Characterization of three solid state dosimetry systems for use in high energy photon dosimetry audits in radiotherapy

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HIGHLIGHTS

- All three dosimetry systems are appropriate for use in large-scale remote audits.
- Each audit methodology requires independent commissioning process.
- All tested systems were found to have intrinsic advantages and disadvantages.

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ABSTRACT

The IAEA Dosimetry Laboratory (DOL) aims to improve the accuracy of clinical dosimetry in hospitals world-wide by providing independent remote audits for high energy photon beams. A thermoluminescent dosimetry (TLD) system has been used by the DOL to provide audit services for over 47 years. Two additional systems: an optically stimulated luminescent dosimetry (OSLD) system and a radiophoto luminescent dosimetry (RPLD) system underwent a commissioning process. The systems' parameters, reading methodology and the dosimetric characteristics were investigated and compared. The read-out procedure for each system was established and optimized. Dosimetric characteristics such as reproducibility, signal fading with time after irradiation, signal per dose dependence and energy response were investigated. Additional tests to check signal depletion per readout and individual sensitivities of dosimeters were performed for RPLDs and OSLDs and also reading position dependence for the RPLD system was checked.

The reproducibility of 4 readings of one dosimeter is 0.48% for TLDs, 0.16% for OSLDs and 0.15% for RPLDs. The fading effect after 100 days was 4% for TLD, 2% for OSLD and 0.4% for RPLD. Energy response of TLDs and RPLDs is comparable, higher corrections were found for OSLDs. The RPLD dose-response is sub-linear whereas TLD and OSLD response is supra-linear at the dose range under study (1–4 Gy). The TLD reading procedure is destructive but OSLDs and RPLDs can be read repeatedly and the signal depletion per reading is 0.036% for OSLDs and 0.017% for RPLDs. The sensitivity correction factors for RPLDs and OSLDs were determined with the standard deviation in response of 1000 dosimeters of 2.2% for OSLD and 0.9% for RPLD. The combined standard uncertainties (k = 1) are 1.60% for TLDs, 1.46% for OSLDs and 1.51% for RPLDs.

All three systems can be successfully used for auditing purposes if corrections for all described effects are applied.

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1. Introduction

With the number of radiotherapy centres increasing year by year to meet the high demand for cancer treatments along with the development of new techniques to provide more effective treatments to the patients, on-going quality assurance (QA) verifications are needed to ensure safe patient radiotherapy. Essential for all types of treatments is to perform dosimetric audits encompassing checks under basic reference conditions and also more complex situations directly related to the patient treatments. There are a few
international and many national institutions providing dosimetry auditing services to radiotherapy hospitals (Clark et al., 2015; Izewska and Andreo, 2000; Kroutilíková et al., 2003; Lye et al., 2014; Mizuno et al., 2008; Pulliam et al., 2014). Where audits provided remotely by post, passive solid state dosimetry systems are commonly used. Thermo Luminescent Dosimetry (TLD) technology has been used by the IAEA’s Dosimetry Laboratory (DOL) to provide audit services for over 47 years (Izewska and Andreo, 2000; Izewska et al., 2007). An optically stimulated luminescent dosimetry (OSL) system and a radiophoto luminescent dosimetry (RPLD) system have become available and coupled with a need to replace aging TLD equipment they were tested by DOL for use in dosimetry audits.

The purpose of this work is to compare the dosimetry systems’ parameters to help identify the merits of each system relevant to the provision of a large scale audit services. The readers’ performances were studied in order to find the best working parameters and monitor their stability. The dosimeters’ characteristics relevant to their use in high energy photon beams have been investigated. There are several publications describing these systems (Dunn et al., 2013; Hsu et al., 2006; Karsch et al., 2012; Knezevic et al., 2011; Mizuno et al., 2008; Rah et al., 2009b), but this work is the first. Microdot present the comparison of the systems’ parameters as well as the operational procedures applicable to the same audit methodology. The sensitivity, reproducibility and the signal stability with time, as well as dosimeter response to different doses and energies, were evaluated. Consideration was also given to the user training and the workload associated with the systems’ commissioning and routine use, as well as the systems’ robustness and reliability.

