Development of the InLight™ Monitoring Service for World-wide Application

C A Perks¹, G LeRoy², C Yoder³ and C Passmore³

¹LANDAUER Europe Ltd, Number 12, North Oxford Business Centre, Lakesmere Close, Kidlington, Oxfordshire, OX5 1LG, United Kingdom
E-mail: chrisperks@landauer.co.uk
²LCIE Landauer, 33 Avenue du General Leclerc, F92260, Fontenay-aux-Roses, France
³Landauer Inc., 2 Science Road, Glenwood, IL 60425, USA

Abstract. This paper describes the development of a new type of personal radiation dosimeter that combines the excellent features of optically stimulated luminescence (OSL) with the convenience of Panasonic type readers. The specification required for the badge in world-wide application is first discussed. The dosemeter is a Panasonic type dosemeter with OSL detectors replacing the thermoluminescence dosemeters (TLDs). The readers are modified, principally by using a LED array as the light source. Thus, we have been able to use an extensively tried and tested system with the minimum of modifications. The readers are computer controlled and can recognise the type of badge being read and the sensitivity of the OSL detectors. Two different badges have been developed to meet the requirements for the American and European markets. The model 1 badge comprises an open window and filters of plastic, copper and lead. A linear algorithm is being developed for this badge. The model 2 badge comprises an open window and filters of plastic, copper and aluminium. The algorithm developed for this badge is function-based (branching). A full programme of type testing the badges has been undertaken. The newly developed system will enable us to expand the service options available to our customers. These will range from full service (supply of badges periodically to customers, receipt and readout through to record keeping) through to supply of equipment, badges and support so that customers can run their own in house service using OSL technology badges.

1. Introduction

This year, Landauer celebrates 50 years of supplying radiation dosimetry services. Initially the service was based on film badges to provide whole body monitoring, then themoluminescence dosimeters provided the core of the service. We then adopted optically stimulated luminescence (OSL) for our whole body dosimeters.

Optically stimulated luminescence using Al₂O₃ has recently been developed for external radiation dosimetry [1-6]. It is currently our preferred method because of a number of key operational and technical features:

- high sensitivity, improves low dose precision and enables thin layer dosemeters;
- elimination of heating permits more possibilities for the design of dosemeters, including: powder coatings on clear film bases; simpler and more reliable analysis instrumentation; and better control over the amount of luminescence emitted;
- re-analysis of dosemeters is possible as very little of the signal is lost in each read.

The relative merits of optically stimulated luminescence dosimetry and thermolminescence dosimetry have been debated by McKeever and Moscovitz [7].

Until now, highly sophisticated, purpose built readers of high capacity have been needed to read out the dosemeters. Thus it has been necessary to return all dosemeters to Landauer’s Glenwood facility in the United States for read out. The only exception to this is two small readers, installed in the UK, for emergency read out to comply with UK legislation. In all cases, the readers have to be installed in darkrooms. In accordance with recent legislation, the service supplied in France has been using film badges, although this restriction is currently being lifted and we are able to introduce our new technology into the French market.
To allow greater flexibility in the application and readout of our dosimeters, a new system called InLight™, has been developed based on modified Panasonic dosimeters and readers. The new service combines the excellent features of Optically Stimulated Luminescence (OSL) with the convenience of Panasonic readers. A method of OSL for radiation dosimetry has previously been described by Akselrod and McKeever (1999) [3]. For the InLight™ monitoring service, four OSL elements are installed in Panasonic type badges replacing the TLDs. Each element is held under a different filter. There is also the possibility of determining whether the dosemeter has been exposed statically or dynamically [8] and for including a CR-39 dosemeter for neutron monitoring. Thus the dosemeter combines all the advantages of thermoluminescence and film dosemeters together with several additional significant advantages:

- high sensitivity and low threshold;
- the ability to re-read the dosemeters many times;
- the small size of the readers; and
- the lack of the need for extensive darkroom facilities for assembly and readout for the monitoring service.

It is also hoped that adopting four elements will allow better energy response for photons and beta particles. In particular, discriminating between high energy beta particles and low energy photons is known to be difficult in some circumstances.

