Journal of RADIATION INDUSTRY
Vol. 20, No. 2, pp. 129-137, 2026
https://doi.org/10.23042/radin.2026.20.2.129

Original article

Standardisation and Quality Assurance of Calibration and Correction Procedures for Radiophotoluminescent Glass Dosemeters

Shuai Wang[1], Zixuan Wang[1], Wenxuan Han[1], Mingyue Zhao[1], and Dae Cheol Kweon[2]

[1]Major in Radiological Science, Department of Health Technology Convergence, Graduate School, Shinhan University, Uijeongbu 11644, Republic of Korea
[2]Department of Radiological Science, College of Health, Shinhan University, Uijeongbu 11644, Republic of Korea

ABSTRACT Radiophotoluminescent (RPL) glass dosimeters are practical for routine monitoring because their stored signal can be read repeatedly and generally remains stable during storage. For routine laboratory use, however, reader output must be linked to a defined reference quantity, and the procedure should include checks to detect short-term changes in instrument behavior. In this study, the operating procedure for an FGD-1000-based RPL system was structured into separate steps for background subtraction, internal sensitivity correction, and absolute calibration. The workflow combined irradiations in a reference photon field with repeated measurements of dedicated control elements. The normalization value assigned to the standard irradiation glass was linked to the certified reference air kerma and used as the reader-displayed standardization value during calibration, enabling corrected reader signals to be converted in a consistent and traceable manner. Five calibration sessions were compared using the standard-glass signal, background level, internal correction term, and system scaling coefficient to evaluate short-term variation and establish tentative QC intervals. Under the fixed experimental conditions, the system scaling coefficient was 161.06 ± 0.94 (CV = 0.58%). Overall, the proposed procedure provides a practical basis for calibration documentation, trend monitoring, and traceable laboratory use of RPL glass dosimeters within an ISO/IEC 17025 framework.

Key words: Radiophotoluminescence, Glass dosimeter, Calibration, Quality assurance, ISO/IEC 17025

1. Introduction

Radiophotoluminescent (RPL) glass dosimeters are based on silver-activated phosphate glass in which irradiation creates stable luminescence centres [1]. Upon optical stimulation (typically by a UV laser), these centres emit radiophotoluminescence, enabling quantitative readout of accumulated dose [1-3]. Because the readout is non-destructive and fading is generally small, RPL dosimeters are well suited to personal and environmental monitoring and to dosimetry audit applications [4,5]. In radiotherapy, RPL glass detectors have been characterised in both low-energy photon beams and megavoltage photon/electron beams, underscoring the need for beam-quality considerations when converting readout to absorbed dose [6,7].

The RPL signal can exhibit post-irradiation build-up and may be affected by photobleaching; once the build-up is complete, Ag-doped phosphate glass has been reported to show high storage stability (typically <5% per year)[1]. Nevertheless, obtaining traceable dose estimates from an integrating passive detector requires more than detector stability: it requires a clearly defined reference quantity, irradiation geometry, and a documented calibration chain that links reader response (instrument units) to a physical quantity with stated uncertainty.

Signal stability alone does not make an RPL result suitable for reporting. Before a reading is treated as dose, the laboratory should define the reference field, radiation quality, exposure geometry, interval before readout, and the dosimetric quantity assigned to the calibrated value. For routine photon calibration, reference exposures are commonly set up with ISO 4037 conditions, while IEC 62387 and ISO 22127 give related expectations for passive integrating systems [4,5,8,9]. The reported quantity may be air kerma, personal dose equivalent, or absorbed dose to water, but that choice needs to be written explicitly in the calibration documentation. The same principle appears in

ISSN 1976-2402 **http://www.ksri.kr/**

Copyright© 2026 by Korean Society of Radiation Industry

***Corresponding author:** Dae Cheol Kweon
Tel: +82-31-870-3411, Fax: +82-31-870-3419, E-mail dckweon@shinhan.ac.kr
Received 23 March 2026 **Revised** 6 April 2026 **Accepted** 7 April 2026

retrospective glass-dosimetry work, where dose interpretation depends on well-documented signal behavior [10].

Routine operation also depends on whether short-term changes in the reader can be recognised and corrected before they influence reported doses. In the Dose Ace/FGD-1000 system, a standard irradiation glass is used for absolute scaling and a separate internal calibration glass is used to correct day-to-day sensitivity changes. Treating the system scaling coefficient (k) and the internal correction factor (C_{int}) as separate quantities, and recording the standard-glass signal, internal-glass signal, background, and k for each session, improves reproducibility and supports quality management consistent with ISO/IEC 17025. Recent commissioning studies for audit applications have similarly emphasised individual sensitivity correction and position/temperature corrections as ways to reduce uncertainty in larger measurement sets [2,3,11,12].

