Performance of a radiophotoluminescence (RPL) system in environmental and area monitoring

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ABSTRACT

The objective of this work was to perform an extensive side-by-side comparison between a radiophotoluminescence (RPL) dosimetry system and thermoluminescent dosimeters (TLDs) or EDIS-1™ Environmental Direct Ion Storage Dosimeters during environmental and area monitoring. The measurement locations include points around and within the perimeter of the Paul Scherrer Institute (PSI) and nearby facilities. These data are complemented by a study on the RPL detection limit, uncertainty and dose linearity, as well as two intercomparisons of environmental dosimeters, a Swiss intercomparison organized by PSI and an international intercomparison organized by the German National Metrology Institute (Physikalisch-Technische Bundesanstalt, PTB, Germany). The laboratory irradiations show that the detection limit of the RPL dosimeters is $<$ 50 μSv if the time between pre-dose measurement and readout is $<$ 200 days, and the response is linear up to at least 100 mSv with less than 15% deviation from linearity, satisfying the requirements of the Swiss dosimetry ordinance. The RPL doses were more consistent than the TLD doses over time. The RPL system shows slightly lower doses (12–14%) in comparison with EDIS-1 dosimeters. The intercomparisons for passive environmental dosimeters in terms of $H^*(10)$ showed a good agreement between the RPL dose values and the conventional true values. Altogether, the results demonstrate the equivalence between RPL and the other dosimetry systems, providing support for the RPL adoption for environmental dosimetry.

1. Introduction

Radiophotoluminescence (RPL) dosimeters based on Ag⁺-doped phosphate glasses are now commercially used for dosimetry worldwide (Miyamoto et al., 2011), having been adopted in Europe by the Institute for Radiological Protection and Nuclear Safety (Institut de radioprotection et de Sûreté Nucléaire, IRSN, France) and the International Atomic Energy Agency (IAEA). The system is used for individual monitoring since 2016 by the accredited Dosimetry Laboratory of the Paul Scherrer Institute (PSI). Assenmacher et al. (2017) presented the commissioning data of the system in terms of the operational personal dose equivalent $H_p(10)$, showing that it satisfies the requirements of the Swiss Ordinance of the Federal Department of Home Affairs (EDI) on Personal and Environmental Dosimetry (hereafter called “Swiss dosimetry ordinance”) (Swiss Federal Council, 2017).

The RPL is based on the UV-induced photoluminescence signal due to luminescence centers (Ag⁰ and Ag⁺) created in Ag⁺-doped phosphate glass upon exposure to ionizing radiation (Miyamoto et al., 2011). The badge design used at PSI, IRSN and IAEA (GBFJ-01) consists of a holder containing five different filter types, which define five areas in the glass detector with different photon energy responses read out by an automated reader (Hocine et al., 2011; Hocine, 2012; Assenmacher et al., 2017). These five signals are combined using a proprietary linear algorithm to calculate the operational quantities $H_p(10)$, $H_p(0.07)$, and $H^*(10)$.

For environmental dosimetry, however, the GBFJ-01 badge design is not necessarily appropriate because of the non-isotropic response. Assenmacher et al. (2017) showed that the $H_p(10)$ angle dependence for S-Cs (Cs-137) and N-80 radiation qualities (ISO, 1999) does not deviate by more than 20% for angles up to 60°. For environmental dosimetry, however, the angle dependence needs to be verified for the operational quantity ambient dose equivalent $H^*(10)$. Furthermore, environmental dosimeters are required to be tested up to larger angles than personal dosimeters, both according to the Swiss dosimetry ordinance and the international standard IEC 62387 (IEC, 2020).

Limited information is available on the applicability of the RPL system for environmental and area monitoring. A previous study on a different environmental RPL dosimetry system reports on characteristics such as batch homogeneity, reproducibility, linearity, detection limit, energy dependence and UV sensitivity (Ranogajec-Komor et al., 2008), but the applicability of those results is limited: firstly, it does not necessarily apply to the dosimetry system used at PSI, IRSN and IAEA; secondly, the results are not presented in terms of $H^*(10)$ and the angle dependence was not investigated.

