

# Investigation of the response characteristics of OSL albedo neutron dosimeters in a $^{241}\text{AmBe}$ reference neutron field

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**Abstract.** The objective of this work was to systematically investigate the response characteristics of optically stimulated luminescence Albedo neutron (OSLN) dosimeters to ensure reliable personal dosimetry service provided by Thailand Institute of Nuclear Technology (TINT). Several batches of InLight® OSLN dosimeters were irradiated in a reference neutron field generated by the in-house  $^{241}\text{AmBe}$  neutron irradiator. The OSL signals were typically measured 24 hours after irradiation using the InLight® Auto 200 Reader. Based on known values of delivered neutron dose equivalent, the reading correction factor to be used by the reader was evaluated. Subsequently, batch homogeneity, dose linearity, lower limit of detection and fading of the OSLN dosimeters were examined. Batch homogeneity was evaluated to be  $0.12 \pm 0.05$ . The neutron dose response exhibited a linear relationship ( $R^2=0.9974$ ) within the detectable neutron dose equivalent range under test (0.4-3 mSv). For this neutron field, the lower limit of detection was between 0.2 and 0.4 mSv. Over different post-irradiation storage times of up to 180 days, the readings fluctuated within  $\pm 5\%$ . Personal dosimetry based on the investigated OSLN dosimeter is considered to be reliable under similar neutron exposure conditions, i.e. similar neutron energy spectra and dose equivalent values.

## 1. Introduction

Reliable evaluation of personal dose equivalent is important for occupational radiation protection and radiation monitoring. Thailand Institute of Nuclear Technology (TINT) provides a personal dosimetry service based on optically stimulated luminescence (OSL) dosimeters for gamma rays, beta rays, x-rays and neutrons. The OSL dosimeters are regularly tested in reference photon fields to ensure reliable photon dose equivalent evaluation, while type testing of the dosimeters in reference neutron fields could not be conveniently done in the past due to a lack of neutron reference fields in Thailand. Until recently, TINT has set up a radioactive neutron irradiator for generating neutron reference fields for detector testing and research purposes [1], making it possible to test the performance and reliability of the OSL dosimeters for neutron dose equivalent evaluation.

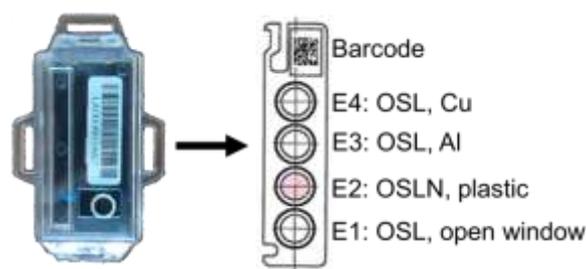
The objective of this work was to investigate the response characteristics of InLight® optically stimulated luminescence albedo neutron (OSLN) dosimeters (Nagase Landauer, Ltd) in a reference neutron field and assess their reliability for neutron personal dosimetry service. For this investigation, the accuracy of evaluated neutron dose equivalent, batch homogeneity, dose linearity, lower limit of detection and fading of the OSLN dosimeters were examined.



## 2. Materials and Methods

### 2.1. OSLN dosimeters

OSL is a process in which a material pre-exposed to ionizing radiation emits light after appropriate optical stimulation. The light signal is proportional to the absorbed dose. Therefore, OSL dosimetry can be used for assessment of occupational dose equivalent. The personal dosimetry service at TINT is based on InLight® OSL/OSLN dosimeters (Nagase Landauer, Ltd). Each dosimeter has four sensors made of aluminum oxide doped with carbon ( $\text{Al}_2\text{O}_3:\text{C}$ ). The sensors are placed in a plastic holder, covered with an open window, plastic and metal filters for measurement of Hp(0.07), Hp(3) and Hp(10) (shallow, lens-of-eye and deep dose, respectively), as shown in Figure 1. E2 is the only neutron-sensitive element of the OSLN dosimeter.