2. Materials and methods

2.1. Dosimetry systems

2.1.1. TLD system

The TLD system used for this work consists of dosimeters in the form of plastic capsules filled in with TLD-100 powder (LiF:Mg,Ti) produced by Thermo Fisher Scientific Inc. and a PCL3 automatic reader from Fimel. Before TLD powder is used for dose measurements it undergoes an annealing process of 1 h in 400 °C, followed by fast cooling for 20 min and 24 h in 80 °C. After the annealing TLD powder is stored in dark glass containers to avoid light exposure. To ensure that the powder consist of homogenous grains it is sieved to result in grain sizes between 80 μm–200 μm. Plastic capsules of inner dimensions of 20 mm in length and 3 mm in diameter are filled with 165 mg of powder. All dosimeters prepared from the same lot of powder are assumed to have the same sensitivity. One TLD capsule allows preparing four samples of powder which are dispensed into stainless steel cupels that are loaded into the reader. Up to 85 cupels can be read together in one session, which takes about 45 min. The TLD system and the readout procedure have been described in detail in (Izewska and Andreo, 2000).

2.1.2. OSLD system

NanoDot OSL dosimeters and microSTARii reader from Landauer Inc. were used in this study. The nanoDot dosimeter has a sensitive element of 4 mm diameter and 0.2 mm thickness which is enclosed in a plastic light tight case (10 mm × 10 mm × 2 mm). The sensitive material is aluminum oxide doped with carbon (Al2O3:C). Pulsed high power LED is used to induce luminescence in the material. To ensure that sensitive material of the nanoDots is not exposed to light, they are stored in light tight containers. Each dosimeter is labeled with a unique serial number and a bar code. The microSTARii reader allows reading of one OSLD at a time and the readout process is very fast, requiring only 1 min to perform four readout measurements of a single dosimeter. The depletion of the signal on a dosimeter is observed with every successive readout. The whole system is very compact requiring only a small space. The OSL dosimeters can be reused after an optical annealing process. A light box was custom made and it has multiple lines of LEDs installed on the top and bottom of the box to provide a uniform light intensity. There is a transparent glass drawer in the middle for positioning of OSLDs and ventilation for the temperature control. Annealing for 60 min per 1 Gy dose is used; it reduces the accumulated signal to the background level and allows nanoDots to be reused.

2.1.3. RPLD system

A Dose Ace system consisting of GD-302M glass rods and a FDG-1000 reader from Asahi Techno Glass Corporation (ATG) was used in this work. The glass rods are made of silver activated phosphate glass; they are 12 mm long and 1.5 mm in diameter, with an ID number engraved on one end. The sensitive area of a dosimeter is 6 mm long. RPLDs are encapsulated in custom made watertight capsules. Each capsule has an ID number and a bar code. The sensitive area is also marked on the capsule to allow precise positioning. The FGD-1000 reader can read up to 20 glass rods in a session of 5 min. After irradiation, the dosimeters are kept in a low humidity storage cabinet for 24 h and are then preheated to 70 °C to stabilize the luminescence centers. RPLDs can be read several times as the read out process is not destructive. Depletion of the signal can be observed when a dosimeter is read repeatedly in quick succession, after which the signal returns to the initial value. Dosimeters can be reused after annealing (20 min in 400 °C) which eliminates luminescence centers.

2.1.4. Dosimeter irradiation

Irradiation of the dosimeters for testing of the parameters of the dosimetry systems in this study was done with two Co-60 units at DOL (Nordion X-200 and Picker V40) and also with an Elekta Synergy accelerator at the Medical University of Vienna. Irradiations at DOL were performed in a source-to-axis distance (SAD) of 100 cm geometry, at 5 cm depth in a Gammex solid water phantom which has specially manufactured inserts for all three dosimeter types. Before each irradiation session DOL Secondary Standard Farmer chambers connected with a Keithley 6517 electrometer were used for determination of the absorbed dose to water. The irradiations with the Elekta Synergy linear accelerator were performed in a MT-150 MedTec water phantom and dosimeters were placed in disk shaped holders (Fig. 1) which could be precisely positioned using a Roos chamber holder. TLD and RPLD capsules were placed in the opening of the disk and for OSLD a screw watertight lid was made to position dosimeter in the holder. The attenuation and scatter influence of the holder was investigated.

