High Accuracy Measurement of Absorbed Dose to Water using Optically Stimulated Luminescence Dosimeter in High-Energy Photon Beam Field

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1. INTRODUCTION

Our research group aims to develop a postal dose audit using a solid-state dosimeter to be used for clinical linear accelerator (linac) quality control. We focused on a small type Optically Stimulated Luminescence (OSL) dosimeter (nanoDotTM, Landauer Inc,. Glenwood IL) which is easy to use and has a very low price (Figure 1).

Recently, TG-191 reported on the use of a OSL dosimeter in a clinical[1]setting, and summarized the uncertainty budget for the OSL dosimeter (Table 1). The reading value (M_0, M_{raw}) and beam quality conversion factor (k_Q) uncertainties are larger than the uncertainty of other components of the OSL dosimeter. In order to perform postal dose audit more accurately, there needs to be a reduction of these uncertainties. This study investigates the procedure of reducing the reading uncertainty, and we evaluated how precisely the OSL dosimeter can measure absorbed dose to water.

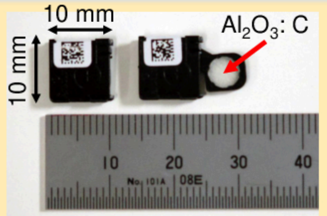


Figure 1: Photograph of small type OSL dosimeter (nanoDotTM)

Table 1: Uncertainty budget for OSL dosimeter[1]

Component of uncertainty: Symbol	Component of uncertainty: Definition	Uncertainty (k=1)
D_0	The standard dose	0.6%
M_0	The standard read value	0.8%
$M_{raw} \times k_{s,i}$	The read value corrected with the element sensitivity	0.8%
k_L	Dose non-linearity correction factor	0.3%
k_F	Signal Fading correction factor	0.1%
k_Q	Beam quality correction factor	0.9%
u_{OSL}	Combined standard uncertainty	1.6%

The aim of this study is…

1. To optimize a reading procedure of an OSL dosimeter.
2. To propose the analytic procedure for precise dose evaluation.

[1] Kry, Stephen F., et al. (2020) "AAPM TG 191" Medical Physics, Vol. 47, Issue 2, Pages e19-e51

2. MATERIALS & METHODS

2-1 Experiment

OSL dosimeters were irradiated with a high-energy photon beam using a Japanese primary standard field[2]. The experimental arrangement is shown in Figure 2.

Experimental conditions

- Nominal photon energy: 6 MV
- Irradiated dose: 10 Gy
- Irradiated field: 10 × 10 cm^2
- Water depth: 10 cm

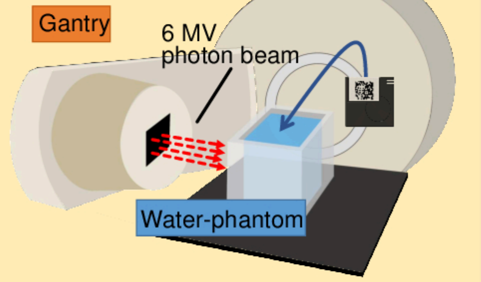


Figure 2: Schematic drawing of the experimental arrangement

2-2 Reading procedure

Exposure dose to dosimeters were read out using a commercial reader (microSTAR II). In order to clarify the component of reading uncertainty (u_r), we performed two different types of reading procedures as shown in Figure 3: consecutive reading and independent reading procedures in which the dosimeter placement was altered after each reading. The uncertainty was evaluated by calculating the standard deviation.

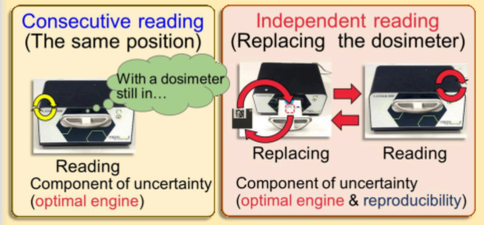


Figure 3: Two types of reading procedures

3. RESULTS & DISCUSSIONS

3-1 Reading uncertainty

Table 2 shows the results of the reading uncertainty experiment. When using the consecutive reading procedure, the SD (σ_{con}) was only 0.2%. We think that it reflects both the statistical uncertainty of the OSL dosimeter and the reproducibility of the optical engine in the reading device. The statistical uncertainty was 0.1% calculated from OSL counts (M). From the propagation formula of uncertainty, the uncertainty of the optical engine was found to be only 0.2%. On the other hand, when we used the independent reading procedure, the SD (σ_{ind}) was 0.8%. This deviation was affected by the reproducibility of the OSL dosimeter position in addition to the uncertainty of the consecutive reading experiment. Namely, this uncertainty was calculated by 0.7% from the propagation formula of uncertainty.