The aim of this paper is to standardise a calibration and correction procedure for an FGD-1000-based RPL system, to provide explicit computation equations linking reader response to a defined reference quantity, and to propose practical routine quality-control indicators that can be adopted in institutional standard operating procedures.

2. Materials and Methods

2.1. Materials

The overall RPL read-out principle and the conceptual energy-band model are shown in Fig. 1. A representative photograph of the RPL glass dosimeter elements and holders used in this study is presented in Fig. 2. The system used in this work was the Dose Ace platform (Chiyoda Technol, Tokyo, Japan), which employs silver-activated phosphate glass elements read with the FGD-1000 automatic reader [13]. Measurements were performed with GD-352M elements intended for low-energy photon use. This model includes a tin filter that suppresses over-response below about 100 keV and is therefore appropriate for the low-energy protection fields used in the present calibration study [13,14]. Manufacturer data describe the GD-352M sensing glass as a small cylindrical element, about 1.5 mm in diameter and 12 mm long; the reported effective atomic number is 12.04 and the density is 2.61 g/cm^3 [14]. In practical work, the same element is often read repeatedly and the mean of the repeated values is used for dose evaluation [15].

Within the QC design used in this study, two reference glasses were assigned separate roles. One element was irradiated to a known level and used to establish the absolute calibration relationship, whereas the other served as a routine internal check on short-term changes in reader output. To reduce handling-related scatter, these control glasses were kept apart from ordinary field elements and were taken out only during planned calibration or QC measurements. Reference glass dosimeters read in the same session as sample dosimeters can provide a practical correction

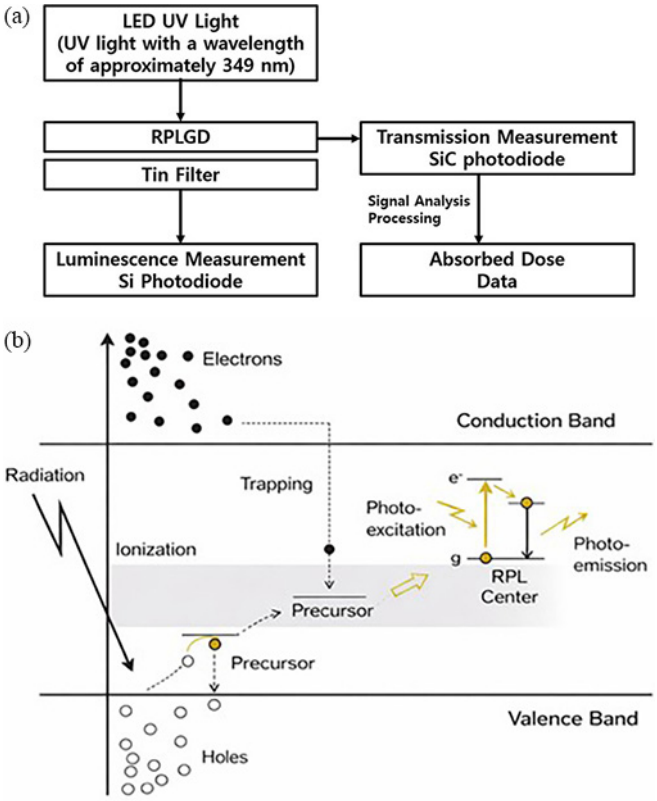

Fig. 1. (a) Schematic of the RPL readout system. (b) Schematic energy-band model for radiophotoluminescence (RPL). The diagram was redrawn based on the conceptual model presented by Yanagida *et al*. [1].

Fig. 2. Representative photograph of RPL glass dosimeter elements and holders prepared for measurement (background and standard/field elements); photograph acquired for this study.

for reader fluctuation; when glasses are stored for long periods without annealing, both fading and natural background dose accumulation should be considered in dose evaluation [16].

