

Safelight for OSL dating laboratories: a follow-up study

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Abstract

We introduce a new lamp for use in optically stimulated luminescence (OSL) dating laboratories. The lamp is based on an LED with the peak emission wavelength at 594 nm that was previously characterised as safe for both samples and operators by Sohbati et al. (2017). We demonstrate that 48 h exposure to this lamp, delivering a power density of $0.2 \mu\text{W}\cdot\text{cm}^{-2}$ at sample position, results in $1 \pm 3 \%$ loss in the infrared stimulated luminescence (IRSL) signal from clean K-rich feldspar grains. The loss in quartz OSL and K-feldspar post-IR IRSL signals is anticipated to be even smaller, given their lower bleaching rate at the lamp's peak wavelength (i.e. 594 nm). We reiterate the conclusion by Sohbati et al. (2017) that the illumination provided by such a lamp is desirable for OSL dating laboratories.

Keywords: Luminescence dating; Laboratory illumination; Safelight; Darkroom; LED

1. Introduction

Samples intended for optically stimulated luminescence (OSL) dating are usually sensitive to light. It is thus important that any inherent signal is preserved during sample preparation prior to measurement. An OSL laboratory lamp ("The Risø Safelight") has been designed to meet this objective, particularly when used with quartz and feldspar. The lamp makes use of the same LED that was identified as safe for both samples and operators by Sohbati et al. (2017). The peak emission wavelength of this amber-coloured LED at 594 nm is far from the feldspar infrared absorption reso-

nance at ~ 850 nm (Hütt et al., 1988) and close to the human eye's maximum spectral sensitivity at 555 nm (Pokorny, 1979). Consequently, it can provide better visibility at lower intensities than the more common red-coloured lamps with typical maximum emission at 625-700 nm (e.g., Lamothe, 1995; Berger & Kratt, 2008), while having effectively less impact on the trapped charge giving rise to the quartz fast-component OSL and feldspar infrared stimulated luminescence (IRSL) signals.

Sohbati et al. (2017) measured the bleaching effect of this LED at a power density of $\sim 12.7 \mu\text{W}\cdot\text{cm}^{-2}$, and calculated that 48 h exposure to it at a power density of $\sim 0.2 \mu\text{W}\cdot\text{cm}^{-2}$ should result in $\leq 1\%$ loss of IRSL signal at 50°C (IR_{50}) from clean K-rich feldspar grains. However, no measurement was carried out directly at $0.2 \mu\text{W}\cdot\text{cm}^{-2}$ to validate this conclusion. The purpose of this study is to directly quantify the bleaching effect of this new laboratory lamp on the K-feldspar IR_{50} signal at a power density of $\sim 0.2 \mu\text{W}\cdot\text{cm}^{-2}$ at sample position.



Figure 1. Photo of the lamp tested in this study.

2. Methods

The new lamp consists of an array of nine LEDs arranged in a ring inside a housing of die-cast aluminium alloy, covered by a stack of transparent (3 mm thick) and semi-transparent (1 mm thick) acrylic light diffusers at the front to enhance illumination uniformity. It is fitted with a user-adjustable power control allowing the output to be adjusted from 1.75 to 100% of full power (Fig. 1). The corresponding minimum and maximum power consumptions of the lamp are 0.3 and 3 W, respectively. Measurement of the light emission spectrum was undertaken using an Ocean Optics MAYA2000-Pro spectrometer, and the power density was determined with a THORLABS PM100D power meter console equipped with a S130C photodiode sensor. The distance between the lamp and the samples was ~1.7 m and the power density at sample position was set to $0.2 \mu\text{W}\cdot\text{cm}^{-2}$.

Two K-rich feldspar (i.e. $\rho < 2.58 \text{ g}\cdot\text{cm}^{-3}$) samples were tested: sample 146610 is a loess sample from South Island, New Zealand (Sohbati et al., 2016) that was originally among the samples tested by Sohbati et al. (2017), and sample H33052 is the K-rich feldspar fraction of a sand sample from a dune ridge in Rømø, Denmark. Risø calibration quartz is produced from the quartz fraction of this sample (Hansen et al., 2018).