Fig. 1. Disk shaped polystyrene holder manufactured for 3 types of dosimeters (left to right: TLD, RPLD, OSLD).
experimentally using a PinPoint chamber by comparing the results of two independent measurements, with and without the holder. Prior to each dosimeter’s irradiation a dose determination in water was done with the PTW 30013 Farmer chamber connected with a UNIDOS electrometer. The calibration of reference dosimetry equipment used in this study is traceable to the Bureau International des Poids et Mesures (BIPM). Dosimeters’ characteristics were tested at a 2 Gy dose except for OSLDs that were irradiated to 1 Gy due to their shorter useful lifetime.

2.2. Determination of dosimeters characteristics

A selection of the dosimetric characteristics and related correction factors is described below. Some individual dosimeter characteristics are not applicable to all three systems.

2.2.1. Dosimeters’ sensitivity correction factors

Individual dosimeter sensitivity correction factors (SCFs) need to be determined for each OSLD and RPLD. Dosimeters were separated into groups of 200 dosimeters coming from the same manufacturer production lot. Each group of dosimeters was irradiated with the dose of 1 Gy for OSLD and 2 Gy for RPLD. The reading of a group of dosimeters was performed without breaks and delay between readouts. During the readout time, environmental conditions were carefully monitored to take into account any possible reader’s drift. SCFs were calculated as the ratio of an average signal of the group of dosimeters to the signal of an individual dosimeter. The sensitivity of the TLD powder was determined for the lot of annealed powder and all dosimeters preprepared from one lot have uniform sensitivity across all TLD capsules.

2.2.2. Readout position correction

For readout, RPLDs are placed in a tray that can accommodate 20 dosimeters. The dosimeter response varies with its position in the readout tray, therefore readout position corrections need to be applied for every of 20 tray positions. Several readout trays were tested and those with the smallest readout position corrections were selected for routine use. A position correction factor is unique to each tray because of small geometrical differences affecting the readout area alignment to the built-in laser system. In the case of OSLD and TLD, there is a single readout position ensuring the same geometry of all dosimeters is achieved and no special correction is required.

2.2.3. Signal depletion

The readout process for TLDs is destructive but the OSLDs and RPLDs can be read repeatedly. The partial loss of the signal (depletion) is observed with every reading and several dosimeters were read 200 times to see what amount of a signal is lost in the readout process. Each set of data was normalized to the first reading and a linear function was fitted to the data to describe and compare the depletion effect. For RPLD it was noticed that time gaps between the readings affect depletion and therefore additional test was performed with 5 min time gaps between the readings.

2.2.4. Readout reproducibility

The readout procedure applicable to the particular dosimeter type was followed. A TLD capsule contains sufficient amount of powder to prepare four readout portions of 35 mg each. The standard deviation of the mean of four readings, corrected for depletion, was calculated.

For RPLD dosimeters, four repeat readings were performed. After each reading the position of the dosimeter in the reading tray was checked, as during the reading process the tray is moving and there is a possibility for the glass rod to rotate. The standard deviation of the mean of four readings, calculated for 2481 dosimeters irradiated with the dose of 2 Gy was derived.

2.2.5. Dosimeter reproducibility

OSLDs and RPLDs can be irradiated and annealed for repeated use and a test was performed to monitor sensitivity changes occurring with the accumulated dose. The uniformity of response of the OSLDs is seen to deteriorate after an accumulated dose of over approximately 12 Gy. Nine OSLDs and 10 RPLDs were irradiated to a dose of 2 Gy, read and annealed several times and their sensitivity was calculated after each irradiation/readout cycle. The standard deviation of five cycles for OSLD and for RPLD was calculated.