**Figure 1.** InLight® OSLN dosimeter (Nagase Landauer, Ltd).

When the  $\text{Al}_2\text{O}_3:\text{C}$  crystal is exposed to ionizing radiation, free electrons and holes are produced. The free charge carriers will be eventually trapped in impurity states. The trapped electrons can be released by optical stimulation with green light of 532 nm wave length produced by a light emitting diode (LED), as illustrated in left panel of Figure 2. The emitted blue light signal (420-440 nm wave length) is measured by the photomultiplier tube (PMT) of the InLight® Auto 200 Reader (Landauer, Inc.). Subsequently, a dose calculation algorithm is applied for determination of dose equivalent received by the wearer. Since neutrons are indirectly ionizing radiations and the OSL material is not directly sensitive to neutrons, one of the  $\text{Al}_2\text{O}_3:\text{C}$  sensors of the OSLN dosimeter (E2) is coated with  $^6\text{LiCo}_3$ . Neutron absorption by  $^6\text{Li}$  produces a tritium ( $^3\text{H}$ ) and an alpha particle ( $^4\text{He}$ ), which can cause ionization and generate free charge carriers in the  $\text{Al}_2\text{O}_3:\text{C}$  crystal, as shown in right panel of Figure 2.



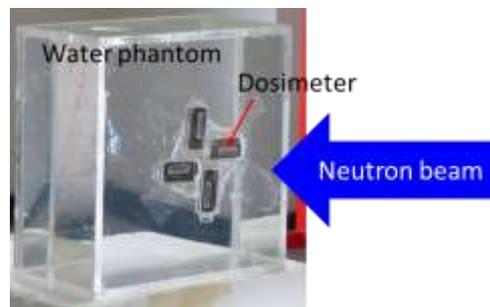
**Figure 2.** The OSL process (left) and the principle of albedo-type OSLN dosimeters.

In the presence of detected neutron signal, the response on the open-window element is used by the reader for estimating the photon contribution on the neutron-sensitive element. The neutron dose is calculated by applying a correction factor (chosen by the operator) to the net neutron signal. Shallow and deep photon doses of the mixed radiation field are calculated from the response of the Cu element, while the signal ratio of the Al element and the Cu element is used as an independent variable for

selecting the function for calculating the lens-of-eye photon dose. Since neutron is strongly penetrating radiation, neutron shallow, lens-of-eye and deep doses are set equal.

### 2.2. Neutron irradiation

Several batches of the OSLN dosimeters were randomly selected for neutron irradiation. For each batch, 4 OSLN dosimeters were placed on a water phantom (30 cm width  $\times$  30 cm height  $\times$  15 cm thick) facing the center of the neutron beam, as shown in Figure 3. The reference neutron field was produced by TINT's 50 Ci  $^{241}\text{AmBe}$  neutron irradiator [1]. Neutron irradiation was done at 100 cm distance from the source with the rectangular beam of 26.7 cm  $\times$  26.7 cm and the beam homogeneity of 10.6% (standard deviation of the average neutron dose equivalent rate of the field).  $H_p(10)$  for neutrons at the irradiation position was determined to be 2,102  $\mu\text{Sv/h}$ , based on Monte Carlo simulation and measurement with a moderated neutron spectrometer [1], with the agreement of 13% between both methods.



**Figure 3.** Irradiation set-up

### 2.3. The response characteristics of the OSLN dosimeters

OSL signals were read using the InLight® Auto 200 Reader before and after irradiation, typically 24 hours after irradiation. The corrected reading corresponded to the difference between the readings post- and pre-irradiation. The dose calculation algorithm implemented in the Neutron Mode of the reader was applied to the corrected reading for evaluation of received neutron dose equivalent. The average dose equivalent for each batch represented its evaluated value.

To test the accuracy of evaluated values, 3 batches of the OSLN dosimeters were irradiated with  $\sim 1\text{-}3$  mSv neutrons. The correction factor for the Neutron Mode of the reader was calculated from the ratio of delivered to evaluated neutron dose equivalent and the average correction factor was applied throughout this study.

