and have some similar characteristics. However, there are variations in the handling, reading methodology, and dose evaluation, including tissue-equivalency.

This document focuses on the RPL dosimetry from the viewpoint of the dosimetry audit in MV X-ray radiotherapy highlighting the procedures for handling, reading, and corrections to the response dependency of beam quality and dose.

Dosimetry with radiophotoluminescent glass dosimeters for dosimetry audit in MV X-ray radiotherapy

1 Scope

This document specifies the dose assessment method when an RPLD is used for dosimetry audit in external high-energy X-ray beam radiotherapy.

The dosimetry for electron beams and X-ray beams of stereotactic radiotherapy, gamma-ray of brachytherapy is not included in this version.

This document addresses RPLD handling, measurement method, conversion of measured value to dose, necessary correction coefficient, and the performance requirements for RPLD systems, including the reader.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

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

3.2
background value
$M_{0,i}$
indicated value (3.11) by a non-irradiated *RPLD detector* (3.25) according to the instruction manual

3.3
batch
number of *RPLD detectors* (3.25) of the same type, which originate from the same manufacturing process, and correspond in their entirety to both the requirements defined in this document and the quality properties guaranteed by the manufacturer with regard to their response, *individual dosimeter sensitivity correction* (3.12), and *nonlinearity* (3.18)

3.4
calibration
operation that, under *reference conditions* ([3.29](#)), in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an *indicated value* ([3.11](#)) of an *RPLD detector* ([3.25](#))

3.5
calibration coefficient
$N_{D,r}$
relation valid under *reference conditions* ([3.29](#))

$$N_{D,r} = \frac{D_{w,Q_0}}{M_{Q_0,r}SCF_r - M_{0,r'}SCF_{r'}}$$

where

D_{w,Q_0} is the conventional true value of the *measured quantity* ([3.14](#));

$M_{Q_0,r}$ and $M_{0,r'}$ are the mean values of *indicated values* ([3.11](#)) of a single *RPLD detector* ([3.25](#)) of element ID r and r′ for several *sessions* ([3.33](#)), or irradiated and unirradiated element respectively;

SCF_r and $SCF_{r'}$ are the *individual dosimeter sensitivity correction* ([3.12](#)) factors.

Note 1 to entry: The *calibration coefficient* ([3.5](#)) is the reciprocal value of the response under *reference conditions* ([3.29](#)).

3.6
casing
capsule, usually made from resin (e.g. acrylonitrile butadiene styrene) of a suitable thickness and shaped as a columnar pipe or tube, into which a small *RPLD detector* ([3.25](#)) can be placed

3.7
correction factor
factor applied to the *indicated value* ([3.11](#)) in order to compensate for the measurement deviation caused by an influence quantity or the *measured quantity* ([3.14](#))

Note 1 to entry: Examples of using a *correction factor* ([3.7](#)) are the corrections for *energy dependence* ([3.10](#)) and *nonlinearity* ([3.18](#)).

3.8
directional dependence
dependence of the response of an *RPLD detector* ([3.25](#)) on the direction of radiation incidence

3.9
direction of preference
direction that refers to the *RPLD detector* ([3.26](#)) and is considered as a reference value for the direction of radiation incidence as an influence quantity

3.10
energy dependence
dependence of the response of an *RPLD detector* ([3.25](#)) on the *radiation quality* ([3.23](#))

3.11
indicated value
$M_{\mathrm{raw},i}$
displayed value by an *RPLD-indicating instrument* ([3.27](#)) of the *i*-th RPLD, which is the mean value of repetitive reading values by pulse laser irradiation

Note 1 to entry: The *measured value* ([3.15](#)) of the dose is determined from the *indicated value* ([3.11](#)) by applying the *calibration coefficient* ([3.5](#)), *correction factor* ([3.7](#)), and correction summand (see [Clause 5](#)).

Note 2 to entry: The *indicated value* ([3.11](#)) is also termed the reading of the *RPLD-indicating instrument* ([3.27](#)).