Readers have been developed so that dosemeters can be read automatically at a speed approaching 10 seconds per dosemeter, with very little need for operator intervention. These are based on the widely used conventional Panasonic readers that have been modified for OSL readout, principally by employing light emitting diodes as a light source.

The development work has included: personal dose equivalent and angular response; sensitivity and threshold characterisation; and development of dose algorithms for the determination of Hp(10), Hp(3) and Hp(0.07) for beta particles, X- and gamma-rays. Comprehensive trials of the dosemeter, its holder and the reader system have been undertaken.

International standards for the application of OSL devices in radiation monitoring services are beginning to be developed. Meanwhile the service is approved in the USA by NVLAP. Approval by the Health and Safety Executive (HSE) in the UK will be sought in the very near future. In France approval is being sought through IRSN. A number of major organisations are using the monitoring service and it is anticipated that the service will find widespread application. Approvals in other countries will be sought as necessary.

2. Specification of the dosemeter

The dosemeter must eventually meet the performance requirements of approval bodies throughout the world in countries we intend to supply a dosimetry service. Since no specific international standard document exists for the type approval of OSL dosimetry systems, we have adopted the standards required for TLD systems IEC 61066 [9]. This standard includes:

- linearity to within ± 10 % for doses in the range 0.1 mSv to 1 Sv for Hp(10) and in the range 0.5 mSv to 1 Sv for Hp(0.07);
- a detection threshold of 50 µSv for badges exposed for 7 days and 200 µSv for badges exposed for 30 days;
- flat energy response to within ± 30 % from 30 keV to 3 MeV;
- isotropy: the mean value of the response, on phantom, for irradiations at 20°, 40° and 60° incidence are within that at normal incidence is within ± 15 %.

There are further requirements on the effect of environmental conditions (light and humidity), mechanical shock, fading and so on.
Specific further requirements are required or desirable in some markets and for specific customers. For example:

- in the UK we need to measure down to 16 keV and have adequate accuracy to measure in mixed fields of low energy photons and beta particles. A linear algorithm is preferred to maximise the confidence that the dosimeter is performing well within the appropriate requirements;
- in France we need to demonstrate that, in free-air, the badge has isotropic response throughout 360°;
- in the USA we need to be able to comply with the requirements of NVLAP accreditation programmes;
- in Canada a total uncertainty from all influencing factors weighted by their probability of occurrence is required to be between −30 % and +50 %.

3. The Dosemeter

3.1. Optically Stimulated luminescence

The application of optically stimulated luminescence for dosimetry has recently been reviewed [1]. The mechanisms for trapping charge during radiation exposure are similar to thermoluminescence. The principal difference to thermoluminescence being the release mechanism in which exposure to optical light is used to obtain the signal which is a function of the dose absorbed. Since this is a quantum process, with no heating, only a small fraction of the trapped charges are released. Thus, much of the trapped charge is retained following stimulation and may be released in subsequent stimulations. This enables OSL dosemeters to be read out many times without significant loss of signal. As its detectors, Landauer use aluminium oxide powder obtained by grinding crystals and sifting the powder to the desired size range. The powder is mixed with a polyester binder and coated onto a roll of polystyrene film. The film roll is subsequently cut to the desired shape and size (for InLight™ dosemeters this is discs approximately 5mm diameter).

3.2. The badge

The InLight™ badge is designed for personnel monitoring of the whole body. The badge consists of a plastic holder (cover and sub carrier), which snaps shut to hold a dosimeter (case and slide), Figure 1.
The badge can also include a neutron dosemeter and an imaging device which, for low energy photons and beta particles distinguishes between static and dynamic exposures [8].

The dosemeter itself consists of a case that contains metal and plastic filters and a plastic slide that contains detector elements, Figure 2. The detector element is a layer of Al₂O₃ sandwiched between two layers of polyester for a total thickness of 0.3mm.