The reliability of neutron personal dosimetry based on the OSLN dosimeter was investigated in terms of batch homogeneity, linearity of the dose-response relationship and fading characteristic. A work instruction for type testing of OSL dosimeters [2], which is based on IEC 61066:2006 [3], was used as the reference of the acceptance tests.

Batch homogeneity was defined as:

$$\text{Batch homogeneity} = (E_{\max} - E_{\min}) / E_{\max} \quad (1)$$

where  $E_{\max}$  and  $E_{\min}$  are the maximum and minimum evaluated values of each batch. The batch homogeneity should not exceed 0.3 [2].

To test the linearity of the OSLN dosimeter response, 7 batches of the OSLN dosimeters were randomly selected for irradiation with  $\sim 0.2\text{-}3$  mSv neutron dose equivalent. Evaluated values were plotted against delivered neutron dose equivalent. Subsequently, linear regression was applied to find the relationship between evaluated and delivered values. The  $R^2$  of linear regression should be at least 0.995 for the dosimeters to be qualified for use [2].

Finally, to investigate the fading property of the OSLN dosimeters, 6 batches were irradiated with 1 mSv neutrons. The exposed dosimeters were kept for 1, 7, 30, 60, 90 and 180 days post irradiation, respectively. Fading at any time point after irradiation should not exceed  $\pm 15\%$  [2].

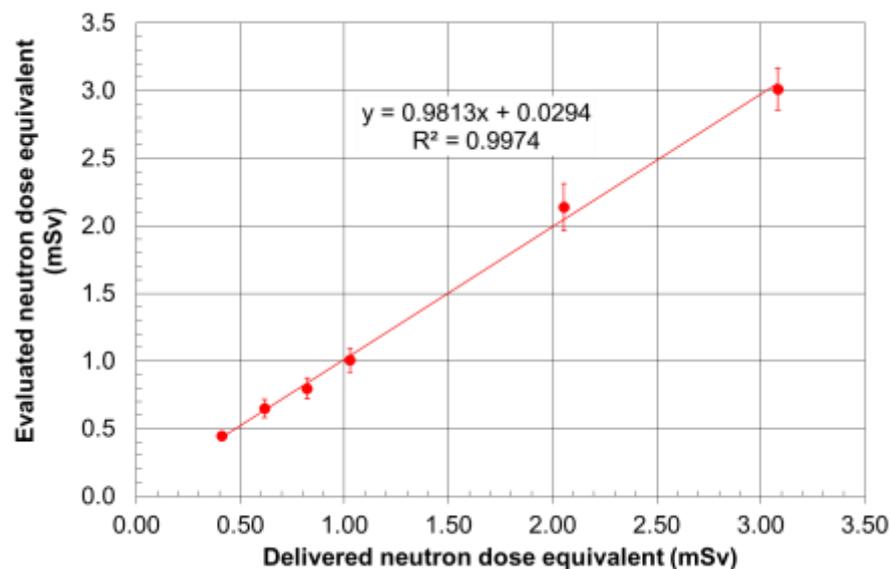
### 3. Results and Discussion

Table 1 shows evaluated values compared with delivered neutron dose equivalent before implementing the new correction factor in the InLight® Auto 200 Reader. The correction factor for the Neutron Mode of the reader was calculated to be  $1.82 \pm 0.06$ , which was used for evaluating neutron dose equivalent in the other tests throughout this study. The batch homogeneity was  $0.12 \pm 0.05$ , complying with the acceptance limit of  $\leq 0.3$ .