The reading uncertainty (u_r) was determined to be 0.8% because the σ_{ind} completely reflected the uncertainties that occur in the actual readout.

Table 2: Results of the reading uncertainty when applying the two types of reading procedures.

Type of reading procedure	SD	Component of reading uncertainty: Statistical uncertainty	Reproducibility: Optical engine	Reproducibility: Detector position
Consecutive reading	σ_{con} 0.2%	$\sqrt{M}$ = 0.1%	$\sqrt{(\sigma_{con})^2-(\sqrt{M})^2}$ =0.2%	-
Independent reading	σ_{ind}=0.8%	$\sqrt{M}$ = 0.1%	$\sqrt{(\sigma_{con})^2-(\sqrt{M})^2}$ =0.2%	$\sqrt{(\sigma_{ind})^2-(\sigma_{con})^2}$ =0.7%

We will now discuss how to optimize the reading procedure for precise dose evaluation. The read value is affected by the statistical uncertainty and reproducibility of a reading device. Statistical uncertainty can be reduced by increasing the number of OSL counts, such as multiple readouts. On the other hand, the uncertainty of reproducibility of reading device can be reduced by carrying out multiple independent readings. This is because a histogram of the measured data is a Gaussian distribution, as shown in Table 2. The relationship between the number of independent reading and uncertainties is shown in Figure 3. The combined uncertainty of measurement value is 0.9% when evaluating a single reading, and it can be reduced to 0.4% by performing independent readings 5-times.

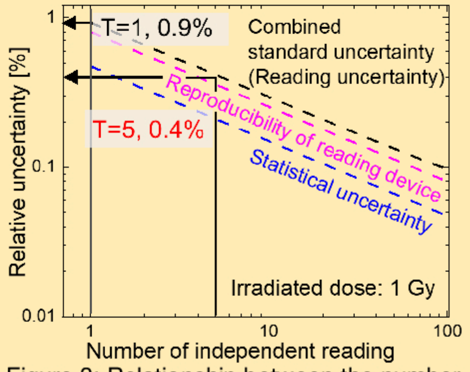


Figure 3: Relationship between the number of independent readouts and uncertainties

3-2 Uncertainty of correction factor

We estimated that the uncertainty of measured value corrected with the individual sensitivity ($M_{raw} \times k_{s,i}$) as shown in Table 1. Figure 4 shows the result of the correction factor for individual sensitivity ($k_{s,i}$) using our reading procedure. A correction value was obtained with an uncertainty of 0.4%. From the histogram of the individual sensitivity shown in the right graph, the uncertainty found to be 2.0%.

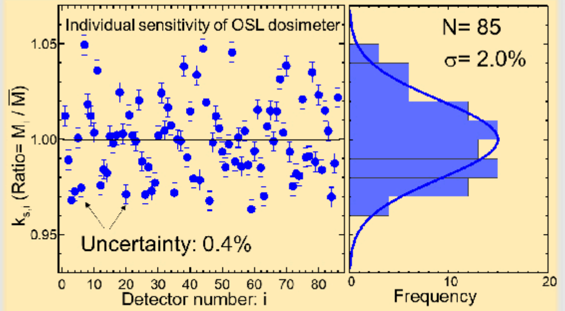


Figure 4: The results for the uncertainty of individual sensitivity experiment

M_{raw} and $k_{s,i}$ can be obtained with an uncertainty of 0.4% when the OSL dosimeter is read out 5-times independently. Namely, $M_{raw} \times k_{s,i}$ can be calculated with 0.6% uncertainty.