![FIG. 2. Exploded view of the dosemeter](image)

In the optimisation of the design of the dosemeter, two filter combinations have been tested. These are: open window, plastic, copper and lead (model 1) and open window, plastic, copper and aluminium (model 2). The thicknesses of the filter components are limited by the clearance within the reader to 0.7 mm. Overall filter thicknesses for these two designs are given in tables 1 and 2.

<table>
<thead>
<tr>
<th>Thickness (mg/cm²)</th>
<th>Open window</th>
<th>Plastic</th>
<th>Copper</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>28.9</td>
<td>274.5</td>
<td>544.7</td>
<td>982.2</td>
</tr>
<tr>
<td>Back</td>
<td>134.0</td>
<td>282.8</td>
<td>553.0</td>
<td>990.5</td>
</tr>
</tbody>
</table>

Table 2 Filter thicknesses for model 2 InLight™ badge

<table>
<thead>
<tr>
<th>Thickness (mg/cm²)</th>
<th>Open window</th>
<th>Plastic</th>
<th>Copper</th>
<th>Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>28.9</td>
<td>274.5</td>
<td>544.7</td>
<td>374.6</td>
</tr>
<tr>
<td>Back</td>
<td>134.0</td>
<td>282.8</td>
<td>553.0</td>
<td>382.9</td>
</tr>
</tbody>
</table>

4. The Reader

Readers have been developed so that dosimeters can be read automatically at a speed approaching 10 seconds per dosimeter, with very little need for operator intervention. These are based on the widely
used conventional Panasonic readers that have been modified for OSL readout, principally by employing light emitting diodes as a light source.

Three models of reader have been developed: a manual reader (as shown in Figure 3); a reader capable of reading out up to 200 dosemeters sequentially without operator intervention; and one capable of up to 500 dosemeters. In the two automatic readers, dosemeters are fed into the reader using magazines each holding 50 dosemeters.

![FIG 3. The manual InLight™ reader](image)

The principal components of the reader are the light source and detector. The light source comprises an array of 38 light emitting diodes (LEDs) which illuminate the whole of the detectors. A test using one LED before readout determines approximately the dose range of the dosemeter. Then for reading out dosemeters with low doses all 38 LEDs are used (strong beam) and for high doses just 6 LEDs (weak beam) are illuminated. The cut off point between low and high dose is an adjustable parameter of the system.

A transport mechanism drives the dosemeter through the reader. A bar code attached to the side of the badge is read to identify the dosemeter and indicates the type of filter combination. A 2 dimensional barcode etched into the slides is used for identification and for information on the sensitivity of the OSL detectors. These are read automatically. Each OSL element is then read in turn and the counts stored.

The reader is controlled by dedicated computers which also performs the initial processing of the data. Raw counts for each of the OSL detectors are automatically converted using the sensitivity of the detector and calibration factor of the reader and the algorithm applied for each badge. Data stored includes: the counts and converted counts (counts corrected for the sensitivity of the detector and the calibration factor of the reader) for each detector and the output from applying the algorithm including Hp(10) and Hp(0.07). Further software is available for data review, subtraction of background and preparation of dose reports for customers.

The dimensions of the manual reader are approximately 60 cm wide, 42 cm deep and 37 cm high, the 200 unit automatic reader 110 cm x 46 cm x 38 cm. Both are suitable for operating on a table top. The
500 unit automatic reader is a free standing model. Both the 200 and 500 unit automatic readers have a throughput of 280 dosemeters per hour. There is additional handling time when using the manual reader which limits the throughput of this reader. All the readers can be operated in a standard laboratory in ambient lighting conditions. The operating procedures are mainly computer controlled and quite straightforward. It is anticipated that the readers will be used both by ourselves as part of our standard service and also by some customers who wish to read out their own badges.

6. Algorithm development

Algorithms are being developed for both model 1 (including the lead filter) and model 2 (including the aluminium filter) dosemeters.

The algorithm for the model 1 dosemeter was developed by Stanford Dosimetry [10], whilst that for the model 2 dosemeter is being developed in-house. For both models the dosemeters were exposed to an extensive range of photons (from 20 keV to 1250 keV) at Pacific Northwest National Laboratory (PNNL). The photon fields were taken from the ANSI N13.11-2001 standard. The dosemeters were also irradiated to two beta sources \(^{85}\text{Kr}\) and \(^{90}\text{Sr}/^{90}\text{Y}\).