2.2. Methods

Absolute calibration was performed in a traceable ^{137}Cs reference photon field. The calibration record for this study defined the beam quality, target quantity, irradiation geometry, and reference-dose delivery conditions in accordance with the ISO 4037 framework. Air kerma (K_a) was selected as the calibration quantity, and the traceability chain was linked to the reference laboratory certificate, the calibration status of the ionization chamber/electrometer system, and the expanded uncertainty ($k=2$) stated for the delivered quantity at the dosimeter position. GD-352M dosimeters were calibrated in terms of air kerma in a ^{137}Cs reference gamma field (662 keV) using the FGD-1000 reader. The source-to-reference point distance was 100 cm, the field size at the reference plane was 10×10 cm², and orientation was kept constant. The reference K_a was determined with a traceably calibrated ionization chamber in free air, and the irradiation time was set to deliver $K_a=6$ mGy. Ten dosimeters were irradiated, and each dosimeter was read 10 times; the mean corrected response for each element was used for subsequent analysis. The irradiation environment, including room-scatter conditions, was documented as part of the calibration geometry description to maintain consistency with ISO 4037-1 requirements for reference irradiations.

Background signal R_{bg} was obtained from unirradiated controls. Corrected readout for dosimeter i was calculated as:

$$R_{i,corr} = (R_{i,raw} - R_{bg})\, ECF_i, \tag{1}$$

where ECF_i is the element correction factor. For the present reader workflow, the system scaling coefficient at the 6 mGy reference condition was determined from the corrected standard-glass response and the reader-displayed standardization value assigned during calibration:

$$k = \frac{N_{st}}{\bar{R}_{corr}} \tag{2}$$

where $\bar{R}_{corr}$ is the mean corrected readout of the irradiated dosimeters ($n=10$), and N_{st} is the reader-displayed standardization value associated with the standard irradiation glass during the calibration routine. In the present software environment, this displayed value was linked to the reference calibration setting used for the standard irradiation glass.

The uncertainty evaluation considered both irradiation-related and readout-related components. Contributions included the reference air-kerma value, source-to-detector distance, irradiation time, positioning accuracy, repeatability of the ten repeated reads, and variation among the ten irradiated dosimeters. When expanded uncertainty was reported, a coverage factor of $k=2$ was used.

For routine dose estimation, the calculation procedure involved three steps: subtraction of the background signal, correction for short-term reader sensitivity variation using the internal

Table 1. Integrated computation workflow for calibration, correction, and dose estimation in the present RPL glass dosimeter system

Step	Input / symbol	Operation	Equation(s)	Output
Raw readout acquisition	Raw element reading R_x; background reading R_{bg}	Measure the raw reader signal for the field element and the mean background signal under the same reading conditions.	Eq. (3)	Net signal $M_x = R_x - R_{bg}$
Reader sensitivity correction	Internal reference response m_c; baseline internal response $m_{c,0}$	Calculate the internal correction factor and apply it to the net field-element signal and standard-glass signal.	Eqs. (4)-(5)	$C_{int} = m_{c,0}/m_c$; corrected signals M'_x and M'_{st}
System scaling	Corrected standard-glass signal M'_{st}; reader-displayed standardization value N_{st}	Relate the corrected standard-glass response to the reader-displayed standardization value used in the calibration routine.	Eq. (6)	System scaling coefficient $k = N_{st}/M'_{st}$
Dose estimation	Corrected field-element signal M'_x; system scaling coefficient k	Convert the corrected field-element signal to the reader-referenced calibrated output within the software-defined standardization framework.	Eqs. (7)-(8)	Estimated dose $D_x = k \cdot M'_x = (N_{st}/M'_{st}) \cdot M'_x$
Repeat-read statistics	Repeated dose estimates $D_{x,i}$ ($i=1, ..., n$)	Summarize repeated readings for one element or one QC session using the mean, SD, and CV.	Eqs. (9)-(11)	Representative value $\bar{D}x$, SD, and CV

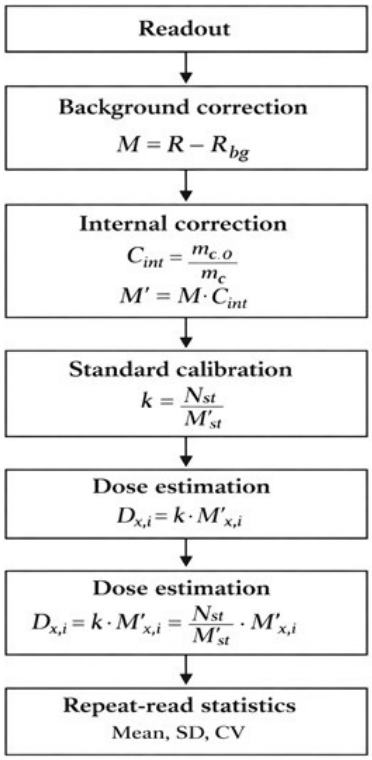

Fig. 3. Flowchart of the readout, background correction, internal sensitivity correction, standard calibration, dose estimation, and repeat-read statistics used in the present RPL glass dosimeter workflow.

