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Research Article

Dose Rate Calibration of β Radiation Source in Risø TL/OSL-DA-20 Reader Device

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Abstract:

This research is focused on determining the dose rate calibration of beta irradiation source in the Risø brand TL/OSL-DA-20 model thermoluminescence (TL) and optically stimulated luminescence (OSL) reader device manufactured by DTU Physics which is an integral component of the Technical University of Denmark (DTU). The beta radiation source of this device comprises a pellet-shaped Strontium ceramic made from the $^{90}Sr/^{90}Y$ radionuclide, with a half-life of approximately 29.1 years. This investigation provides a thorough examination of reproducing equivalent dose levels by comparing reproduced OSL signals with the OSL signals of calibration quartz crystals which were previously exposed to a 5 Gy beta radiation emission. Throughout this process, dose durations and equivalent dose levels were analysed on optically stimulated luminescence signals. The collected OSL data aims to ensure the precise calibration of the radioactive source, contributing to reliable results in dosimetric measurements. This calibrated device is utilized in the Luminescence Laboratory co-run by the Physics Department and Nuclear Materials Research and Application Center of Selçuk University. The determined dose rate of the beta radiation source is found as 0.065 Gy/s.

1. Introduction

Calibration process has a very crucial role in various fields, ensuring the accuracy and reliability of measurement instruments, devices, or systems. This process consists of comparing the output of a device against a known standard to identify and correct any discrepancies. Also, it ensures the precision of measurements that is essential in scientific research, manufacturing, industries, and etc. Calibration is also important for maintaining the integrity of experimental results, supporting the validity of scientific studies, and improving trust in data-driven decision-making. The absence of proper calibration, might give rise to a risk of inaccurate readings, potentially leading to flawed analyses. Thus, the meticulous attention to calibration is indispensable for upholding the quality and reliability of measurements across diverse applications. Such as accurate calibration of radioactive sources is paramount for obtaining reliable measurements in dosimetric applications.

Apart from the calibration aspect, the ionizing effect of radiation leads to the induction of electrons at the energy level of the valence band of a material, in accordance with the band theory. When there is a localized energy level present between the energy levels of the conduction band and the valence band, electrons have the potential to become trapped. The liberation of these trapped electrons can be facilitated through the stimulation of heat or light, which is commonly referred to as thermoluminescence (TL) and optically stimulated luminescence (OSL), respectively. This process enables the electrons to return to their ground energy level, accompanied by the emission of photons with energy proportional to the local energy level[1–10]. The effective application of these methods in radiation measurements requires obtaining reliable measurements.

2. Material and Methods

This investigation delves into the process of calibration that is carried out using the Risø TL/OSL-DA-20 model TL/OSL reader device [11,12]. The primary focus of this examination revolves around the outcomes of the calibration performed on calibration quartz crystals, which are supplied by DTU Physics and have been pre-exposed to a beta emission of 5 Gy beta radiation. Ensuring the precision of these calibrations is of utmost importance as it establishes the device's capability to provide accurate assessments of dose, thus making a significant contribution to the studies that will be conducted in the Luminescence Laboratory co-run by the Physics Department and Nuclear Materials Research and Application Center of Selçuk University (Figure 1).

Figure 1. *Risø TL/OSL-DA-20 model TL/OSL reader device situated in Luminescence Laboratory co-run by the Physics Department and Nuclear Materials Research and Application Center of Selçuk University.*

The beta irradiation source to be calibrated of this device is a pellet shaped Strontium ceramic made of $^{90}Sr/^{90}Y$ radionuclide which has a half-life of ~29.1 years [13]. Risø calibration quartz crystals [14], DTU Physics-supplied and pre-exposed to a 5 Gy level of beta irradiation, are shown in Figure 2 as in its protection package (Figure 2-a) and as in measurement position within a stainless-steel cup (planchets) on the carousel (Figure2-b).

A local energy level between the valence band and conduction band of a semiconductor or insulator material is called a “deep electron trap” if that local energy level is closer to the Fermi energy level. In a similar way, that trap is specified as a “shallow electron trap” if that is closer to the conduction band [1–10] (Figure 3).

a)

b)

Figure 2. *Risø calibration quartz crystal which were supplied by DTU Physics.* ***a)*** *in the package* ***b)*** *on the stainless-steel cup (planchet).*

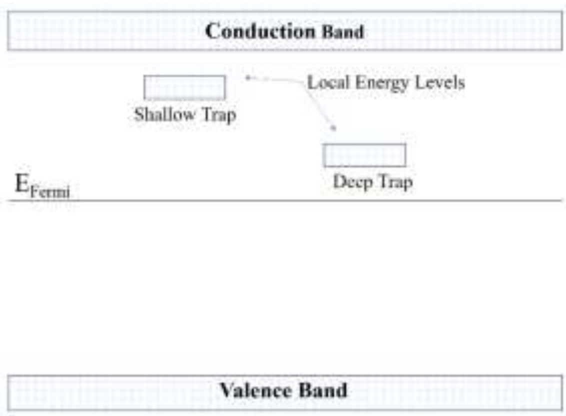

Figure 3. *A schematical representation of local energy levels and the band gap structure of a semiconductor or insulator material.*

In the calibration experiments, a thermal cleaning step was applied to measurements in order to read only reliable information deposited in deep traps, and cooled back to room temperature [14,15]. Then

OSL signal readout step was completed. This reading process was applied on the first OSL readout of Risø calibration quartz crystals which were pre-exposed to a 5 Gy level of beta irradiation, and the rest of the regeneration of new OSL signals using devices beta irradiation source for different irradiation durations, single aliquot regeneration process was applied in other words[16]. Identical thermal cleaning and readout settings were applied for each individual experimental step.