3-3 Analytic procedure for precise dose measurement

Finally, we will discuss the analytic procedure for obtaining precise OSL dosimetry. A comparison between the analytic procedure found in a conventional report (AAPM TG 191) and that proposed in this study is shown in Figure 5. The different points in our procedure from the previous study are to optimize the reading procedure and to calibrate the OSL dosimeter using photon beams. By performing 5-times independent readings, uncertainty concerning read values can be reduced. Specifically, the uncertainty of OSL counts corrected with the individual sensitivity ($M_{raw} \times k_{s,i}$), and that of the calibration coefficient ($N_{D,W}$) can be reduced to 0.6% and 0.7%, respectively. Furthermore, in our proposed procedure, it is not necessary to correct the beam quality conversion factors (k_Q) by calibrating the OSL dosimeter using a high energy photon beam used in a linear accelerator. We found that the absorbed dose to water can be determined with a 1.0% uncertainty (k=1) when performing our procedure.

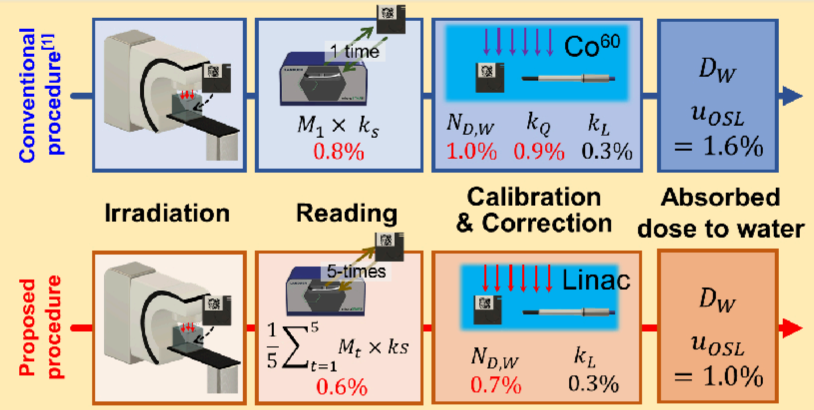
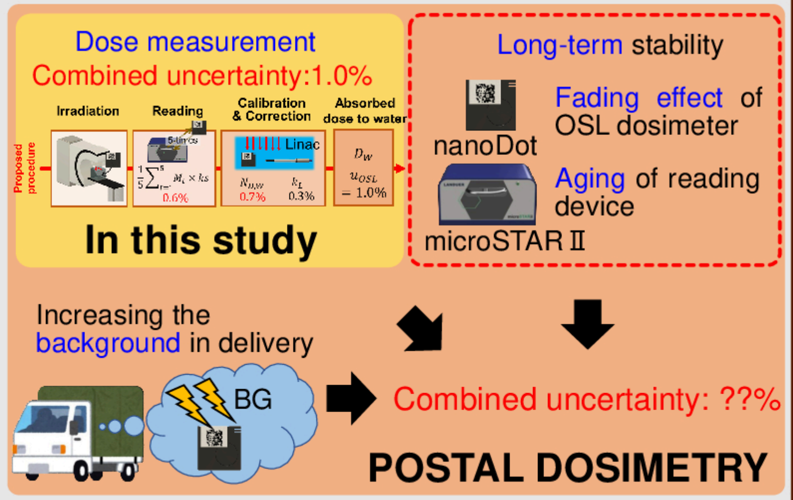


Figure 5: A comparison between combined uncertainty using the conventional and the proposed measurement procedures

4. LIMITATION IN THIS STUDY

In this study, we evaluated uncertainties such as reading and correction factors, and found that OSL dosimetry can be performed with an uncertainty of 1.0%. Here, it should be noted that the value reflects only the uncertainty component of dose measurement. In order to perform a postal dose audit, it is necessary to clarify other components as shown in the right figure. We are currently studying these subjects.



5. CONCLUSION

1. We estimated the uncertainty related to reading the OSL dosimeter.
2. The reading uncertainty is estimated to be 0.8% (k=1), and can be reduced by performing multiple independent readings.
3. OSL dosimeter can measure the absorbed dose to water with a 1.0% (k=1) uncertainty when performing our proposed procedure.

REFERENCES

[1] Kry, Stephen F., et al. (2020) "AAPM TG 191" Medical Physics, Volume 47, Issue 2, Pages 19-51

[2] M. Shimizu, et al. (2014) Radiation Protection Dosimetry, Volume 164, Issue 3, Pages 181-186

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