

Medical dosimetry using Optically Stimulated Luminescence dots and microStar[®] readers

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Abstract. Landauer has developed a portable dosimetry system based on its Optically Stimulated Luminescence (OSL) technology. It is called the microStar[®], and its core technology is the same as that in its personnel monitors used throughout the world (more commonly known by their trade names, Luxel[®], and InLight[®]).

OSL using aluminium oxide doped with carbon (Al₂O₃:C) has been used extensively for personal radiation dosimetry for many years. It has the advantages of low detection threshold and re-analysis. Recently, single dots of OSL material and a portable reader have been developed with a view to medical applications. A number of organisations asked to make trials of this system.

The acceptance of this system has grown worldwide with recent trials at various hospitals in France, the USA and the UK. Most recently, the IAEA has undertaken a Coordinated Research Program (CRP) to identify dosimetry systems for use in developing countries.

The trials, some of which have already been reported in the scientific literature, have included studies of the energy and dose response, the stability of the readout and the overall accuracy of the measurements as compared to other systems used in patient dosimetry. It is evident that the OSL system is capable of achieving the high degree of accuracy required for medical applications (reproducibility (< 2%)) and has a number of advantages over current methodologies such as a wide dynamic range (0.01 mGy to 15 Gy) and negligible energy, angle, dose rate, and temperature dependence. In addition, one unique feature relative to TLD's is the ability to re-read the dose many times (with potential application for archiving the dosimeter with patient records) as only a fraction of the stored charged is consumed in each analysis.

This paper will review the results of these trials highlighting similarities and differences. Where differences were found, possible explanations will be presented. The overall properties of the system will be summarised drawing out the advantages and disadvantages over current systems (TLD, MOSFET and Diode dosimetry). In the light of the experience with these trials, new developments of the system will be presented.

KEYWORDS: *Optically Stimulated Luminescence, microStar, patient dosimetry.*

1 Introduction

The application of optically stimulated luminescence (OSL) for dosimetry has been reviewed previously [1]. Landauer has developed the application of aluminium oxide doped with carbon (Al₂O₃:C) as an OSL detector material for its external personal radiation dosimetry services [2-6]. It is currently Landauer's preferred method because of a number of key operational and technical features:

- high sensitivity, improving low dose precision and enabling thin layer dosimeters;
- elimination of heating permits more possibilities for the design of dosimeters, including: powder coatings on clear film bases; simpler and more reliable analysis instrumentation; and better control over the amount of luminescence emitted;

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- re-analysis of dosimeters is possible as less than 0.25% of the stored charge is consumed in each analysis.

Landauer have recently developed a new system, called InLight® [2], based on modified Panasonic dosimeters and readers. In addition, we have developed a small, manual reader, called microStar™, able to read-out small dots of our OSL detector material. This extends our range of application into medical and other fields where single point measurements are required.

This paper describes the microStar system, outlines the principal characteristics of the system and some trials of the system.

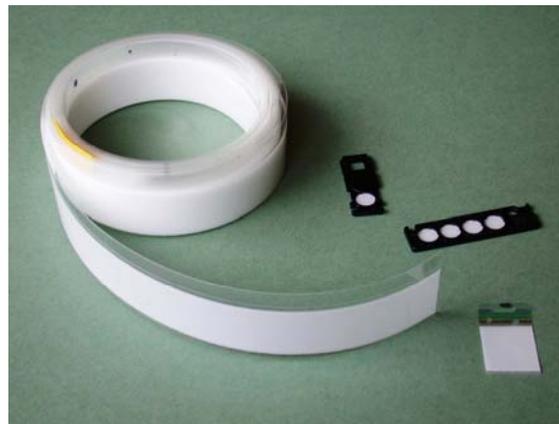
2 The microStar system

The microStar system comprises dosimeters, which may take the form of conventional personal monitoring dosimeters or individual dots, and a purpose designed reader, as described below.