3.12
individual dosimeter sensitivity correction
SCF_i
deviation of the response of a single *RPLD detector*, *i*, ([3.25](#)) from the mean response of a *batch* ([3.3](#)) of *RPLD detectors* ([3.25](#)) under identical irradiation and evaluation conditions

3.13
internal calibration glass
internal calibration glass with a constant RPLD luminescence intensity, used for operation checks for the *RPLD-indicating instrument* ([3.27](#)) (except for the heating device)

3.14
measured quantity
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* ([3.20](#)).

3.15
measured value
value of a *measured quantity* ([3.14](#)), *absorbed dose* ([3.1](#)) to water, determined by an *RPLD system* ([3.26](#)) at the *point of measurement* ([3.20](#))

Note 1 to entry: The *measured value* ([3.15](#)) is determined as the product of the *correction factors* ([3.7](#)) and the mean of the *indicated values* ([3.11](#)) of the single *RPLD detectors* ([3.25](#)) that has been corrected for the background value ([3.2](#)), and then multiplied by the *calibration coefficient* ([3.5](#)).

3.16
measurement cycle
sequence of working steps in RPLD dosimetry, consisting of *pre-irradiation annealing* ([3.22](#)), irradiation, *pre-heat* ([3.21](#)), and evaluation of *RPLD detectors* ([3.25](#))

3.17
measuring range
range of dose values in which the *RPLD system* ([3.26](#)) meets the requirements for the operation characteristics

Note 1 to entry: The limits of the measuring range of an *RPLD system* ([3.26](#)) are within the interval spanned by the smallest and the largest *measured values* ([3.15](#)).

3.18
nonlinearity
dependence of the change in response on dose

Note 1 to entry: Linearity means a constant dosimeter sensitivity on dose; supralinearity denotes an increase in dosimeter sensitivity with increasing dose; sublinearity denotes a decrease in dosimeter sensitivity with increasing dose.

3.19
parameters for tests
values of influence quantities that are agreed upon for testing the impact of other influence quantities

3.20
point of measurement
point on or in a phantom at which the *absorbed dose* (3.1) to water is measured

3.21
pre-heat
controlled heat treatment for an *RPLD detector* (3.25) after irradiation and before evaluation

Note 1 to entry: Pre-heat serves to stabilize the RPLD luminescence intensity.

3.22
pre-irradiation annealing
controlled heat treatment for an evaluated *RPLD detector* (3.25) before reuse

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

3.23
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, a simply measurable parameter, such as the quality index of a photon radiation, is used for the characterization of radiation quality[28].

3.24
radiophotoluminescence
RPL
light emission in the visible range or an adjacent spectral range, which is based on the radiation-induced occupation of trapping centres by the charge carriers of certain ion crystals, and occurs when these charge carriers transit into activator levels as a consequence of UV excitation

3.25
radiophotoluminescent glass dosimeter detector
RPLD detector
detector
quantity of RPLD material of a certain chemical composition in a homogeneous matrix, e.g., silver-activated phosphate glass

Note 1 to entry: The properties of an *RPLD detector* (3.25) are determined by its material composition, mass, and shape.

3.26
radiophotoluminescent glass dosimeter system
RPLD system
system consisting of a number of *RPLD detectors* (3.25) and, if necessary, the supporting instruments, the instruction manual containing the descriptions of the evaluation procedures, and the calibration instructions for the *RPLD system* (3.26)

3.27
radiophotoluminescent glass dosimeter -indicating instrument
RPLD-indicating instrument
instrument for measuring the intensity of the luminescence emitted by an *RPLD detector* (3.25)

Note 1 to entry: The instrument is equipped with devices for exciting the *RPLD detector* (3.25) with UV light, for recording the intensity of the RPLD luminescence emitted by the *RPLD detector* (3.25), and for indicating a measurement signal proportional to the emitted light intensity.

Note 2 to entry: The *RPLD-indicating instrument* (3.27) is also called the reader.

3.28
rated range of use
variation range of an influence quantity that causes a change in response, and 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

3.29
reference conditions
set of reference values of all influence quantities and the *measured quantity* (3.14)

Note 1 to entry: If one or more influence quantities or the *measured quantity* (3.14) deviate from their reference values, the measurement conditions are denoted as non-reference conditions.