To fill this knowledge gap, the energy and angle dependence of the $H^*(10)$ for the dosimetry system consisting of the glass type FD-7, GBFJ-
01 badge, FGD-660 reader and CDEC-Easy software (Chiyoda Technol Corp.) was investigated (Assenmacher et al., 2020). Although the energy dependence was shown to satisfy both the Swiss dosimetry ordinance and the IEC 62387, the response for angles close to 90° exceed the limits of the Swiss dosimetry ordinance (±20%) for the N-80 radiation quality. Regarding the IEC 62387 standard, the response at 90° shall be determined by rotating the dosimeter 360° around the reference direction of the dosimeter or by eight irradiations rotated by 45° each. In this “full rotation” scenario, the response of the RPL dosimeters was within the limits of the IEC 62387. At 75° irradiation for the N-80, however, the response was still outside the requirements of the IEC 62387.

Nevertheless, the environmental radiation is typically non-directional and characterized by a broad photon energy spectrum (Tereda et al., 1980). Therefore, the angle dependence investigated in laboratory with directional irradiation at low energies may not be relevant for practical environmental and area monitoring, except in the case of an unexpected low energy irradiation at angles close to 90°. For this reason, it is important to carry out a side-by-side comparison between the RPL dosimetry system and other dosimetry systems used for environmental and area monitoring, to demonstrate the equivalence of RPL in realistic conditions.

PSI’s Dosimetry Laboratory performs routine environmental and area monitoring within and outside PSI’s perimeter and in the vicinity of various other facilities, including at the fence of the Beznau nuclear power plant and the central interim storage facility Zwilag (Zwilag Zwischenlager Würenlingen AG). Because of the diversity of dose rates and energy spectra in the various measurement points, this monitoring network offers a perfect opportunity to perform this comparison between RPL and other techniques. Outside PSI’s perimeter the radiation field is dominated by cosmic and terrestrial natural radiation (typically ~0.6 mSv/year). Inside PSI’s perimeter, the radiation field can be increased due to radiation from the various accelerator facilities, generated by bremsstrahlung with energies up to hundreds of MeV or a few GeV, depending on the accelerator, as well as prompt gamma radiation due to nuclear reactions and activation of the shielding components. In monitored points within sealed off areas the photon dose can reach values >10 mSv/year.

To demonstrate the feasibility of using RPL for environmental dosimetry for the direct applications at PSI, since 2017 we have carried out a side-by-side comparison between the RPL dosimetry system and other dosimetry systems, including Al₂O₃:C, TLDs and EDIS-1™ Environmental Direct Ion Storage Dosimeters. In addition, we participated in two intercomparison for environmental dosimeters, a Swiss intercomparison organized by PSI, and an international intercomparison organized by the Physikalisch-Technische Bundesanstalt (PTB, Germany) (Dombrowski, 2019).

In this paper we report representative results of this extensive side-by-side comparison between the RPL system and the TLD or EDIS-1™ Environmental Direct Ion Storage Dosimeters. In addition, we participated in two intercomparisons for environmental dosimeters, a Swiss intercomparison organized by PSI, and an international intercomparison organized by the Physikalisch-Technische Bundesanstalt (PTB, Germany) (Dombrowski, 2019).

2. Materials and methods

2.1. Dosimetry systems

The RPL dosimetry system used in this study is described in Table 1. Before use, the RPL glass detectors were regenerated and the pre-dose (PD) signal of the detector (intrinsic background signal) was read and automatically stored in the database. The RPL glass detectors were then assembled in the badges and stored in the laboratory until deployment. After deployment, the RPL dosimeters were disassembled and the RPL glass detectors were pre-heated for 1 h at 100 °C to accelerate the build-up process of the RPL signal and then read out. Two identical RPL readers were available for these studies.

### Table 1 Luminescence dosimetry systems used in this study.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RPL</th>
<th>TLD (Al₂O₃:C)</th>
<th>TLD (LiF:Mg,Ti)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector</td>
<td>FG-7 Ag-doped phosphate glass detectors (35 mm × 7 mm)</td>
<td>Al₂O₃:C single crystal (5 mm diameter × 0.9 mm thickness)</td>
<td>LiF:Mg,Ti pellet (4.5 mm diameter × 0.9 mm thickness)</td>
</tr>
<tr>
<td>Dosimeter</td>
<td>FB3J-01</td>
<td>ALNOR-type with 2 detectors</td>
<td>ALNOR-type with 3 detectors</td>
</tr>
<tr>
<td>annealing</td>
<td>370 °C/10 min for regeneration</td>
<td>310 °C for 15 s in reader</td>
<td>305 °C for 10 s in reader</td>
</tr>
<tr>
<td>Readout</td>
<td>–</td>
<td>265 °C for 12 s</td>
<td>305 °C for 10 s</td>
</tr>
<tr>
<td>Readers</td>
<td>FGD-660 (two identical readers)</td>
<td>DOSACUS</td>
<td>DOSACUS</td>
</tr>
<tr>
<td>calculation</td>
<td>CDEC-Easy</td>
<td>Average of two detectors, corrected for individual detector sensitivity</td>
<td>Average of three detectors, corrected for individual detector sensitivity</td>
</tr>
<tr>
<td>software/method</td>
<td></td>
<td></td>
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</tbody>
</table>