Forty-eight small aliquots (~2 mm in diameter) from each sample were prepared by fixing the grains in stainless steel cups using Rüschi Silkospray silicone oil. Six of these were stored in the dark as a reference, while the rest were exposed for cumulative exposure periods of 3, 6, 12, 24, 48, 96 and 192 hours. Six aliquots were measured after each exposure period. In the case of sample H33052, eight aliquots were displaced during transportation. These are missing from exposure groups of 12 h (1 aliquot), 24 h (1 aliquot), 48 h (1 aliquot), 96 h (2 aliquots) and 192 h (3 aliquots).

All IR₅₀ L_n/T_n measurements were performed on a Risø TL/OSL Risø Model-DA-20 with an automated Detection And Stimulation Head (DASH) (Lapp et al., 2015). The IRSL signal was stimulated for 100 s using infrared diodes delivering a power density of ~175 mW·cm⁻² at 850 nm, and measured through a blue filter pack composed of a 3-mm-thick Schott BG3 and a 2-mm-thick Schott BG39 filters. The preheat temperature was 250 °C, maintained for 60 s and the test dose size was ~1.2 Gy for all IRSL measurements. The heating rate was 5 °C·s⁻¹ during all thermal treatments. All L_n/T_n values were calculated using the first 1 s of the signals subtracted by the average of the last 10 s.

3. Results

The lamp emits at a peak wavelength of 594 nm, which is similar to that identified as being optimum by Sohbati et al. (2017). Output power was adjusted so that the power density at the position of the aliquots was ~0.2 $\mu\text{W}\cdot\text{cm}^{-2}$. According to the calculations by Sohbati et al. (2017), these conditions should result in $\leq 1\%$ loss of the K-rich feldspar IR₅₀ signal after 48 h. It is noteworthy to add that the IR₅₀ signal is

more easily bleached than the quartz OSL signal at the peak emission wavelength of the lamp (i.e. 594 nm), presumably because the feldspar IRSL trap photoionization cross section at this wavelength is greater than that of the source trap for the quartz fast-component OSL signal (Spooner, 1994a,b). This is supported by the results of Sohbati et al. (2017), who, on average, observed ~30% lower bleaching in the quartz OSL signal than the K-rich feldspar IR₅₀ signal from their samples exposed to this wavelength. Consequently, if we can establish the safety of the lamp using the IR₅₀ signal, we can be confident that it is also safe for use with the quartz OSL and the more-difficult-to-bleach K-feldspar post-IR IRSL signals.

The measured L_n/T_n values for both samples are summarised in Fig. 2. A visual inspection of the data indicates that there are a few outlying datapoints (Fig. 2). For the purpose of identifying and removing the outliers objectively and quantitatively, an outlier detection method using quantile regression (Breiman, 2001; Meinshausen, 2006) was applied to both datasets. In this approach, the conditional quartiles ($Q1$, $Q2$ and $Q3$) and the interquartile range (IQR) of all the observations (i.e. L_n/T_n values) are estimated within the range of the predictor variable (i.e. the exposure time) based on a quantile random forest of regression trees (Breiman, 2001; Meinshausen, 2006). The individual observations are then compared to the quantities $F1 = Q1 - 1.5 \times IQR$ and $F2 = Q3 + 1.5 \times IQR$ defined as outlier detection thresholds; the so-called “fences”. Any observation that is less than $F1$ or greater than $F2$ is considered an outlier. Using this approach, three and one outliers were detected in the 146610 and H33052 datasets, respectively (Fig. 2). These are excluded from further analysis and not included in calculating the bleaching rates.

To derive the bleaching rate of each sample individually, the data were fitted using the model by Bailiff & Barnett (1994) with the functional form of $I = I_0(1 + Bt)^{-P}$, where I_0 is initial intensity, t is exposure time, and B and P are constants such that $1 \leq P \leq 2$ (Fig. 3). For both samples, the resulting best-fit parameter values translate into an IR₅₀ signal loss of $1 \pm 3\%$ after 48 h of exposure to the lamp (Table 1).