6.1 Model 1 algorithm

To meet the requirements of the European market, a linear algorithm for the model 1 badge is being developed. This is being achieved by fitting the available data to a simple polynomial of the converted counts on the four elements of the dosemeter. To date we have achieved our objective with the exception of low energies at large angles of incidence. Further work is being undertaken to understand this issue and to further improve the algorithm.

6.2 Model 2 algorithm

The dose algorithm for the InLight™ model 2 dosemeter has been developed to satisfy the proficiency testing prescribed in HPS N13.11-2001 [11]. This function-based (branching) dose algorithm for the four-element dosemeter successfully meets the challenges of the standard including:

- photon fields from 20 keV to over 1300 keV;
- beta particle fields from 760 keV to over 2 MeV;
- mixtures of photons of different energies;
- mixtures of photons plus betas; and
- irradiations at non-perpendicular angles of incidence.

The design follows the general principles first described by Stanford [12] and subsequently implemented at both NVLAP and DOELAP accredited facilities for other dosemeter systems. By using smooth correction factor curves based on element ratios, the algorithm is able to accommodate the full range of photon energies with no field knowledge. In addition, using a function to estimate the photon interference on the lightly filtered beta-sensitive elements allows excellent performance for mixed fields, including beta with low energy photons. Response data for over 30 radiation fields were used in the design the algorithm and it was tested in over 900 pure and mixed field conditions with ratios up to 10:1 with over 90% of the results within 20% of the expected dose [10].

5. Type testing

Whilst separate approvals are required for each country in which we intend to operate an InLight™ dosimetry service, to minimise the difficulty in preparing numerous approval documents, a comprehensive programme of type testing has been undertaken. The type testing programme includes:

- energy and angular response of the dosimeter;
- lower limit of detection;
- effect of UV and visible light on the response and lower limit of detection;
- long and short term fading;
- response of the dosimeter to environmental conditions (including temperature and humidity);
- effect of non-ionising irradiation; and
- effect of radiations other than those to be measured.

Internal reports have been prepared as the type testing programme is completed. These have been brought together in the form of an overall technical specification of the final design of dosemeter. The technical specification will be used as required in submissions to national authorities for approval of the dosemeter and dosimetry service.

A particular advantage of the OSL technology is the ability to reanalyse the dosimeter many times following exposure. A separate report to this Congress gives further information on this aspect of the InLight™ badge [13].

7. Service options

A key benefit of developing the InLight™ dosemeter is that it allows a more diverse range of service options. To date the only option has been a full service option in which Landauer supply the badges to the customer, following the monitoring period, dosemeters are returned to Landauer for readout, analysis and in almost all cases record keeping. There will be three service options available using the InLight™ badge:

- a full service as currently operated;
- a partial service in which the client assembles and assigns the dosemeters and returns them to Landauer after the monitoring period for read-out and analysis; and
- supply of equipment and dosemeters to the client, with appropriate support, so that the client essentially runs their own in-house service.

Many clients will still prefer the full service, however a number of larger clients, possibly with sensitivity regarding the doses their employees are receiving may prefer the third option.

8. Future developments

Initial trials are under way with a number of key clients and the service is being rolled out to a number of clients in France. Further improvements are required to the linear algorithm for the model 1 badge. Approval of the system has been gained by NVLAP in the United States. Full approvals in France (by IRSN) and the UK (from HSE) will be sought in the very near future. Independent (blind) trials are being undertaken with a range of mixed field irradiations in the UK.

9. Concluding remarks

A dosimetry service based on optically simulated dosimetry has been described. Using modified Panasonic badges and readers we have combined the technical advantages of OSL dosimetry with the tried and tested system offered by Panasonic. To offer the service in a wide number of markets throughout the world a comprehensive type testing programme has been undertaken, and it may be necessary to adopt two models of the dosemeter with different combinations of filter. Nevertheless the new system will expand the options for providing dosimetry services.

References