3.30
reference point of detector
point located within or on the surface of an *RPLD detector* (3.25) whose spatial coordinates serve to specify its position respective to its surroundings

Note 1 to entry: The position of the reference point within or on the *RPLD detector* (3.25) is defined by the manufacturer. In dose measurements, the reference point of an *RPLD detector* (3.25) is placed at the *point of measurement* (3.20) either on or in the phantom. For *calibration* (3.4), the reference point of an *RPLD detector* (3.25) is placed at a point where the *absorbed dose* (3.1) to water under *reference conditions* (3.29) is known.

3.31
reference RPLD
RPLD detector (3.25) used to determine the *correction factor* (3.7) for the change in response during successive *measurement cycles* (3.16)

Note 1 to entry: See 4.7.4.

3.32
reusability
usability of *RPLD detectors* (3.25) in several successive *measurement cycles* (3.16)

3.33
session
single sequential reading of an *RPLD system* (3.26)

Note 1 to entry: A *session* (3.33) reading is expressed as $M_{\text{raw},i}$ (3.11) and the mean value of the several *sessions* (3.33) of element ID i is expressed as M_i.

3.34
uncertainty of measurement
parameter obtained by measurement or calibration, which, together with the *measured value* (3.15), marks the value range where the true value of the *measured quantity* (3.14) lies

Note 1 to entry: The *uncertainty of measurement* (3.34) is the positive root obtained from the sum of the squares of the standard uncertainties, for all uncertainty components.

4   Rules for the RPLD handling/reading procedure

4.1   Principle of measurement

Most common RPLDs consist of silver-activated phosphate glass. Ionizations produced by external radiation generate RPL centres. The number of RPL centres is directly proportional to the number of generated ion pairs, as well as to the absorbed dose. The quantity of RPL centres can be determined by exciting them with a pulse type ultra-violet laser. In order to take advantage of the repeatable readout characteristics of RPLD, a pulse laser is used instead of a continuous wave laser. The RPLD emits visible orange light immediately after this excitation. Since the energy state of the RPL centres are maintained after the light emission, the RPL can be read repeatedly after the first reading.

4.2   Objective quantity of measurement

The measured quantity is the absorbed dose to water, D_w, at the point of measurement in the absence of the RPLD. The unit of this quantity is the gray (Gy). The measured values of the absorbed dose to water can be converted into the absorbed dose of other materials, such as tissues of interest.

4.3   Handling of RPLDs

4.3.1   General remarks

Mechanical shock should not be given to avoid cracking the RPLD. If there is dirt or oil on the surface of the element, the readings may change. It is recommended to use vacuum tweezers because dust on the RPLD surface can also be removed. The major process flow of the RPLD reading shall be detailed in the instruction manual of each RPL system. One typical type of RPLD is a rod type measuring 1,5 mm in diameter and 12 mm in length. The element is installed in a case made of acrylonitrile butadiene styrene (ABS) with a mass density of 1,05 g/cm³ and a thickness of 0,5 mm. This type is considered a typical RPLD type because the effective readout volume is small enough to apply to the audit dosimetry. The effective readout volume is diameter of 1 mm and a length of 6 mm.

4.3.2   Cleaning of RPLD element

Ultrasonic cleaning with alcohol or wiping by cloth should be performed. Typically, annual cleaning is enough unless there is evidence of response variation or evidence of dirt on the RGD element.

4.4   Annealing

Annealing should be performed before the use of a new RPLD or to clear the background from the last annealing. Annealing conditions of RPLD elements should be carefully described in the instruction manual of each RPL system. For example, for the rod type silver-activated RGDs, the annealing condition is 400 °C for 20 min. After annealing, it is recommended to read one element and confirm that the indicated value is the background level to ensure any residual signal has been erased.

4.5   Irradiation of RPLD

4.5.1   Effective centre of measurement

During element irradiation, accurate positioning is necessary to minimize the difference between the geometric centre and the effective centre of the readout area, particularly if a steep dose gradient exists. The position of the effective centre within the RPLD shall be indicated by the manufacturer in the instruction manual. The density difference between the RPLD element and water should also be considered for depth setting. It may be necessary to acquire a correction factor in advance.