The TLD dosimetry system used in this study is part of the ISO/IEC 17025 (ISO/IEC, 2017) accredited system from the Paul Scherrer Institute (accreditation number STS 0491, Swiss Accreditation Service SAS) and is described in Table 1. Because of their high sensitivity, Al₂O₃:C detectors are used in the environmental dosimeters and in area dosimeters outside controlled areas, whereas LiF:Mg,Ti detectors are used inside controlled areas, where the dose limits are higher. The TLDs were regenerated approximately 14 days before deployment. For each data point, the same TLD is used in alternating quarters (e.g., 2018Q01, 2018Q03, 2019Q01, 2019Q3, etc.). The glow curves and integral values are stored in a database to be processed later. Auxiliary TLDs (AUSD) were used to estimate the dose accumulated while in storage after the reset and before deployment. The TLD readout is performed typically the day after return of the dosimeters.

The EDIS-1™ Environmental Direct Ion Storage Dosimeters are commercialized by Mirion Technologies, Inc.

2.2. Dose calculation algorithm

The RPL dose calculation was performed using one of the dose calculation algorithms included in the software CDEC-EASY. The selected algorithm calculates H*(10) without background subtraction, only subtraction of the pre-dose (PD) value read after regeneration. The dose is, therefore, the total dose since the PD measurement.

For the environmental and area monitoring, the ambient dose equivalent rate during storage in the laboratory, estimated as 1.9 μSv/day at PSI based on historical data and confirmed here (see Section 3.1), was subtracted from the measured values using:

\[ M = H_{10X} - 1.9 \frac{\mu Sv}{day} \times (T_d - d) \]  

(1)

where \( M \) is the final (background subtracted) estimate for the dose equivalent \( H^{*}(10) \), \( H_{10X} \) is the RPL indicated value in terms of \( H^{*}(10) \) calculated by CDEC-EASY, \( T_d \) is the total number of days between the pre-dose measurement and the detector readout, \( d \) is the number of days the detector was deployed. For the intercomparisons no subtraction was done, since the dose transport and storage doses were evaluated using transport detectors.

For the study of the detection limit, uncertainties and dose response, the detectors were evaluated in terms of \( H_{6}(10) \) without subtraction of the background. This study was performed in terms of \( H_{6}(10) \) because it was part of a characterization of the RPL system for personal dosimetry. Nevertheless, the difference between the \( H_{6}(10) \) and \( H^{*}(10) \) calculation algorithm is only ~12% and, therefore, the results are approximately...
The TLD doses are calculated as the average dose of two or three detector elements (see Table 1), corrected by the individual element sensitivity. The calibration factor is determined using calibration detectors irradiated using Cs-137 with $H^*(10) = 1.25$ mSv in case of $\text{Al}_{2}O_{3}$:C TLDs and $H^*(10) = 2.5$ mSv in case of $\text{LiF}:\text{Mg,Ti}$ TLDs. The dose due to the period between the dosimeter’s regeneration and start of the deployment is subtracted using the AUSD dosimeters, prepared together with the routine dosimeters, but read when the deployment begins.

Here the indicated values of the systems are also referred to as “RPL doses”, “TLD doses” or “EDIS-1 doses”.

### 2.3. Calibration and laboratory irradiations

The RPL and TLD systems used in this study are calibrated at PSI’s Calibration Laboratory using a Cs-137 source. The source calibration is traceable to the primary standards at the PTB (Germany) and has a relative uncertainty (coverage factor $k = 2$) of the irradiated dose values in the range from 3.4% to 3.9%. The EDIS-1 detectors are calibrated by the manufacturer (Mirion Technologies). In the case of the RPL, the entire system is calibrated every quarter using calibration dosimeters. In the case of TLDs, calibration detectors are irradiated in the middle of the monitoring interval to account for the possible fading.