2.1 Dosimeters

As its detectors, Landauer use aluminium oxide doped with carbon ($\text{Al}_2\text{O}_3:\text{C}$). The aluminium oxide, $\text{Al}_2\text{O}_3:\text{C}$, used in our dosimeters is produced at the Landauer Crystal Growth Facility in Stillwater, USA. $\text{Al}_2\text{O}_3:\text{C}$ (corundum or sapphire) is used primarily because of its high sensitivity to radiation (40 – 60 times that of LiF (TLD-100)). It has a principal emission peak at 410 – 420 nm (blue). It also has excellent properties for radiation dosimetry, including linear response up to 300 cGy. $\text{Al}_2\text{O}_3:\text{C}$ powder is obtained by grinding crystals and sifting the powder to the desired size range. This powder is mixed with a polyester binder and coated onto a roll of polystyrene film. The aluminium oxide layer is approximately 0.2 mm thick sandwiched between polyester foils 0.03 mm thick (top) and 0.1 mm thick (bottom). The film roll is subsequently cut to the desired shape and size (for InLight dosimeters and dots this is discs approximately 5 mm diameter). In commercial applications these discs are either inserted into Panasonic type dosimeters or small holders for individual dots.

Figure 1: OSL strip and dosimeters.



2.2 Reader

A number of methods have been developed for analysis of the OSL from $\text{Al}_2\text{O}_3:\text{C}$ detectors, including the pulsed optically stimulated luminescence method adopted for Landauer's Luxel badges [4]. However, in the InLight system, Light Emitting Diodes (LED) emitting light at a wavelength of 532 nm (green) are used as the light source. These offer several important advantages over traditional thermal stimulation systems (TLDs). In particular, they are inexpensive, robust and compact, enabling the readers to be much more reliable (by eliminating high temperatures, combustion, external gas

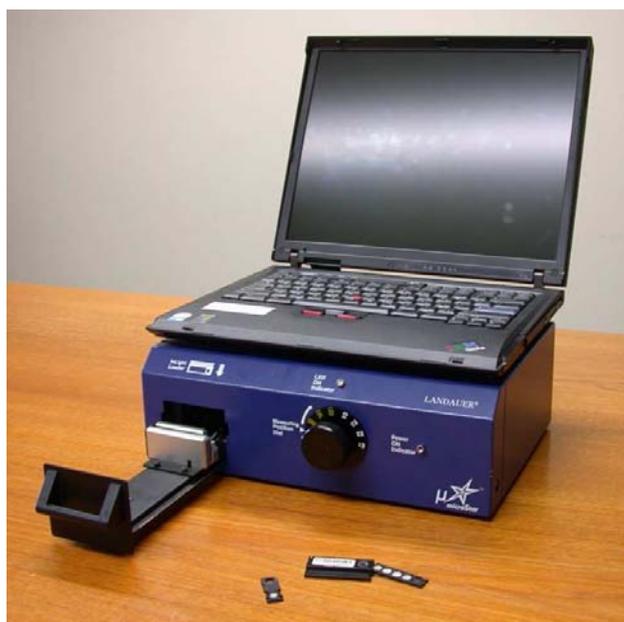
supplies, etc). The LED based readers can therefore achieve much higher precision and repeatability. The InLight system utilises an array of 36 LEDs; all 36 (strong beam) are illuminated for low dose exposures and only 6 LEDs (weak beam) are illuminated for high dose exposures. A pre-test under the dosimeter's open window determines the LED strength required.

A number of readers are available, including fully automatic readers for reading up to 500 dosimetry badges in a single process.

The microStar reader is a small, portable reader, capable of reading out personal monitoring dosimeters or dot detectors. This was designed for a variety of applications, including medical dosimetry. The microStar measures approximately 30 x 20 x 10 cm and weighs approximately 15 kg. It uses a conventional electrical power source (110 – 240 V, 1.5 amp, 50 – 60 Hz) and no other connections. It is therefore a 'plug-in and operate' piece of equipment.

To control and monitor the operation, microStar has a dial and two indicator lights. The reader connects via a USB cable to an external computer that controls the setup, analysis and data recording. Quality control (QC) procedures to ensure accurate dose results include: the measurement of a low intensity light photon source calibration standard; dark current and LED intensity; the ability to calibrate to any set of reference conditions; and the use of quality control dosimeters for periodic QC testing. The frequency of quality control procedures is user defined and depends upon the desired accuracy. For normal measurements (bias < 5%), calibration is needed once a month or after transport.

Figure 2: The microStar reader



3 Characteristics of the system

In medical dosimetry, there are a wide range of clinical conditions (e.g. technique, energy, angle, dose rate, etc.) which require the user to have a very thorough understanding of their dosimetry system and how it performs in these various environments. This translates into a series of correction factors which are typically applied by hand after the measurement has been made. So, while electronic devices such as diodes and MOSFETs provide instantaneous output, it is entirely possible that an accurate measurement may require minutes or hours of post-measurement analysis, or a knowledge of the exposure conditions that is not practical (e.g. irradiation angle during an IMRT treatment).