4.5.2   Irradiation dose

For audit irradiations, it is important to set the irradiation dose in the range of clinical use. In this document, the assumed dose level is from 0,1 Gy to 30 Gy. It is also necessary to clarify whether the dose should be calculated assuming that the irradiation dose is given to the glass element itself or if the phantom including the glass element is equivalent to water. In the latter case, the auditing site needs a conversion factor, such as a correction factor for radiation quality or phantom material. The dose should be within the range of RPLD usage written in the instruction manual supplied from the manufacturer.

4.6   Pre-heating

Without pre-treatment, a stabilization period of more than 10 days after irradiation is necessary before measurement for some RPLDs. To shorten the interval between irradiation and measurement, pre-heating done at temperatures lower than annealing should be performed after irradiation. Typical pre-heating condition should be carefully described in the instruction manual of each RPL system. For

example, for rod type silver-activated RGDs, the pre-heating condition is 70 °C for 30 min. Immediately after the irradiation, the indicated value rapidly rises, which is called build-up. For this type of detector, applying the pre-heating just after irradiation within about 1 h should be avoided, because the build-up effect is still dominant. Typically, pre-heating is performed at least several hours after irradiation. This characteristic is important in transferring the dosimeter in a hot climate region for the dose audit. It is recommended to keep the RPLD condition below the pre-heat condition through the transfer process.

4.7 RPLD Reading

4.7.1 General remarks

The room temperature should be kept constant to avoid affecting the reader stability. Some types of RPLDs are sensitive to humidity and significantly affected by the presence of dust in the reading area. Thus, for each type of RPLD the effect of the ambient conditions on the readings shall be investigated and the ambient conditions adapted accordingly.

4.7.2 Positioning RPLD elements on the reading tray

A precise positioning of the RPLD elements during the reading can be critical for signal reproducibility. The optimal positioning of the RPLD elements on the reading tray of an automated reader should be carefully described in the instruction manual of each RPL system.

4.7.3 Determination of the RPL reading

To improve statistics, multiple readings should be performed. During a session, the position of the RPLD elements should be corrected if necessary between readings, according to 4.7.2. A single reading preserves the RPL signals. However, a tiny portion of the RPL signal could get lost if, for example, a single rod type silver-activated RPLD element continuously is read with no time interval between readings. The signal depletion would become around 1,5 % after 100 readings. Alternately, the RPL signal also undergoes a recovery from the depletion over time. For example, if one reads a single rod type silver-activated RPLD element continuously with a 10 min time interval between each sessions, no depletion effect can be observed.

4.7.4 Reader stability compensation by reference RPLDs

It is practically important to compensate for the daily reader fluctuation due to environmental conditions such as room temperature, humidity, or stability of the electricity of the RPLD reader. For example, within a reading of 20 RPLD elements in a single session, it is recommended to include at least three "reference" RPLD elements for this purpose. These "reference" RPLD elements are exposed to a known dose close to the dose that is supposed to be delivered to the other RPLDs in the reading tray in calibration (reference) condition. By applying the ratio between the intended absorbed dose and the measured value of the "reference" RPLDs to every other RPLD measured value issued from the same session, a corrected measured value without the effect of the reader's fluctuation can be obtained.

5 Evaluation of absorbed dose to water

5.1 Basic formula for the determination of absorbed dose to water

The measured value of the absorbed dose to water, $D_{w,i}$, results from the M_i, which is mean of indicated values of every session of the i-th RPLD , according to Formula (1).

$$D_{w,i} = \left(M_i \cdot SCF_i - M_{0,i'} \cdot SCF_{i'} \right) \cdot N_{D,r} \cdot f_{en} \cdot f_{p} \cdot f_{lin} \tag{1}$$

where

$M_{0,i'}$ is the background value of the *i'*-th RPLD (see 5.3);

SCF_i is the individual dosimeter sensitivity correction factor of the *i*-th RPLD (see 5.4);

$N_{D,r}$ is the calibration coefficient for the reference radiation quality (see 5.5);

f_{en} is the correction factor for the radiation quality (see 5.7);

f_p is the correction factor for phantom material (see 5.8);

f_{lin} is the correction factor of nonlinearity (see 5.9).