Additional laboratory irradiations were carried out at PSI’s Calibration Laboratory to characterize the dose response, uncertainties involved, and detection limits. Various RPL glasses were used for each dose as specified in the text and the dosimeters were read various times after irradiation. As mentioned in Section 2.2, in these studies the dosimeters were irradiated on phantom with Cs-137 in terms of $H_p(10)$ (on phantom) with 2 mm PMMA build-up and with doses values ranging from 0.010 mSv to 100 mSv. Unirradiated detectors were also used. The readouts (after pre-heating) were carried out at various times after the irradiation.

### 2.4. Environmental and area monitoring network

The environmental monitoring network of PSI includes ~35 measurement points outside PSI’s perimeter, up to almost 10 km distant from PSI. These are complemented by ~42 points inside PSI’s perimeter or at the fence, as well as ~22 points at the fence of nearby facilities (Beznau nuclear power plant and Zwilot). These were measured using $\text{Al}_{2}O_{3}$:C TLDs and RPL dosimeters.

Area dosimeters (inside PSI’s perimeter) outside controlled areas consisted of $\text{Al}_{2}O_{3}$:C TLDs and RPL dosimeters. Because of the low doses in these points, the results are similar to the environmental monitoring network described above and will not be presented. Area dosimeters inside controlled areas were carried out using $\text{LiF}:\text{Mg,Ti}$ TLDs and RPL dosimeters installed in wooden boxes with a transparent plastic cover affixed to the wall inside the buildings. The reference levels are 80 mSv/year for permanent workplaces, 200 mSv/year for temporary workplaces; locked-off areas have no reference levels. These reference levels were established considering the occupancy of the areas and the occupational dose limits for radiation workers of 20 mSv/year.

In addition to the environmental and area monitoring of PSI, measurements were also carried out using $\text{Al}_{2}O_{3}$:C TLDs from PSI in parallel with the EDIS-1 dosimeters used routinely by the Leibstadt nuclear power plant (Kernkraftwerk Leibstadt, KKL) in their environmental monitoring program.

### 2.5. Intercomparisons

#### 2.5.1. Swiss intercomparison 2016

The Swiss intercomparison was organized by PSI’s Calibration Laboratory under commission of the Swiss Federal Nuclear Safety Inspectorate (ENS) in agreement with the Swiss Federal Office of Public Health (FOPH). PSI’s Dosimetry Laboratory was an independent participant in the intercomparison and was not involved in its organization. The intercomparison included passive detectors (TLD, RPL) from three institutions, as well as active detectors and spectrometers (ionization chambers, Geiger-Müller counters and high-purity germanium detectors) from a total of nine institutions.

The passive dosimeters were exposed in a reference location at PSI for a period of six months in 2016. Irradiations were also carried out in laboratory with Cs-137 at two dose levels, one typical for environmental dosimeters (0.3 mSv) and a higher dose to check the calibration of the dosimeters (1.7 mSv). Transport detectors were also used and stored in a lead shielding for the period the other dosimeters were exposed in the field. The dose in the lead shielding was provided by the organizers and subtracted from the measured values.

The dose for the field irradiation was estimated using a pressurized ionization chamber. RSDetection (model RS-131-S131-200) from the PSI’s Calibration Laboratory, calibrated in the PTB reference fields for the ambient dose equivalent rate $dH^*(10)/dt$ for photon energies between 65 keV and 6700 keV.

#### 2.5.2. IC2017prep intercomparison

The objective of the IC2017prep intercomparison, which took place between October 2017 and April 2018, was to evaluate passive $H^*(10)$ dosimeters that could be used in the aftermath of a radiological or nuclear event. The dosimeters were exposed in two reference sites of the PTR: a free field (terrestrial and secondary cosmic radiation) and a free-floating platform (secondary cosmic radiation). In addition, irradiations were performed with Cs-137 at 0° and 90°. Transport detectors were stored in a lead shielding at an underground facility, where the accumulated dose for a 6-month period is ~0.5 μSv only. For a complete detail of the intercomparison, please see Dombrowski (2019).

### 3. Results

#### 3.1. Dose response and detection limit

To demonstrate the ability of the RPL detectors to measure the low doses involved in environmental dosimetry and their uncertainties, we first analyzed twenty RPL detectors that were annealed and stored in the laboratory for a period of up to ~270 days. The same detectors were read repeatedly at different periods (pre-heated only the first time), in some cases with two identical readers, here called reader 1 and reader 2, in the same day.