**Table 1.** Delivered and evaluated neutron dose equivalent before implementation of the new correction factor (CF).

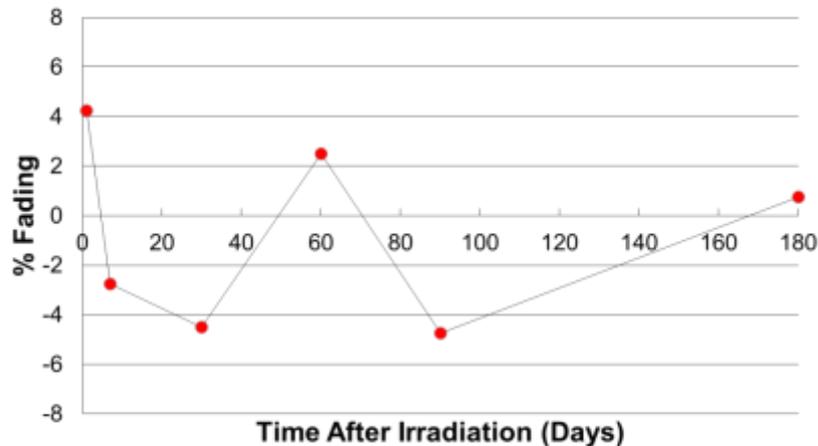
Delivered neutron dose equivalent (mSv)	Evaluated values (mSv)	Correction factors
1.03	$0.56 \pm 0.07$	1.84
2.05	$1.17 \pm 0.10$	1.75
3.08	$1.65 \pm 0.09$	1.86
Average		$1.82 \pm 0.06$

By irradiating the OSLN dosimeters with  $\sim 0.2$ -3 mSv neutrons, the relationship between evaluated and delivered neutron dose equivalent was obtained, as shown in Figure 4. The evaluated value for 0.2 mSv was found to be 60% lower than the delivered dose equivalent. Therefore, the result of this dose level was excluded from the linearity test and it was concluded that the lower limit of detection of the OSLN dosimeters should be in the range of 0.2-0.4 mSv. Linear regression was applied to the data of 0.4-3 mSv delivered neutron dose equivalent, yielding an excellent  $R^2$  value of 0.9974, which complied with the acceptance limit of  $\geq 0.995$ . The slope of the graph was 0.9813, i.e. close to 1, indicating good consistence between evaluated and delivered dose equivalent.



**Figure 4.** Dose-response of the OSLN dosimeters.

Six batches of the OSLN dosimeters were used in the fading test over the period of 1-180 days after irradiation. The result of the fading test is shown in Figure 5, indicating that the evaluated values fluctuated over time in the range of -4.75 to 4.25%, which were within the acceptance limit of  $\pm 15\%$ .



**Figure 5.** Fading of the OSLN dosimeters. Percentage fading corresponds to percentage discrepancy of the evaluated value from the delivered neutron dose equivalent

#### 4. Conclusions

The InLight® OSLN dosimeters as used for the personal dosimetry service of TINT were tested with a reference neutron field generated by the in-house 50 Ci  $^{241}\text{AmBe}$  neutron irradiator. Using the Neutron Mode of the InLight® Auto 200 Reader, a correction factor of  $1.82 \pm 0.06$  was required for accurate evaluation of personal neutron dose equivalent. The evaluated values exhibited excellent linearity and good agreement with delivered neutron dose equivalent in the detectable neutron dose equivalent under test from  $\sim 0.4$  to 3 mSv. The lower limit of detection of the OSLN dosimeters was found to be in the range of 0.2-0.4 mSv. Fading of OSL signals did not exceed  $\pm 5\%$  over the different time periods of up to 180 days post irradiation. From this study, personal dosimetry based on the investigated OSLN dosimeters is acceptably reliable under similar neutron exposure conditions, i.e. similar neutron energy spectra and dose equivalent values. Since the response of OSLN dosimeters depends highly on neutron energy spectra, the correction factor used by the reader should be determined for specific workplace neutron fields. Nevertheless, linearity of the dose-response relationship and fading of the OSLN dosimeters are expected to be independent of neutron fields and should be similar to the results presented in this paper.

#### References

- [1] Liamswan T, Channuie J and Ratanatongchai W 2015 Characterization of neutron calibration fields at the TINT's 50 Ci americium-241/beryllium neutron irradiator *J. Phys. Conf. Ser.* **611** 012004
- [2] Monthonwattana S and Esoa J 2014 *Work Instruction: Type testing for OSL dosimeters (WI-NSC-29)*, Thailand Institute of Nuclear Technology
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