5.2 Mean readings of raw data

$M_{raw,i}$ is the mean value of repetitive reading values by pulse laser irradiation. After all the elements placed on the reading tray have been read (session 1), the next session starts. M_i is the mean of the indicated values of element *i* of multiple sessions executed by checking the rotation and position of the element between each session. Calculate M_i according to Formula (2).

$$M_i = \overline{M_{raw,i}}$$
(2)

5.3 Evaluation of background element

The read mean value of the background element *i'* is $M_{0,i'}$. The net reading value of element *i* is given by the subtraction between M_i and $M_{0,i'}$ after applying each SCF.

5.4 Individual dosimeter sensitivity correction factor of each element

In order to correct the difference in sensitivity for each element, an individual dosimeter sensitivity correction factor SCF_i is applied. The correction factor is determined by using the result of uniform irradiation for each batch. Let $M_{uniform,i}$ be the mean of the indicated value under uniform irradiation of element *i* and $\bar{M}_{uniform}$ be the mean of each $M_{uniform,i}$ from the same batch, the individual dosimeter sensitivity correction factor SCF_i is given by Formula (3).

$$SCF_i = \frac{\bar{M}_{uniform}}{M_{uniform,i}}$$
(3)

The correction factors should be checked periodically and revised as needed. A frequency of once every one or two years is recommended if there are no suspicious data related to the coefficients. Typical uniformity of the batch is about 1 % in 1 standard deviation[25].

5.5 Calibration coefficient with reference RPLD element

The RPLD measured value for the audit is calibrated with the reference RPLD measured value irradiated with a known dose and beam quality. As an irradiation field for reference RPLDs, a stable irradiation beam such as available at a standard dosimetry laboratory is recommended. Ionization chamber dosimetry, the current standard dose evaluation tool, should be used to evaluate dose to the reference RPLD. The calibration coefficient is expressed by Formula (4).

$$N_{D,r} = \frac{D_{w,Q_0}}{M_{Q_0,r}SCF_r - M_{0,i'}SCF_{i'}}$$
(4)

where

$M_{Q_0,r}$ is the mean of the reference RPLD indicated values;

$M_{0,i'}$ is the mean of the background RPLD indicated values;

SCF_r and $SCF_{i'}$ are the individual dosimeter sensitivity correction factors;

D_{w,Q_0} is the absolute dose measured by ionization chamber with the same condition of the reference RPLD irradiation.

If the beam for the reference RPLD is not equal to the beam for audit in the beam energy and field size, it is necessary to acquire the correction factor beforehand. Read the RPLD for audit and reference RPLD with the same reading tray within a session. This minimizes the effect of changes in reader sensitivity.

5.6 Correction factor for individual reading tray position dependence

As the value of reading depends on the install position of the reading tray, it is recommended to use a specific element, a specific reading tray, and install position as a set. This prevents deterioration of reading precision. If the installation position is not fixed, it is expected that the reading precision be improved by acquiring and applying the correction factor on the reading tray position. As there are also individual differences in machining of the reading trays, there may be a "good" or "bad" reading tray. The user should evaluate the precision of various trays before using them.

5.7 Correction factor for the radiation quality

In order to obtain the correction factor for the radiation quality of RPLD, elements irradiated at a known dose with a certain beam quality are read at the same time. The correction factor is determined by using the relative reading value of the element. Ionization chamber dosimetry, the current dosimetry standard, should be used to determine the absolute dose. In this document, the assumed beam energy is ^{60}Co-gamma rays and X-rays from 4 MV to 20 MV. The correction factor is expressed by Formula (5).

$$f_{en} = \frac{D_Q}{D_{Q_0}} \cdot \frac{M_{Q_0}}{M_Q} \tag{5}$$

where

D_Q and D_{Q_0} are the absolute doses measured by ionization chamber;

M_Q and M_{Q_0} are the mean of RPLD indicated values multiplied by individual dosimeter sensitivity correction factor of beam quality Q and Q_0, respectively.

Q is the beam quality used for the audit and Q_0 is the beam quality used for the reference RPLD irradiation. Since the RPLD measured values depend on the irradiation field size and depth, the correction factor should be determined under the same conditions as the beam to be audited.