Fig. 1a shows the indicated value of the dosimeters as a function of the time interval since the PD measurement. The indicated value follows essentially the line corresponding to a dose rate of 1.9 μSv/day, which corresponds to the estimated background radiation level at PSI. A broadening of the response with time within the dosimeters was observed, but the reason for this broadening is unclear. Previous data has shown that the coefficient of variation for glasses is below 2.0% for doses >0.5 μSv (Assenmacher et al., 2017), whereas the coefficient of variation in Fig. 1a is ~4.0% for the highest doses. Therefore, this broadening can only be partially explained by difference in glass sensitivities.

Subtracting the fixed dose of 1.9 μSv/day from the data, we obtain the background-subtracted doses shown in Fig. 1b, where the black data points are for the measurements obtained using reader 1 and the red data points are for the measurements obtained using reader 2. The readouts with two identical RPL readers were performed to demonstrate the equivalence of the readers. For short periods the intra-day variation (detector-to-detector variability) is small, but there is a large inter-day variation. This suggests that for short intervals the uncertainties are mostly due to reader sensitivity fluctuations. As the time interval increases, however, the detector-to-detector variability starts to dominate. One can also see that the increase in the indicated value is not linear, but the background-subtracted dose deviates by not more than ±10 μSv up to 200 days since the PD measurement.
The background-subtracted doses in Fig. 1b can then be used to estimate the detection limit of the system. The detection limit (DL) was defined in a first approximation as $DL \approx 3.3 \times \sigma_0$, where $\sigma_0$ is the standard deviation of the background (standard deviation of the net indicated value), assuming the standard deviation of the signal as being approximately the same as the standard deviation of the background (Currie, 1968; ISO, 2019). If the detection limit is plotted for each time interval, we obtain the black (reader 1) and red lines (reader 2) shown in Fig. 1c. The detection limit increases with time, mainly because of the increase in the detector-to-detector variability with time.

For short periods of time, however, the detection limit is underestimated when using only the readouts in a single day, because the uncertainty is dominated by the day-to-day reader variation. Therefore, to improve this detection limit estimate we took all the detector readouts up to 90 days and obtained the mean net indicated value of $(2.9 \pm 5.0) \mu Sv$, which leads to the detection limit of $\sim 16.5 \mu Sv$ indicated in Fig. 1c. This value is well below the lower dose measurement range of $50 \mu Sv$ required by the Swiss dosimetry ordinance.

For completeness, Fig. 2 presents the dose response for the set of dosimeters irradiated with doses from 0.010 mSv to 100 mSv. The deviation from linearity remains within 15% for the entire range, also satisfying the Swiss dosimetry ordinance.

3.2. Comparison between RPL and TL dosimeters

3.2.1. Environmental monitoring

Fig. 3 shows the RPL doses plotted versus the TLD (Al$_2$O$_3$:C) doses for all environmental dosimeters around PSI. The solid line indicates the 1:1 relationship and the dashed lines indicate the $\pm 10\%$ deviation. The data in Fig. 3 shows an overall good agreement between the RPL and TL dosimetry systems, with an average daily dose of approximately 1.9 $\mu Sv$. Deviations outside the $\pm 10\%$ are observed in a few quarters (e.g. 2019Q01, 2019Q03). Nevertheless, this is more likely an underestimation from the TLDs. As mentioned before (Section 2.1), the same TLDs are used in alternating quarters, e.g. in 2019Q01, 2019Q03, which indicates that the same sets of TLDs are affected.

Fig. 4 shows a box-and-whisker plot of the average RPL and TLD values for all quarters. The box indicate approximately the first and third quartiles, the black dot in the center represents the median, the whiskers represent the largest and smallest data points within 1.5 times the size of the box from the quartiles, and the points outside are considered as
Fig. 3. Comparison between doses per day estimated using RPL dosimeters and Al\textsubscript{2}O\textsubscript{3}:C TLDs for environmental measurements around PSI. The solid line indicates the 1:1 relation, whereas the dashed lines indicate a ±10% deviation.

Fig. 4. Comparison between the average dose per day estimated using RPL and TLD dosimeters in the environmental monitoring network of PSI’s Dosimetry Laboratory, presented as box-and-whisker plots (see text for details).
“outliers” and are used to indicate when the distributions are skewed (Dalgaard, 2008). In this graph it is possible to see that the median RPL value stays constant over time, whereas the TLD system occasionally shows lower values than the RPL system (e.g. 2019Q01).