2.2.6. Signal fading

The long term fading was investigated using the dosimeters irradiated in a Co-60 beam with a dose of 2 Gy for TLD and RPLD and 1 Gy for OSLD. Measurements started immediately after irradiation for TLDs and OSLDs. The fading study for RPLDs started one day after irradiation and the preheating of the dosimeters was performed. The groups of 9 OSLDs and 20 RPLDs as well as a portion of TLD powder allowing 10 readings at a time were read on regular basis over a three month period; the stability of the readers was also monitored. The change of the readout signal was observed and the fading function calculated. A long term fading was studied as the turn over time of dosimeters from the audited centre to the laboratory can take several weeks in international scale postal audits. The day seven post irradiation was established as the normalization point for long term fading study; typical for large scale audit services.

2.2.7. Dose response non-linearity

The relation between the dose delivered and the signal measured was checked for a dose range of 1–4 Gy. Four to six dosimeters were irradiated per dose point in the reference conditions using a Co-60 beam. The dose to signal response was normalized to the dose of 2 Gy; a function for the dose response non-linearity effect was determined for each of dosimeter types.

2.2.8. Energy dependence

The response of dosimeters irradiated with a range of photon beams (6 MV, 10 MV and 18 MV) was compared to the response of a dosimeter irradiated in Co-60 beam with the same dose. In this paper we discuss the results obtained from two independent measurement sessions using at least three dosimeters per dose point. The absorbed dose to water was determined under the reference conditions following the TRS-398 code of practice (International Atomic Energy Agency, 2005) for each of the available energies. Following the ionization chamber measurements, the irradiation of dosimeters was performed within the same session in an identical geometry setup.

2.2.9. Dose determination

The absorbed dose was determined from the dosimeter readings using the following equation:

\[ D = M \times SCF \times N \times f_{\text{un}} \times f_{\text{em}} \times f_{\text{fad}} \times f_{\text{hol}} \]  

where \( M \) is the mean of the readings from one dosimeter (corrected for depletion and readout position where applicable), \( SCF \) is the dosimeter sensitivity correction factor (not relevant to TLDs), \( N \) is
the dosimetry system calibration coefficient, $f_{\text{d}}$ is the dose response non-linearity correction factor, $f_{\text{e}}$ is the energy correction factor, $f_{\text{f}}$ is the fading correction factor and $f_{\text{h}}$ is the holder correction factor.

2.2.10. Uncertainties

The combined standard uncertainty was evaluated and compared for each dosimetry system investigated in this study. Calculations were performed following the “Guide to the expression of uncertainty in measurement” (JCGM100:2008, 2008). The overall combined standard uncertainty addresses individual components in the calibration of the dosimetry system $N$, which involves the uncertainty in the determination of the dose from ionization chamber readings, uncertainty in the dosimeter and phantom positioning during irradiation, uncertainties in solid water to water correction, dosimeters’ readout, positioning and sensitivity. Other group of uncertainty components is related to the determination of the dose from a user’s dosimeter; it includes uncertainties in the dosimeter readout $M$ (depletion uncertainty is incorporated), individual dosimeter sensitivity factor SCF, non-linearity dose response $f_{\text{d}}$, energy $f_{\text{e}}$, fading $f_{\text{f}}$ and holder $f_{\text{h}}$ corrections, and the dosimeter positioning during readout. For the purpose of comparing three dosimeter types, irradiations were performed using a disk shaped holder (Fig. 1) and the uncertainty analysis above relates to this holder. However, for auditing activities different holders are used and each holder type needs its own uncertainty estimation but these are not described here.

3. Results

3.1. Dosimeters’ sensitivity correction factors

The distribution of SCFs for 1000 OSLDs and RPLDs can be seen in Fig. 2. The OSLDs were received from the manufacturer having been pre-screened to ensure a $\pm 5\%$ uniformity of sensitivity and our results showed that 97% of dosimeters are within that range. The distribution of experimentally determined SCF values gave a standard deviation of 2.2% for OSLDs (SCFs in the range of 0.930 and 1.134). The SCFs determined for RPLDs were in a narrower range of the distribution, between 0.970 and 1.046; 97% of SCFs were within $\pm 2\%$ limits with 0.9% standard deviation for 1000 RPLDs. Both dosimeter types show differences in sensitivities across the dosimeter batch and require application of correction factors.