Table 1 summarizes the examples of values of the correction factor f_{en} that are valid for the rod type silver-activated RPLD calibrated with a ^{60}Co-gamma ray beam at a depth of 10 cm in a water phantom[3].

Table 1 — Example of the experimentally determined f_{en} values for high-energy photon radiation, that are valid for rod type silver-activated RPLDs and calibrated with ^{60}Co gamma radiation at a depth of 10 cm in water (SCD: 100 cm, field size: 10 cm × 10 cm, on beam axis)

Nominal acceleration voltage MV	Beam quality, Q	Depth of measurement cm	f_{en}	Source
^{60}Co	0,58	10	1,000	Reference [3]

Table 1 *(continued)*

Nominal acceleration voltage MV	Beam quality, Q	Depth of measurement cm	f_{en}	Source
4	0,624	10	1,007 ± 0,005	Reference [3]
6	0,669	10	1,014 ± 0,009	Reference [3]
10	0,740	10	1,026 ± 0,007	Reference [3]
20	0,791	10	1,029 ± 0,004	Reference [3]

NOTE   The values of f_{en} indicated in Table 1 are valid under reference conditions (i.e. for 100 cm SCD, 10 cm × 10 cm field size, on axis, at a depth of 10 cm in a water phantom). The additional correction factor needed when RPLDs are applied under non-reference conditions, such as other depths, field sizes, and wedged fields, is described in the literature[3][15][22]. Values of the correction factor that are smaller than 1 are correcting for over response; values of the correction factor that are larger than 1 are correcting for under response.

5.8   Correction factor for phantom material

When using water as a phantom during the audit, it is not necessary to use a correction factor on the phantom. However, there are cases where solid phantoms are used due to ease of setup. In that case, it is necessary to correct by using the output ratio obtained by measuring using RPLD and ionization chamber dosimeter for each of water and solid phantom. The correction factor is expressed by Formula (6).

$$f_p = \frac{D_w}{D_p}$$ (6)

where

   D_w is the measured dose in the water phantom;

   D_p is the measured dose in the solid phantom.

Both measurements should be performed using an ionization chamber. In addition, this correction factor can be obtained by the Monte-Carlo calculation with a very good uncertainty.

5.9   Correction factor for nonlinearity

Although dose nonlinearity has no large dose dependency in RPLD, correction of dose nonlinearity is necessary in order to allow accurate dose measurements at doses which are different from the delivered dose to the reference RPLD element. This correction factor is obtained from the measured value ratio between the RPLD irradiated with a certain dose and the RPLD irradiated with a known dose under the same irradiation condition. The correction factor is expressed by Formula (7).

$$f_{lin} = \frac{D_{2,ion}}{D_{1,ion}} \cdot \frac{M_{1,RPLD}}{M_{2,RPLD}}$$ (7)

where

$D_{1,\text{ion}}$ and $D_{2,\text{ion}}$ are absolute doses measured by the ionization chamber at a certain dose difference level;

$M_{1,\text{RPLD}}$ and $M_{2,\text{RPLD}}$ are the mean of RPLD indicated values multiplied by individual dosimeter sensitivity correction factor irradiated at each dose.

Actual correction factors are derived by the fitting the several points obtained by several dose irradiations in a given dose range.

5.10 Uncertainty of measurement of the absorbed dose

The uncertainty of the measured value of the absorbed dose to water is determined in accordance with ISO/IEC Guide 98-3, using Formula (1). Type A statistical methods are applied to determine the standard uncertainties when the mean of RPLD indicated values multiplied by individual dosimeter sensitivity correction factor ($M_i \cdot SCF_i - M_{0,i'} \cdot SCF_{i'}$) is the input variable. Type B components, such as digits for a digital display or the smallest reading quantity for analogical displays, were neglected as this estimate was made with 6 digits display. Other Type B methods are used to determine the standard uncertainties when the calibration coefficients $N_{D,r}$ and all other correction factors are the input variables.

It is recommended that the uncertainty estimation for the measured value should comprise the following items presented in Table 2. The numerical values of the estimated uncertainties vary in accordance with the applied methods. Some typical values, from Reference [22] are reproduced in Table 2 as an example.