Landauer's microStar system provides two different solutions to this problem. On one hand, the reader is flexible and can be calibrated to any set of reference conditions. These calibrations can be individually stored and recalled at a later time as necessary. At the same time, the dosimeter itself is virtually invariant with energy, angle, dose rate, etc. in the radiotherapy environment. This eliminates the need for post-measurement correction factors and allows a medical technician rather than a medical physicist to perform the measurement.

These advantages will be described in further detail using data from published sources as necessary.

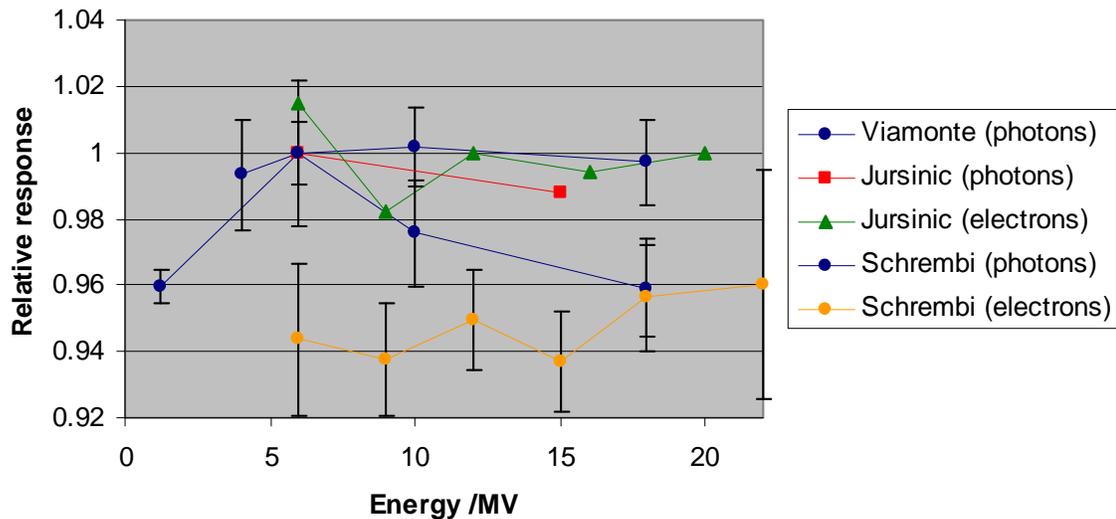
3.1 Energy response

In this section we describe the energy dependence, dose-response, and accuracy of measurements made with OSL dot detectors read out using the microStar reader.

3.1.1 Radiotherapy fields

For radiotherapy the energy range of interest is for ^{60}Co (mean energy 1.250 MeV) upward to 20 MeV using both photons and electrons. The on-phantom response at these energies is about 3 times less than the response at 48 keV. Figure 3 gives the energy response for the dots over the radiotherapy range [7, 8 and 9]. It can be seen that the energy response typically varies by less than 4 % over this range. If one further considers only the output from a linear accelerator (ignoring Co-60), this variation is reduced to 2% or less. This allows a technician to use a single calibration for all clinical conditions. In the event that the user does not record the exposure energy, the readings are still valid. For those cases where even greater precision is desired, the microStar is flexible enough to be individually calibrated to each particular field.

Figure 3: Energy response in the radiotherapy range [7, 8 and 9].