3.2. Readout position correction

Following the thorough testing of several RPLD readout trays, four trays were selected for routine use. The variation in the RPLD readout position correction was within $\pm 0.5\%$ for all dosimeter positions in these trays. Readout position corrections need careful testing and verification after extensive tray use, as they can deform slightly, which might lead to differences in the position corrections.

3.3. Signal depletion

Depletion of 0.036% and 0.017% per reading for OSLD and RPLD, respectively, were determined from the normalized data points collected in a session of 200 reading with no time delay between the readings (Fig. 3). The signal depletion for OSLD is related to the optical intensity and the readout stimulation time. Our results are comparable to previous findings by (Dunn et al., 2013) where a depletion of 0.03% per reading was reported on an earlier reader model. However, the depletion of RPLD signal is dependent on the time gap between the readings and it was observed that the signal returns to its initial value after a time gap of the order of days. The standard RPLD readout procedure involves time gap of 5 min between the readouts. The relevant depletion measured as for this standard readout procedure was 0.008% per reading.

3.4. Readout reproducibility

The reading reproducibility derived from 10751 TLDs gives 0.48% mean standard deviation. The number of OSLDs and RPLDs readouts is not as large as in the case of TLD system which has been in use for many years, yet the reading reproducibility was determined from over 2000 dosimeters for each OSLD and RPLD. The mean standard deviation values obtained for OSLDs and RPLDs are 0.15% and 0.16%, respectively. To compare, the nanoDots reproducibility reported by (Dunn et al., 2013) had the standard deviation equal to 0.64%. However, these data were obtained for a
previous model of the microStar reader. For the RPLD a comparable range of standard deviations was presented by (Araki et al., 2004) where standard deviation was approximately 0.2%.

3.5. Dosimeter reproducibility

After five irradiation/reading cycles the standard deviation of OSLD response was 0.43% which is lower than previous results of (Jursinic, 2007) who reported a value of 0.63% obtained in 6 cycles. Also 5 cycles were performed for RPLDs, and they showed the standard deviation of 0.42% which is lower than results of (Mizuno et al., 2008) where 0.8% standard deviation was reported. In an extended reproducibility study with 23 cycles of 2 Gy irradiations the results showed reproducibility of 0.68% standard deviation.

3.6. Signal fading

After irradiation, all three dosimeter types need a waiting period for the signal to stabilize and then the constant loss of the signal is observed. As can be seen in Fig. 4, the drop of the signal of 4% was noted for TLD, for the period of 100 days with the normalization to the 7th day. An initial phosphorescence signal occurs in the OSLDs immediately after irradiation which is avoided by conducting the first measurements 24 h after irradiation (Yukiara et al., 2004; Yukiara and McKeever, 2008). Over 100 days the OSLDs signal is reduced by about 2%. The signal drop in the first month is due to the low temperature traps which can decay at the room temperature. To compare, OSLD fading reported by Dunn (Dunn et al., 2013) was 3.5% six months after irradiation, normalized to the 1st day. RPLDs showed the most stable behavior, but the fading effect is not entirely negligible showing about 0.4% signal loss after one hundred days. Rah et al. (2009b) reported higher signal fading effect of 1.7% after 160 days. All three dosimeter types show signal fading and a correction should be applied for this effect. However, if RPLDs are read within two weeks post irradiation, the fading correction is negligible.