Table 2 — Example of uncertainty budget of the absorbed dose to water measured by RPLD (typical values from Reference [22])

Source of uncertainty	Estimated relative uncertainty, s %
Mean value	0,3 (Average of 3 RPLD elements)
Individual dosimeter sensitivity factor	
Correction factor for beam quality	0,9
Correction factor for phantom material	0,1
Calibration coefficient of RPLDs (Calibration of the dosimetry system)	0,6 (Average of 6 RPLD elements)
Others	0,2
Overall uncertainty	1,1

6 Requirements for the RPLD system

6.1 General information

The RPLD system is composed of RPLD detectors, RPLD-indicating instruments, and the auxiliary instruments. The requirements apply to each component (see 6.3, 6.4, and 6.5).

6.2 Recommendations concerning completeness of the RPLD system

6.2.1 Technical components

An RPLD system shall contain at least the following technical components:

a) a number of RPLD detectors of the same type;

       11

b) an indicating instrument for RPLD measurements, equipped with one or more devices for the UV excitation of RPLD detectors as well as the measurement and indication of the RPL;

c) auxiliary instruments, including an oven and a tray for heat treatment.

6.2.2 Hardware and software components

An RPLD system shall be applied to determine dose values from the indicated value of the RPLD-indicating instrument. The hardware required for this purpose as well as the software allowing the measurements record, dose calculations and stability check are part of the RPLD system.

6.2.3 Operating instructions

6.2.3.1 General

The manufacturer of the RPLD dosimetry system should provide the customer of the system with detailed instruction manuals.

6.2.3.2 General requirements

The instruction manual should contain the following information about the RPLD system:

a) safety instructions pertaining to the instruments;

b) block diagram of RPLD system;

c) name and version information of software;

d) description of menu and sub-menu about the software functions;

e) detailed description for the operation of RPLD system;

f) procedure for maintenance and calibration of RPLD system;

g) information about the pre-irradiation annealing process;

h) information about the pre-heat process;

i) description of the reading procedure;

j) information about the stability check including reading reproducibility of RPLD-indicating instruments;

k) functions and operations of all keys and switches, and the meanings of the output plugs, indicator scales, and signal lights;

l) information about the required supply voltage, the rated use range of the supply voltage and frequency, and the line voltage switching;

m) information to help decide whether or not an RPLD detector shall continue to be used, if necessary;

n) information about the adjustment and calibration of the RPLD system after worn parts have been replaced;

o) stabilizing time of the RPLD-indicating instrument;

p) for the RPLD-indicating instrument, information about the type and size of the required detectors;

q) dimensions, density, and type of the detector casing material; and, if necessary and supplied, those of the auxiliary components;

r) information about storage and cleaning;

s) warning, if a long storage period in high humidity can be damaging;

t) recommended method for cleaning and drying the RPLD detectors, if required.

6.2.3.3 Imperative information about technical data

The following technical data should be provided by the manufacturer:

a) type of the RPLD system, type designation, and designation of the manufacturer;

b) measured quantity as well as radiation quality for which the RPLD system is intended;

c) indication range and measuring range for the dose;

d) rated range of use of RPLD detectors and other components of the RPLD system, together with the corresponding values for the following influence quantities:

   1) rated range of photon energy and direction of radiation for the parallel incidence of the photon radiation;

   2) recommended range of ambient temperature and relative humidity;

   3) supply voltage;

e) information or marks defining the position of the reference point of detector and the direction of preference;

f) diagram of the energy dependence and the directional dependence of the response, if required;

g) information on nonlinearity, with diagram, if necessary;

h) variation coefficient of the response of a sample, with diagram, if necessary;

i) information on computer interfacing;

j) computer platform necessary to support supplied software;

k) software media;

l) installation procedure;

m) backup of data;

n) critical software parameters;

o) passwords;

p) software revision date and updates.

6.3 Requirements for RPLD detectors

6.3.1 Characteristics of RPLD materials

Basic characteristics of RPLD, such as physical size, energy dependence, and nonlinearity, should not vary between different elements. In addition, if RPLD detectors are reusable, the mechanical, thermal, chemical, and optical properties shall remain constant, within the specified uncertainty of measurement.