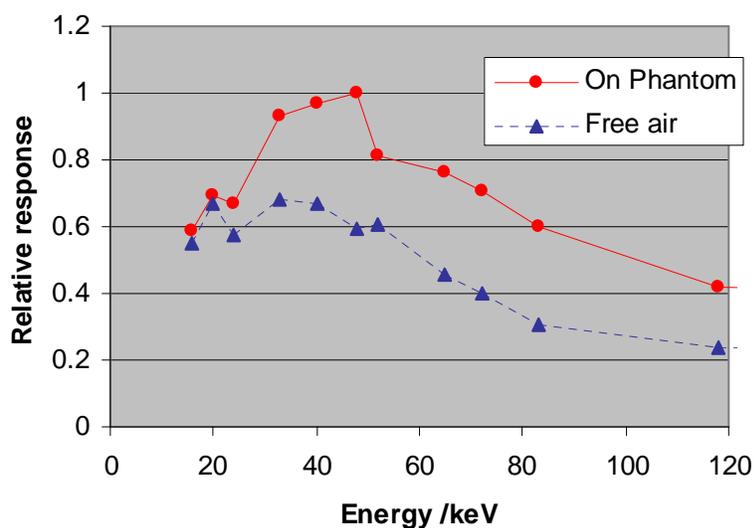


Shembri and Heijmen [7] noticed a difference of 3.7 % in the response between the photon and electron beams. There is also a significant difference for 18 MV photons between the results for Viamonte et al [9] and Schembri and Heijman [7]. The reasons for these variations are not yet understood and indicate the need for a careful understanding of the measurement protocol used before comparing the results.

3.1.2 Mammography, diagnostic and CT fields

With an effective Z of ~10, the Al₂O₃:C detector material will over-respond to the x-rays typically found in diagnostic applications. The expected energy range for these exposures is from 20 kVp (mammography) to 120 kVp (Computed Tomography (CT)). The energy response of the OSL dot detectors has been determined [10] both for exposures on phantom (30 x 30 x 15 cm PMMA) and free in air for energies in this range and is shown in Figure 4. To minimize the measurement bias of this effect, Landauer supplies a set of calibrated dot dosimeters. These calibrates are created using an 80 kVp Philips Industrial x-ray generator with a 2.5 mm filter of Al (2.9 mm Al HVL) with the dosimeters exposed on a PMMA phantom. The energy response given in Figure 4 is normalized to this exposure condition.

Figure 4: Energy response of dot detectors in mammography, diagnostic and CT fields [10]



Using this set of reference conditions, a minimal correction factor (Table 1) can be applied to measurements made for mammography, fluoroscopy, and CT. These correction factors can be directly entered into the microStar, effectively creating a separate calibration which can then be applied as necessary.

Table 1: Correction factors for mammography, fluoroscopy and CT.

Calibration Set	Mammography (~32 kVp)	Fluoroscopy (~80 kVp)	Computed Tomography (~120 kVp)
80 kVp*	1.39	1.00	1.12

* 80 kVp Philips Industrial x-ray generator with a 2.5 mm filter of Al (2.9 mm Al HVL)

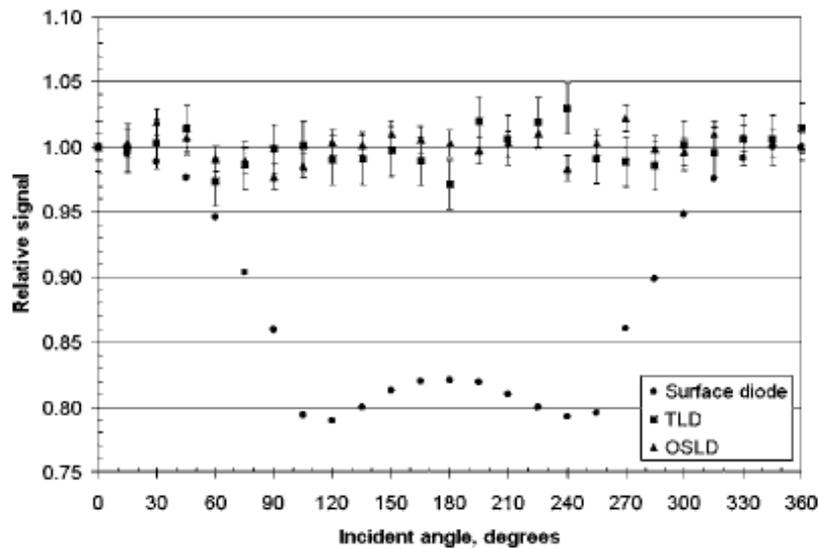
Again, the flexibility of the microStar allows the user to calibrate the device to virtually any environment and achieve accurate results.

3.2 Angular response

3.2.1 Radiotherapy fields

At radiotherapy energies the angular response of the OSL dose detector is uniform from 0 – 360° incident angles (Figure 5 [8]). This allows the technician to make a measurement without knowing the exposure angle. This is important for a variety of treatments in which the gantry angle is changed throughout the procedure.