reference element, and conversion of the corrected signal to dose with the absolute calibration factor obtained from the standard irradiation glass. The overall calculation process used in this study is summarized in Table 1, which presents the relevant inputs, correction steps, equations, and outputs in a single sequence. A schematic overview of the calibration, internal sensitivity correction, and dose calculation workflow is also provided in Fig. 3. First, the raw readout signal (R) was corrected for background to obtain $M = R - R_{bg}$. The background-corrected value was then adjusted using the internal sensitivity correction factor, defined as $C_{int} = m_{c,0}/m_c$, to yield the corrected readout $M' = M \cdot C_{int}$. The standard calibration factor was determined from the response of the reference glass as $k = N_{st}/M'_{st}$, where N_{st} is the stored reference value corresponding to the delivered reference quantity and $M_{st'}$ is the corrected readout of the standard glass. Using this calibration factor, the dose for each repeated readout was estimated as $D_{x,i} = kM_{x,i'} = (N_{st}/M'_{st})M_{x,i}$. Finally, repeatability was evaluated from the repeated dose estimates ($i = 1,\ldots,n$) using the mean, standard deviation (SD), and coefficient of variation (CV).

2.3. Equations for calibration and correction

2.3.1. Raw readout and background correction

Let the raw readout of an RPL glass element be denoted by R (counts or arbitrary units, a.u.). Using the background (unirradiated) readout R_{bg}, the net signal M is given by:

$$M_x = R_x - R_{bg} \tag{3}$$

Here, R_{bg} is defined as the mean background reading measured under identical conditions.

2.3.2. Internal calibration (sensitivity correction) factor

To compensate reader sensitivity drift (e.g., lamp intensity, optical chain and detector drift), the net signal of an internal calibration glass is denoted by m_c. Let $m_{c,0}$ be the internal calibration signal at the reference state; the internal correction factor C_{int} is:

$$C_{\mathrm{int}} = \frac{m_{c,0}}{m_c} \tag{4}$$

$$M'_x = C_{int} \cdot M_x \text{ and } M'_{st} = C_{int} \cdot M_{st} \tag{5}$$

In Table 2, m_c corresponds to the internal calibration glass net signal (or an equivalent instrument correction reference).

Table 2. Example standard calibration parameters (M'_{st}, m_c, N_{st}) from five repeated measurements. N_{st} denotes the reader-displayed standardization value used during the FGD-1000 calibration routine and may vary slightly between runs because of internal rounding or system state

	1	2	3	4	5	Mean
M'_{st}	6.515	6.548	6.532	6.534	6.499	6.526
m_c	5.268	5.284	5.280	5.276	5.276	5.277
N_{st}	1053	1047	1050	1050	1055	1051

2.3.3. System scaling coefficient using a standard irradiation glass

Let M'_{st} be the sensitivity-corrected net signal of the standard irradiation glass and N_{st} the reader-displayed standardization value associated with that glass during each calibration run. In the present workflow, the numeric value assigned to N_{st} was linked to the known reference air kerma delivered to the standard glass at the dosimeter position, but N_{st} itself was treated operationally as the reader-displayed standardization value used in the FGD-1000 calibration routine. Accordingly, the coefficient k was defined as a system scaling coefficient derived from the ratio N_{st}/M'_{st}. Because M'_{st} and M'_x are reader response values in instrument units (counts or arbitrary units, a.u.), k is interpreted here as a scaling coefficient within the software-defined calibration framework rather than as an independent physical calibration coefficient.

In practice, N_{st} is entered or stored as the numeric value of the reference quantity Q_{ref} delivered to the standard glass at the dosimeter position. In this study, Q_{ref} corresponds to the reference air kerma, $K_{a,ref}$, reported on the calibration certificate and expressed in μGy. The reader then displays this stored reference value as N_{st} for each calibration run. In the present software environment, N_{st} was treated operationally as the reader-displayed standardization value used in the standard calibration routine.

$$k = \frac{N_{st}}{M'_{st}} \tag{6}$$

Thus, when the corrected standard-glass signal is M'_{st}, k scales the system response to the reader-displayed standardization value N_{st}. Because M'_{st} and M'_x are reader-response values in instrument units (counts or arbitrary units, a.u.), k is interpreted here as a system scaling coefficient within the software-defined calibration framework rather than as an independent physical calibration coefficient.