The actual mean dose in these measured points is not known and, therefore, one cannot affirm that one system is more correct than the other. Nevertheless, one can state that the RPL system showed a more constant mean dose per day over the period investigated.

### 3.2.2. Area monitoring at PSI inside controlled areas

Fig. 5 compares the doses measured using RPL with those measured using $^7$LiF:Mg,Ti TLDs inside controlled areas at PSI. The doses are again below the reference levels per quarter (80 mSv/year or 20 mSv/quarter), even though the data points include locked-off areas. Furthermore, the RPL doses correlate with the TLD doses, with a few exceptions.

### 3.3. Comparison between RPL and EDIS-1 dosimeters

Fig. 6 compares the RPL data with the EDIS-1 dosimeters exposed during two quarters at various measurement points at KKL (see Section 2.4). The figure shows that the points with higher dose rate are correctly tracked by both RPL and EDIS-1 dosimeters. The data again shows an overall good agreement between the two dosimetry systems, with deviations $<5\%$ from the reference value. For the field irradiation, both TLD and RPL showed an under-response of $\sim8\%$ in comparison with the dose estimated using the RS Detection pressurized ionization chamber, but both TLD and RPL systems showed the same dose.

### 3.4. Intercomparisons

#### 3.4.1. Swiss intercomparison

The results of the Swiss intercomparison are presented in Table 2 for both $\text{Al}_2\text{O}_3$:C TLDs and RPL dosimeters. Because of the small number of detectors used, all values are presented and only the mean of the relative response was calculated.

The results show an overall agreement of the TLDs and RPL dosimeters in reference conditions (Cs-137) for both doses, with deviations $<5\%$ from the reference value. For the field irradiation, both TLD and RPL showed an under-response of $\sim8\%$ in comparison with the dose estimated using the RS Detection pressurized ionization chamber, but both TLD and RPL systems showed the same dose.

#### 3.4.2. IC2019prep intercomparison

IC2019prep results for the RPL dosimetry system are shown in Table 3. The initial objective was to compare the TLD and the RPL dosimetry systems, but the light-sensitive $\text{Al}_2\text{O}_3$:C TLDs were exposed to light by mistake and could not be evaluated.

The results for the reference irradiation with Cs-137 at $0^\circ$ showed a good agreement with the conventional true value. The irradiation with Cs-137 at $90^\circ$ showed an under-response, as also reported by Assenmacher et al. (2020). The results for both free field exposure (terrestrial plus secondary cosmic radiation) and floating platform exposure (secondary cosmic radiation) were in good agreement with the conventional true values, with an over-response of the RPLs between 8 and 14%.

### 4. Conclusions

The results reported here provide further supporting data for the application of RPL in environmental and area dosimetry.

The laboratory irradiations show that the detection limit of the RPL dosimeters is below the 50 μSv up to $\sim200$ total days of use (time between pre-dose measurement and readout). Moreover, the response is linear up to 100 mSv, with less than 15% deviation. Both characteristics satisfy the requirements of the Swiss dosimetry ordinance for passive environmental dosimeters.

The comprehensive comparison between the RPL, TLD and EDIS-1 dosimetry systems for the environmental and area measurement points in various locations (outside the PSI perimeter, inside PSI perimeter inside controlled areas, environmental measurements at KKL) showed a good agreement between the techniques. In general the environmental doses obtained using the RPL system were more constant.
over time, the dose per day remaining around 1.9 μSv, whereas the TLD system shows larger deviations from this value. In locations where higher dose rates are expected, the RPLs also showed reliable performance, tracking the TLD or EDIS-1 doses.

In the case of the comparison with EDIS-1 dosimeters, slightly lower doses (12–14%) were observed using RPL. Because of the very different construction of the EDIS-1 dosimeters, a large difference in the energy dependence between the two types of dosimeters is expected and, therefore, such discrepancies are not unusual.

The intercomparisons for passive dosimeters in terms of $H^*(10)$ showed a good agreement between the RPL dose values and the conventional true values. In the Swiss intercomparison, both TLD and RPL results under-estimated the conventional true value by ~8%, whereas in the IC2019prep intercomparison the RPL over-estimated the conventional true value by ~8–14%, depending on the radiation field. These discrepancies are not related to the calibration of the dosimeters, which was independently checked using Cs-137 irradiations.

The results presented here, combined with the characterization of the RPL dosimetry system for personal and environmental applications (Assenmacher et al., 2017, 2020), support the adoption of the RPL dosimetry system for environmental dosimetry.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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