3. Results and Discussions

For this experiment, OSL signals were recorded using a Hoya U-340 optical bandpass filter. Before starting the OSL reading of Risø calibration quartz which is pre-irradiated at 5 Gy beta irradiation dose level, a thermal cleaning step was applied from room temperature (RT) up to 220°C using a linear heating rate of 5°C/s and kept at 220°C for 10 seconds [14]. Sample then cooled back to RT. Then OSL reading was applied using blue light emitting diodes (LEDs) at 125°C. Thus, a reference OSL signal of calibration quartz was obtained for a 5 Gy beta irradiation dose level. After recoding reference signal, the next step started by irradiating the sample via using beta radiation source for 1 second to record the minimum possible dose level of the source. Then identical thermal cleaning process was applied, in other words sample was heated up from RT up to 220°C using a linear heating rate of 5°C/s and kept at 220°C for 10 seconds. Then OSL signal was recorded using identical readout conditions and same optical bandpass filter: blue LEDs used at 125°C. This regeneration process was applied for different irradiation duration as follows: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 150 and 200 seconds. Recorded reference OSL signal and regenerated ones are plotted as semi-log together in Figure 4.

In Figure 4 x-axis is time in seconds, y-axis is OSL intensity in photon counts per photo multiplier tube's channel time (0.2 seconds here). Bold drawn black colored OSL curve represents the OSL signal of Risø calibration quartz, the rest of the OSL curves represent with transition of colors from purple to red. OSL maximum values of OSL emissions, in units of photon counts per channel time, were plotted against exposure time to beta radiation in seconds and given in Figure 5. Distribution of OSL maximum value against irradiation duration fitted with Equation 1, and interpolated value for $y = 1$ was found as ~77 seconds. This implies that, an exposure to beta radiation of this source is equal to 5 Gy and if 5 Gy is divided by 77 seconds, it results as ~0.065 Gy/s

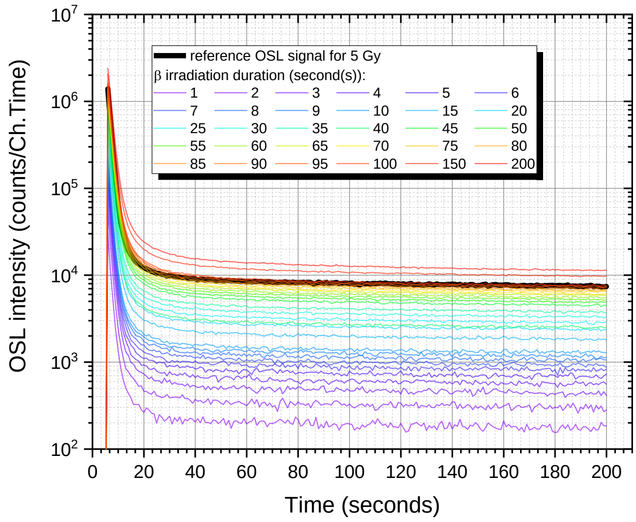

Figure 4. *Reference OSL signal and regenerated OSL signals.*

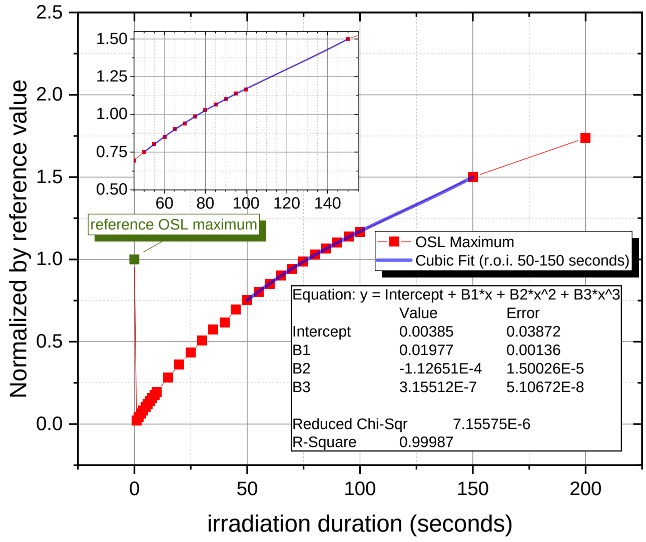

Figure 5. *Distribution of OSL maximum values against different irradiation durations.*

which is the dose rate of this radionuclide as of the calibration date January 26th 2023.

$$y = intercept + B_1x + B_2x^2 + B_3x^3 \qquad (1)$$

4. Conclusions

A series of OSL measurements were completed with the purpose of calibration the dose rate of pellet shaped Strontium ceramic made of $^{90}Sr/^{90}Y$ radionuclide in Risø TL/OSL-DA-20 model TL/OSL reader device which is situated in TL/OSL Dosimetry Measurements and Dating Laboratory located in the Physics Department of Selçuk University/ Konya/ Türkiye. DTU Physics supplied Risø calibration quartz crystals which pre-exposed to a 5 Gy beta irradiation was used as reference material. Its OSL signal was recorded after a thermal cleaning and irradiated with the to-be-calibrated source for different irradiation durations from 1 second up to 200 seconds to regenerate the OSL signal of the calibration crystal to compare with the reference OSL signal of it. Dose rate of the new device's $^{90}Sr/^{90}Y$ radionuclide was determined as 0.065 Gy/s. Risø TL/OSL-DA-20 model TL/OSL reader device is ready for reliable and precise measurements in the aforementioned Luminescence Laboratory.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of 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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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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