2.3.4. Dose estimation for an unknown (field) element

For an unknown (field) element with sensitivity-corrected net signal M'_x, the estimated value D_x is obtained as follows. In the present formulation, D_x represents a calibrated reader-referenced output within the same standardization framework as N_{st}. If the result is to be reported as a directly traceable physical dosimetric quantity, the link between the software-defined standardization value and the certified reference quantity should be explicitly documented in the calibration record.

$$D_x = k \cdot M'_x \tag{7}$$

$$D_x = \left(\frac{N_{st}}{M'_{st}}\right) M'_x \tag{8}$$

Eq. (8) follows by substituting Eq. (6) into Eq. (7).

2.3.5. Representative value and variability indices for repeated readings

For n repeated readings of the same element producing $D_{x,i}$ ($i = 1,\ldots,n$), the mean and standard deviation are:

$$\bar{D}_x = \left(\frac{1}{n}\right)\sum_{i=1}^{n} D_{x,i} \tag{9}$$

$$SD = \sqrt{\frac{1}{n-1}\Sigma_{i=1}^{n}(D_{x,i} - \overline{D_x})2(D_{x,i} - \bar{D}_x)^2} \tag{10}$$

The coefficient of variation (CV) is computed as in Equation (11) (corresponding to mean, SD and CV in Table 3).

$$CV\ (\%) = 100 \cdot \frac{SD}{\bar{D}_x} \tag{11}$$

$$NC(t) = \frac{\bar{D}_x(t)}{\bar{D}_{x,baseline}} \tag{12}$$

Notation: R_x, R_{bg}, M_x, m_c, $m_{c,0}$, C_{int}, M'_{st}, N_{st}, k, and D_x follow the definitions given above. *Mx, M'x, and* M'_{st}, denote reader response values (counts or arbitrary units, a.u.). N_{st} denotes the reader-displayed standardization value used in the FGD-1000 standard calibration routine, rather than the delivered reference air kerma itself. Accordingly, $k = N_{st}/M'_{st}$ is interpreted in this study as a system scaling coefficient referenced to the software-defined standardization value.

Table 3. Summary of repeat-read results (mean, SD, CV, and NC) for the standard irradiation and background elements

	Mean	SD	CV (%)	NC
Standard irradiation (signal, a.u.)	7596	25.03	0.33	1.03
Background (signal, a.u.)	1540	6.7	0.44	1.03

Note: NC is the normalization coefficient (dimensionless) set in the reader software; it was kept constant (NC = 1.03) for both standard and background during the repeat-read test.

Table 4. Derived system scaling coefficient (k) and internal sensitivity correction factor (C_{int}) from the five repeated readings in Table 2

Repeat	k	C_{int}	Normalized k
1	161.63	1.0017	1.0035
2	159.90	0.9987	0.9928
3	160.75	0.9994	0.9981
4	160.70	1.0002	0.9978
5	162.33	1.0002	1.0079
Mean±SD (CV%)	161.06±0.94 (0.58%)	1.0000±0.0011 (0.11%)	1.0000

2.4. Data processing and statistics

Repeat-read tests were performed by measuring the same element multiple times under fixed reader settings. Mean, SD, and CV were calculated using Eqs. (9)-(11). For longitudinal QC, a normalization coefficient (NC) can be treated as a relative index against a baseline mean and plotted over time to reveal gradual drift or abrupt change.

3. Results

The five repeated calibration checks showed highly consistent standard-glass and internal-reference responses (Table 2). For the standard irradiation glass, M'_{st} ranged from 6.499 to 6.548 a.u., with a mean of 6.5256±0.0189 a.u. (CV=0.29%). The internal reference response, mc, ranged from 5.268 to 5.284 a.u., with a mean of 5.2768±0.0059 a.u. (CV=0.11%). The reader-stored reference quantity value, N_{st}, ranged from 1,047 to 1,055 μGy, with a mean of 1,051±3.08 μGy.

Across the five repeated calibration checks, the system scaling coefficient k ranged from 159.90 to 162.33, with a mean of 161.06±0.94 (CV=0.58%). The internal sensitivity correction factor C_{int} ranged from 0.9987 to 1.0017, with a mean of 1.0000 ± 0.0011 (CV=0.11%) (Table 4). Based on the t distribution for n=5, the 95% confidence interval for k was 159.90-162.22. The normalised scaling coefficient ranged from 0.9928 to 1.0079 and showed only minor variation among the five calibration checks.

Repeat-read testing also showed low dispersion for the signal and background elements (Table 3). The standard irradiation element yielded a mean signal of 7,596 a.u. with an SD of 25.03 (CV=0.33%), whereas the background element yielded a mean of 1,540 a.u. with an SD of 6.7 (CV=0.44%).