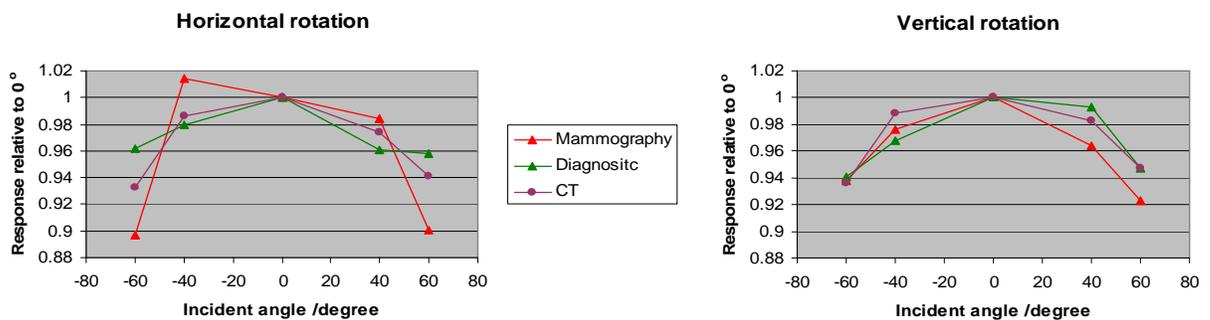
Figure 5: The angular response of the OSL dot detectors [8]



3.2.2 Mammography, diagnostic and CT fields

At lower energies (relevant to mammography (~32 kVp), diagnostic (~80 kVp) and CT (~120 kVp) fields) the variation (relative to 1 at normal incidence) is within 10% up to incidence angles of 60°. (Figure 6).

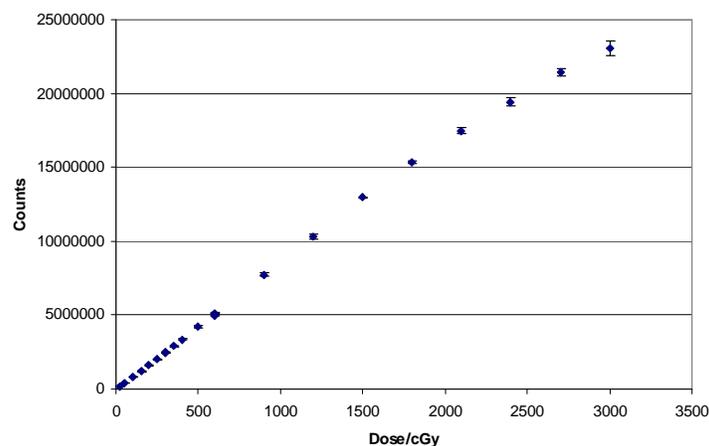
Figure 6: Angular response in the mammography, diagnostic and CT



3.3 Dose response

The dose response has been determined by a number of authors for a number of photon energies and irradiation conditions for example Figure 7 [11].

Figure 7: Dose linearity for dots irradiated with ^{60}Co [11]



They find a linear response up to 600 cGy with a slight concavity at higher doses. Similar results have been found by Jursinic [8], Viamonte et al [9] and Schembri and Heijman [7]. The slight non-linear response above about 600 cGy is reproducible and several authors have fitted the curve either with a two linear equations covering different regions [11] or by a simple linear-quadratic equation [8].

Schembri and Heijmen [7] also examined the dose rate response up to 6 Gy per minute finding that all the results were within 1 %.

Jursinc [8] found that the deviation from linearity became measureable at 300 cGy. This response is predictable and the microStar provides its users with the ability to fit a second-order polynomial to address this non-linear response. Additionally, a user could simply calibrate the device over a more narrow range tailored to their clinical conditions (e.g. 100-300 cGy for 200 cGy dose fractions).

4 Trials undertaken

A number of trials have been undertaken with the OSL dot system, some of which have been reported, and others are at various stages of completion. We have restricted the comments in this paper to those trails which have been reported. These include with Erasmus MC [7], West Michigan Cancer Center [8] and IAEA [9].

5 Comparison with other methodologies

Other existing methods used in radiotherapy and medical applications include the use of ion chambers TLD, diodes and MOSFETs. A number of the trials undertaken with the OSL dots have compared the properties of these devices and commented on the relative advantages and disadvantages. Viamomonte et al [9] note that the use of TLDs is often considered as a complex read-out process involving heating and annealing which precludes instantaneous or near instantaneous readout. Diodes, which are commonly used for in vivo dosimetry, give an instantaneous readout, but their calibration factor is dependent upon energy, angle, temperature, and dose-rate. MOSFETs dosimeters are largely free of these drawbacks, but their life-time is limited. Both diodes and MOSFETs and active devices and their wiring need to be considered.