3.7. Dose response non-linearity

The dose response of the dosimeters is shown in Fig. 5. The

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![Fig. 3. Depletion of dosimeters signal.](image)

![Fig. 4. Fading effect: a group of 9 OSLDs and 20 RPLDs were read repeatedly and a portion of TLD powder irradiated to a uniform dose was read on regular basis.](image)
response functions were determined for each dosimeter type over a range of doses relevant to their intended use, i.e. \(1 \times 10^4\) Gy. The RPLD response is sub-linear whereas TLD and OSLD response is supra-linear in the dose range of interest. It can be seen that the largest corrections are needed for TLDs and OSLDs, whereas for the RPLDs the correction is less pronounced. The paper of (Rah et al., 2009a) on comparison of RPLD and TLD parameters showed similar characteristics of dose vs dosimeter response. The supra-linearity of dose response for OSLD is described by (Dunn et al., 2013) but the correction factors required in the range of \(1 \sim 4\) Gy are larger than the ones found here. The correction for the dose response non-linearity needs to be applied when calculating the dose for each of the dosimetry systems tested here.

3.8. Energy dependence

The results of energy dependence study are presented as the relevant correction factors in Table 1. The energy correction for the photon beams of 6 MV–18 MV ranged from 1.029 up to 1.046 for OSLDs, 1.020–1.032 and 1.019–1.032 for TLDs and RPLDs, respectively. Viamonte et al. (2008) also reported similar results for OSLDs with 4% decrease in dosimeter sensitivity with higher beam energies. Mizuno et al. (2008) reported on comparable dosimeter response to high energy photon beams for RPLD and TLD. The highest correction factor found by them for 20 MV beam was 1.029. These data were corrected for attenuation and scatter in the disk shaped holder (shown in Fig. 1) which is in the range from 1.003 to

Table 1
Energy correction factors.

<table>
<thead>
<tr>
<th></th>
<th>TPR20/10</th>
<th>OSLD</th>
<th>TLD</th>
<th>RPLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>1.029</td>
<td>1.020</td>
<td>1.019</td>
<td></td>
</tr>
<tr>
<td>6 MV</td>
<td>1.068</td>
<td>1.029</td>
<td>1.020</td>
<td>1.019</td>
</tr>
<tr>
<td>10 MV</td>
<td>1.073</td>
<td>1.038</td>
<td>1.026</td>
<td>1.026</td>
</tr>
<tr>
<td>18 MV</td>
<td>0.766</td>
<td>1.046</td>
<td>1.032</td>
<td>1.032</td>
</tr>
</tbody>
</table>

Fig. 5. Dose response non-linearity where each dose point was measured with a group of dosimeters (six TLDs, five RPLDs and four OSLDs). Data are normalized at the 2 Gy dose.

Table 2
Summary of uncertainty components of TLD, OSLD and RPLD systems.

<table>
<thead>
<tr>
<th>Uncertainty component</th>
<th>TLD system</th>
<th>OSLD system</th>
<th>RPLD system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type A</td>
<td>Type B</td>
<td>Type A</td>
</tr>
<tr>
<td>Calibration of the dosimetry system</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Determination of Co-60 dose from ionisation chamber readings</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Solid water to water dose correction</td>
<td>0.05</td>
<td>0.05</td>
<td>0.50</td>
</tr>
<tr>
<td>Dosimeter positioning during irradiation</td>
<td>0.03</td>
<td>0.07</td>
<td>0.12</td>
</tr>
<tr>
<td>Dosimeter readout(^a)</td>
<td>0.48</td>
<td>0.16</td>
<td>0.42</td>
</tr>
<tr>
<td>Individual dosimeter sensitivity factor</td>
<td>--</td>
<td>0.43</td>
<td>--</td>
</tr>
<tr>
<td>Dosimeter positioning during readout</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Combined standard uncertainty ((k – 1))</td>
<td>0.68</td>
<td>0.68</td>
<td>0.54</td>
</tr>
<tr>
<td>Determination of the absorbed dose from dosimeters</td>
<td>0.80</td>
<td>0.80</td>
<td>0.54</td>
</tr>
<tr>
<td>Calibration of the dosimetry system</td>
<td>0.60</td>
<td>0.50</td>
<td>0.68</td>
</tr>
<tr>
<td>Dosimeter readout(^a)</td>
<td>0.48</td>
<td>0.16</td>
<td>0.42</td>
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<tr>
<td>Individual dosimeter sensitivity factor</td>
<td>--</td>
<td>0.43</td>
<td>--</td>
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<tr>
<td>Dosimeter positioning during readout</td>
<td>--</td>
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<tr>
<td>Non-linearity dose response correction factor</td>
<td>0.90</td>
<td>0.70</td>
<td>0.55</td>
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<tr>
<td>Energy correction factors</td>
<td>0.95</td>
<td>0.82</td>
<td>0.81</td>
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<tr>
<td>Fading correction factor</td>
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<tr>
<td>Holder correction</td>
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<td>0.10</td>
<td>0.10</td>
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<tr>
<td>Combined standard uncertainty ((k – 1))</td>
<td>1.60</td>
<td>1.46</td>
<td>1.51</td>
</tr>
</tbody>
</table>