4. Discussion

The present results support the practical use of RPL glass dosimeters in monitoring programmes where repeat readout and low signal loss during storage are advantageous [1-4]. At the same time, reliable reporting depends on how consistently the entire measurement chain is managed, not solely on the inherent properties of the glass. In routine work, small changes in lamp output, detector gain, alignment, or environmental conditions can shift the reader response even when the detector itself is unchanged. A useful control strategy therefore separates two tasks: maintaining traceability to the reference field and checking short-term behavior of the reader. In this study, traceability was anchored by periodic calibration in a defined reference field, whereas session-to-session drift was followed with an internal reference element [8,9]. Recording both quantities over time makes it easier to recognize abrupt changes after service work and slower drift during routine operation.

In the reader software used in this study, the delivered standard irradiation dose and the displayed standardization value were treated as separate quantities; accordingly, the present workflow distinguishes the documented reference irradiation condition from the internal scaling value used in the reader calculation. Because the monitoring period was limited, the present QC results should be regarded as preliminary local control data rather than as general acceptance limits.

In particular, the mean±3SD ranges shown in Table 5 were based on only five repeated calibration checks performed under a single beam quality (^{137}Cs), a single delivered dose level, one readout protocol, and one reader-dosimeter configuration. For this reason, these ranges are more appropriately interpreted as provisional control values for the current laboratory setting and should not be directly applied to other institutions or measurement conditions. Laboratories operating under different irradiation geometries, dose levels, dosimeter batches, readout timing, environmental conditions, or correction procedures should define their own warning and action limits on the basis of longer-term QC records. Even so, the five calibration checks

Table 5. Results of five repeat calibration checks used as short-term QC indicators; the last column shows the provisional in-house reference interval defined as mean±3SD

QC item	Mean	SD	CV (%)	Min-max	Mean ± 3SD reference
Standard glass response, M'_{st} (a.u.)	6.5256	0.0189	0.29	6.4990-6.5480	6.4688-6.5824
Internal reference response, m_c (a.u.)	5.2768	0.0059	0.11	5.2680-5.2840	5.2590-5.2946
System scaling coefficient, k	161.06	0.94	0.58	159.90-162.33	158.24-163.88
Internal correction factor, C_{int}	1.0000	0.0011	0.11	0.9987-1.0017	0.9966-1.0034

Table 6. Example relative standard uncertainty components for one reference irradiation condition (1σ terms)

Component	Type (A/B)	Source for estimate	u_i (%, 1σ)	c_i	$u_i c_i$ (%, 1σ)
Reference irradiation condition / delivered air kerma (certificate)	B	Certificate U (k=2); use u=U/2	1.00	1	1.00
Readout repeatability (k or scaled output)	A	Repeat-read CV (Table 4)	0.60	1	0.60
Reader drift correction (C_{int})	B	Internal calibration SD (Table 4)	0.11	1	0.11
Background subtraction (R_{bg})	B	BG SD at dose level (Table 3)	0.30	1	0.30
Positioning / geometry reproducibility	B	Alignment, SDD, build-up	0.50	1	0.50
Element correction / inter-element variability	B	Residual after ECF / batch	0.70	1	0.70
Beam-quality / angle dependence	B	If field differs; otherwise 0	0.50	1	0.50

Note: Type A components were evaluated from repeated measurements, whereas Type B components were estimated from non-statistical sources. For the certificate-based term, U (k=2) was converted to u using u=U/2. u_i is the relative standard uncertainty, c_i the sensitivity coefficient, and $u_i c_i$ the corresponding contribution to the final result.

showed close agreement, and the main QC variables varied by about 1% or less between sessions. If repeated measurements fall outside the provisional mean±3SD ranges, or show a persistent trend toward those limits, a reasonable local response would be to repeat the readout and review the background response, internal reference response, positioning, and reader status before reporting field-dose results. If the deviation persists after these checks, recalibration or instrument maintenance may be considered and documented in the laboratory SOP.

Calibration of glass dosimeters in a 137Cs reference field has also been described in earlier dosimetric work, supporting the practical relevance of the present irradiation arrangement [17]. The possible contribution of scattered radiation to ISO 4037 reference fields has also been discussed in previous work, which supports the need to document room-scatter conditions as part of the calibration geometry [18].