5.1 Energy dependence

As noted above (Figure 3), the energy response for the OSL dot detectors is relatively independent of energy in radiotherapy fields. In contrast diodes have a reduction ion response as a function of energy up to about 10 % in this energy range (see for example Jursinic figure 9 [8]).

5.2 Angular dependence

The angular dependence of the OSL dot detectors for radiotherapy applications is similarly independent of angle.

5.3 Dose response

Schembri and Heijmen [7] noted that, in contrast to GafChromic and radiographic films, the response of the OSL dots is linear in the clinically relevant dose range of 1 – 200cGy.

5.4 Stability of the signal

Jursinic [8] made some detailed measurements of the stability of the signal as a function of time after irradiation. He found that (with 6 MV there is an initial drop in the signal relative to that measured one minute after irradiation of about 30 %, but that after 8 minutes the signal becomes very stable with a 2% decay from 10 to 3600 minutes.

5.5 Re-readability

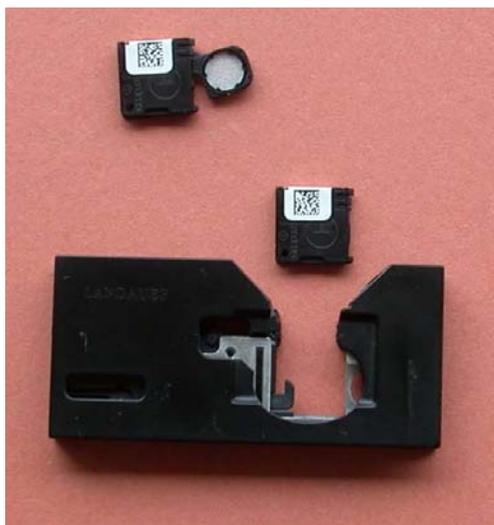
Jursinic [8] have noted that one particular advantage of the OSL dot dosimeters is that they can be read repeatedly with very little loss in signal (0.05% per reading). Combined with the very small long term fading of the signal, this gives the possibility of reading the dosimeter and retaining it for future analysis or indeed as a permanent record of the measured dose (for example attached to patient records).

In addition, the re-analysis capability allows for the dosimeter to be repeatedly analyzed, thereby reducing the measurement uncertainty ($\sim 1/\sqrt{n}$) while eliminating the need for multiple dosimeters in a single measurement (e.g TLD's).

6 New developments

To better accommodate the emerging needs of the medical community, Landauer has recently released a new dosimeter, called the 'nanoDot'. A picture of this device is shown in Figure 8.

Figure 8: The new 'nanoDot' and adaptor for readout in the microStar reader.



The new dosimeter has the same detector material as previous dots and dosimeters, but in a form factor 50% of the standard Dot measuring 10 mm x 10 mm x 2 mm. This allows it to be placed in more restricted spaces such as the eyelid. As with the previous dots an adaptor (also shown in figure 8) has been developed to allow it to be easily read-out with the standard reader and all operations (exposure, readout and storage) can be undertaken in ambient light conditions.

Future developments will be driven by our increasing understanding of the applications for which the system is being used. In particular these include the use of the Al_2O_3 material in stereotactic measurements where the detector's extremely high sensitivity allows for very small detectors (< 1mm diameter).

7 Concluding remarks

The OSL microStar system developed for medical applications could be an ideal tool for radiotherapy applications. In comparison to TLD, the detectors are identified with individual serial numbers the can be repeatedly read out enabling them to be archived with the patient record as a permanent record of dose and can be readout within minutes of exposure. In comparison with electronic detectors (Diodes and MOSFETs), they require no cabling and are relatively cheap. For radiotherapy applications the variation in response at different energies and angles is negligible and a number of authors have noted their suitability for this application, particularly entrance dose. The important corollary of these features is that the system doesn't require a medical physicist to operate it thereby allowing the staff to make more measurements, ultimately improving the quality of care to the patient. In addition, with the application of small correction factors for the calibration factors, the system is capable of use in the mammography, diagnostic and CT fields. Such applications include patient dosimetry and quality control of x-ray beams. Further work is in hand both internally, within Landauer, and by external trials to more fully validate the system in medical fields and to extend its range of application.

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