\(^a\) This component includes depletion uncertainty.
3.9. Uncertainties

The combined standard uncertainty associated with each dosimetry system in this study addresses individual components in the determination of the absorbed dose from dosimeters. All components are summarized in Table 2. The uncertainty in the calibration of the dosimetry systems in this study arise largely from the uncertainty in the ionization chamber calibration of 0.5%, solid water to water dose correction of 0.5% and then to a smaller extent from the reproducibility in the phantom positioning of 0.2% and dosimeter irradiation positions corrections (TLDs of 0.03%, OSLD 0.12% and for RPLD of 0.07%). In addition to this, there are the readout uncertainties (TLDs of 0.48%, OSLD 0.16% and for RPLD of 0.15%), SCF uncertainties (OSLD of 0.43% and 0.42% for RPLD) and dosimeter positioning during the readout applicable to RPLD only (0.42%). For clarity the calibration of the dosimetry system component is repeated in second part of Table 2 where uncertainty of determination of the dose from a user’s dosimeter is summarized, it includes contribution from each of the correction factors of Eq. (1). The quadratic summation of all components leads to an overall combined uncertainty of 1.60% for TLDs, 1.46% for OSLDs and 1.51% for RPLD. The uncertainty of 1.2% (Lye et al., 2014) and 1.8% (Aguirre et al., 2011) were determined for OSLD and are described in the literature. Lower uncertainty value of 1.1% was reported by (Mizuno et al., 2014) for RPLD dosimeters.

3.10. Practical considerations

When looking into the practical aspects of the commissioning and use of the dosimetry systems in this study, an advantage of RPL and OSL dosimeters is that the reading process is non-destructive and dosimeters can be read repeatedly. The OSLD system has an advantage of ease of operation and user-friendliness, whereas the TLD and RPLD systems require very careful handling procedures in order to achieve the adequate reading accuracy. When considering all associated procedures needed to perform an audit, the TLD system is labor intensive in routine use but the system commissioning process is simpler as the whole portion of TLD powder has the same characteristics and there is no need to determine individual sensitivity correction factors as is needed for the two other dosimetry systems types. The disadvantage of the OSLD system is relatively short useful life of dosimeters, where after a few irradiation/readout cycles, the dosimeters have to be replaced and new ones characterized for routine use. Both TLD and RPLD systems require stable environmental conditions, as changes in temperature and humidity affect the reader’s response. In addition, RPLD system should be kept in clean environment as dust particles located on the dosimeter during the readout can affect its response.

4. Conclusion

This work gives a direct comparison of three dosimetry systems characterized for use in large-scale remote audits of high energy photon beams applied in radiotherapy. To successfully use each system, characteristics must be quantified and appropriate correction factors determined and applied to the measurements. It was found that all three systems are appropriate for auditing purposes, with the overall uncertainty adequate for radiotherapy level audits. However, each audit methodology requires independent commissioning process directed for use with specific conditions and phantoms. The dosimetry systems tested within this work, were found to each have intrinsic advantages and disadvantages that take into account the quantitative parameters as well as the system complexity, user-friendliness and operator labour requirements.

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References