The effect of beam quality should also be considered whenever the RPL glass is used in photon fields that do not match the calibration spectrum. Differences in spectral composition, angle of incidence, or scatter surroundings can change the relationship between the calibrated reader response and the quantity ultimately being estimated. Under such conditions, additional correction factors or a field-specific calibration may be required, particularly when the calibration quantity differs from the reported operational quantity, for example, when an absorbed-dose calibration is applied to H_p (10) or H_p (0.07) [6,7,19]. For this reason, reports that compare institutions or studies should identify the calibration quantity, the reference radiation field, and any extra corrections used during dose assessment.

In addition, previous work has shown that the build-up behavior of radiophotoluminescent glass dosimeters can vary with X-ray exposure time, indicating that the timing of post-irradiation readout should be standardized and documented as part of the laboratory procedure [20]. If measurement has to be performed before the signal is fully stabilised, controlled heating may be used to reduce the waiting period. For reusable FD-7-type glasses, conventional annealing near 380-400°C followed by slow cooling may be inconvenient in day-to-day laboratory practice and can increase handling demands. Recently reported UV-based reset techniques may therefore provide a practical alternative for repeated-use workflows [21].

A further issue in routine practice is the exposure history of each individual glass element. Although repeated readout is feasible, cumulative absorbed dose, reuse history, and element-to-element differences may gradually influence response behavior [12,22]. For that reason, laboratories should maintain element-level records for cumulative exposure, number of reuse

cycles, and any annealing or reset procedures applied. Glass elements showing unstable response, unsatisfactory repeatability, or unusually high background should be set aside from routine measurements until their performance has been checked again against the laboratory acceptance rules.

The procedure can be strengthened further by attaching a concise uncertainty budget that separates Type A and Type B contributions as illustrated in Table 6. Using the repeat-read data in this paper as an illustration, and assuming a 1.0% standard uncertainty for the delivered reference quantity, the minimum combined standard uncertainty for D_x under the same beam quality and geometry is about 1.6%, which corresponds to an expanded uncertainty of roughly 3.1% for $k=2$. When the method is applied to different energies, angular conditions, or mixed and strongly scattered fields, extra terms associated with beam-quality dependence should be added and the budget should be revised for that application [8,9,11,14].

5. Conclusion

This study evaluated a calibration and routine quality-control procedure for an FGD-1000-based RPL glass dosimeter system. Under a single ^{137}Cs calibration condition ($K_a=6$ mGy, SDD = 100 cm, field size 10×10 cm^2), repeated calibration checks gave a mean system scaling coefficient of 161.06 ± 0.94 (CV = 0.58%) and an internal correction factor of 1.0000 ± 0.0011 (CV = 0.11%). The integrated calculation workflow added in this revision also makes the procedure easier to follow by presenting the variables and equations in a single sequence. These findings support the use of the proposed procedure and QC indices as provisional local in-house references for routine calibration documentation, short-term trend checking, and consistent application of the reader-defined calibration framework. However, the control limits presented here should be regarded as preliminary local values until they are confirmed over a longer follow-up period and under additional beam qualities and operating conditions.

References

1. Yanagida T, Okada G, Kato T, Nakauchi D and Kawaguchi N. 2022. A review and future of RPL dosimetry. *Radiat Meas* **158**:106847. https://doi.org/10.1016/j.radmeas.2022.106847.
2. Chiyoda Technol Corporation. n.d. *Dose Ace: RPL Glass Dosemeter/Small Element System (GD-300 Series; Reader FGD-1000).* Product documentation.
3. PTW-Freiburg. n.d. *Dose Ace System: RPL Glass Dosimetry Equipment (D741.219.0/0) and commissioning materials.*
4. ISO. 2019. *Dosimetry with radiophotoluminescent glass dosimeters for dosimetry audit in MV X-ray radiotherapy. ISO 22127:2019.* Geneva: International Organization for Standardization.
5. IEC. 2020. *Radiation protection instrumentation - Dosimetry systems with integrating passive detectors for individual, workplace and environmental monitoring of photon and beta radiation. IEC 62387:2020.* Geneva: International Electrotechnical Commission.
6. Araki F and Ohno T. 2014. The response of a radiophotoluminescent glass dosimeter in megavoltage photon and electron beams. *Med Phys* **41**(12):122102. https://doi.org/10.1118/1.4901639.
7. Kadoya N, Shimomura K, Kitou S, Shiota Y, Fujita Y, Dobashi S, Takeda K, Jingu K, Matsushita H, Namito Y, Ban S, Koyama S and Tabushi K. 2012. Dosimetric properties of radiophotoluminescent glass detector in low-energy photon beams. *Med Phys* **39**(10):5910-5916. https://doi.org/10.1118/1.4747261.
8. ISO. 2019. *Radiological protection — X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy — Part 1: Radiation characteristics and production methods. ISO 4037-1:2019.* Geneva: International Organization for Standardization.
9. ISO. 2019. *Radiological protection — X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy — Part 3: Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence. ISO 4037-3:2019.* Geneva: International Organization for Standardization.
10. Marciniak A, Juniewicz M, Ciesielski B, Prawdzik-Dampc A and Karczewski J. 2022. Comparison of three methods of EPR retrospective dosimetry in watch glass. *Front Public Health* **10**:1063769. https://doi.org/10.3389/fpubh.2022.1063769.
11. ISO/IEC. 2017. *General requirements for the competence of testing and calibration laboratories. ISO/IEC 17025:2017.* Geneva: International Organization for Standardization.
12. Dimitriadis A, Kazantsev P, Titovich E, Ule-Duque G, Abdulrahim R, Magnus T, Azangwe G and Swamidas J. 2024. An efficient protocol for commissioning radiophotoluminescence dosimeters for radiotherapy dosimetry audits. *Radiat Meas* **177**:107268. https://doi.org/10.1016/j.radmeas.2024.107268.
13. Moon YM, Kim HJ, Kwak DW, Kang YR, Lee MW, Ro TI, Kim JK and Jeong DH. 2014. Effective dose measurement for cone beam computed tomography using glass dosimeter. *Nucl Eng Technol* **46**(2):255-262. https://doi.org/10.5516/NET.08.2012.080.
14. Kim JS, Park BR, Yoo J, Ha WH, Jang S, Jang WI, Cho GS, Kim H, Chang I and Kim YK. 2022. Measurement uncertainty analysis of radiophotoluminescent glass dosimeter reader system based on GD-352M for estimation of protection quantity. *Nucl Eng Technol* **54**:479-485. https://doi.org/10.1016/j.net.2021.08.016.
15. Ryu JC, Yoon JT, Kim BJ, Kim MH, Moon EJ, Suh PS, Roh YH, Moon HH, Kwon B, Lee DH and Song Y. 2023. Reduction of Radiation Dose to Eye Lens in Cerebral 3D Rotational Angiography Using Head Off-Centering by Table Height Adjustment: A Prospective Study. *Korean J Radiol* **24**(7):681-689. https://doi.org/10.3348/kjr.2023.0169.
16. Park KY, Kim HC and Kim BC. 2023. A formalism for the absorbed dose evaluation of the glass dosimeter. *Nucl Eng Technol* **55**:2283-2287. https://doi.org/10.1016/j.net.2023.03.014.

17. Moon YM, Rhee DJ, Kim JK, Kang YR, Lee MW, Lim H and Jeong DH. 2013. Reference dosimetry and calibration of glass dosimeters for Cs-137 gamma-rays. *Prog Med Phys* **24**(3):140-144. https://doi.org/10.14316/pmp.2013.24.3.140.
18. Qian YK, Liu YX, Mao BJ, Zhang S, Liu Y and Feng P. 2022. Research on the relationship between the scattering contribution and physical factors of the reference radiation regulated by ISO 4037-1. *PLoS One* **17**(12):e0279188. https://doi.org/10.1371/journal.pone.0279188.
19. Hashimoto S, Nakajima Y, Kadoya N, Abe K and Karasawa K. 2019. Energy dependence of a radiophotoluminescent glass dosimeter for HDR 192Ir brachytherapy sources. *Med Phys* **46**(2):964-972. https://doi.org/10.1002/mp.13304.
20. Kweon DC. 2017. Buildup characteristics of radiophotoluminescent glass dosimeters with exposure time of X-ray. *J Biomed Eng Res* **38**(5):256-263. https://doi.org/10.9718/JBER.2017.38.5.256.
21. Aghabaklooei S and Yasuda H. 2025. UV-annealing method for initializing FD-7 radiophotoluminescent glass as an alternative to thermal annealing. *Radiat Meas* **189**:107525. https://doi.org/10.1016/j.radmeas.2025.107525.
22. Kim DW, Sung J, Son J, Shin HB, Kim MJ, Noh YY, Kim H, Han MC, Kim J, Han SC, Chang KH, Kim H, Park K, Yoon M, Kim J and Shin D. 2020. Sensitivity of radio-photoluminescence glass dosimeters to accumulated doses. *PLoS One* **15**(12):e0234829. https://doi.org/10.1371/journal.pone.0234829.