4. Discussion

The K-rich feldspar IR₅₀ signal loss of $1 \pm 3\%$ calculated here is, within the error limits, consistent with the predicted value of $\leq 1\%$ previously reported by Sohbati et al. (2017). However, the calculated upper bound of 4% implies that, given the measurement and fitting errors, the apparent signal reduction can be as high as 4%. Sohbati et al. (2017) observed a difference up to ~14% ($n = 4$) in the bleaching rate of the K-feldspar samples tested in their study. It is thus curious that, despite their very different geological origin, depositional environment and grain size, both samples studied here appear to have similar bleaching rates. This may be due to the insignificant loss of the IR₅₀ signal and thus the limited range of the observed L_n/T_n values that hinder us from calculating the true bleaching rate of the two samples over these

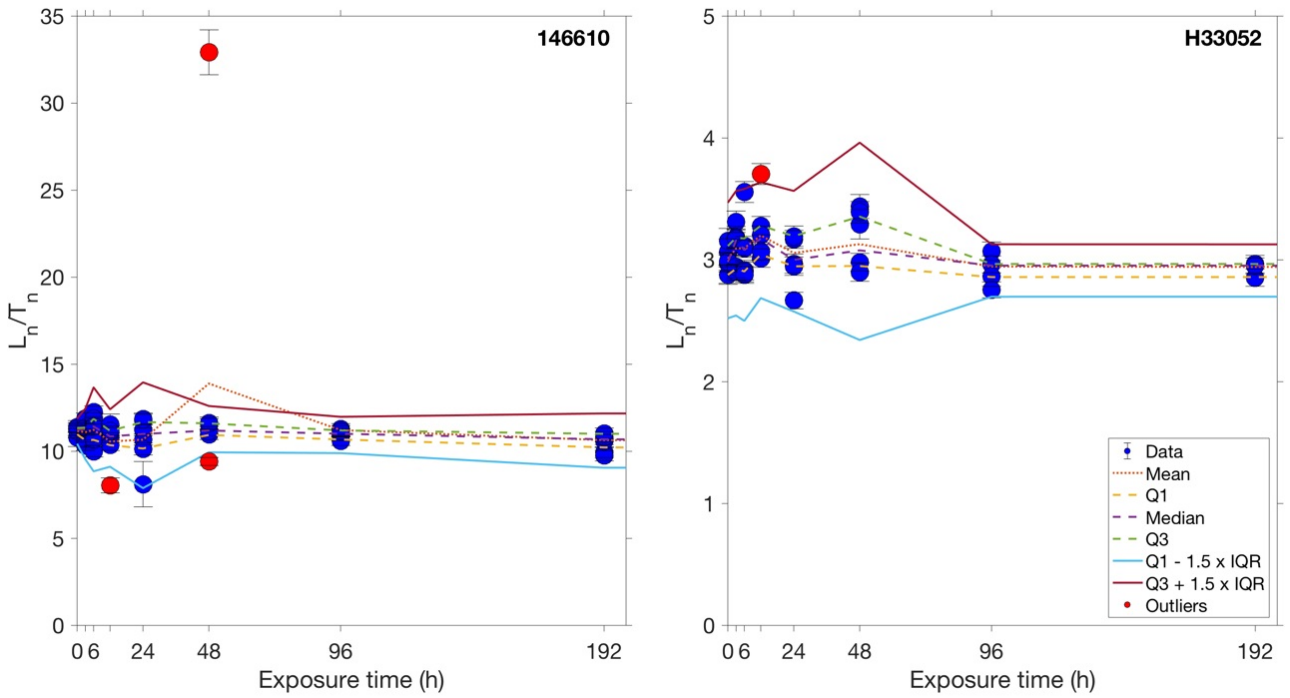


Figure 2. The IR₅₀ L_n/T_n measurements versus exposure time. Dashed lines indicate the first ($Q1$), the second ($Q2$ or median) and the third ($Q3$) conditional quartiles and the dotted lines show the mean. Solid lines represent the quantities $F1 = Q1 - 1.5 \times IQR$ and $F2 = Q3 + 1.5 \times IQR$ defined as threshold for outlier detection. Circles in red denote the detected outliers, which lie below $F1$ or above $F2$.

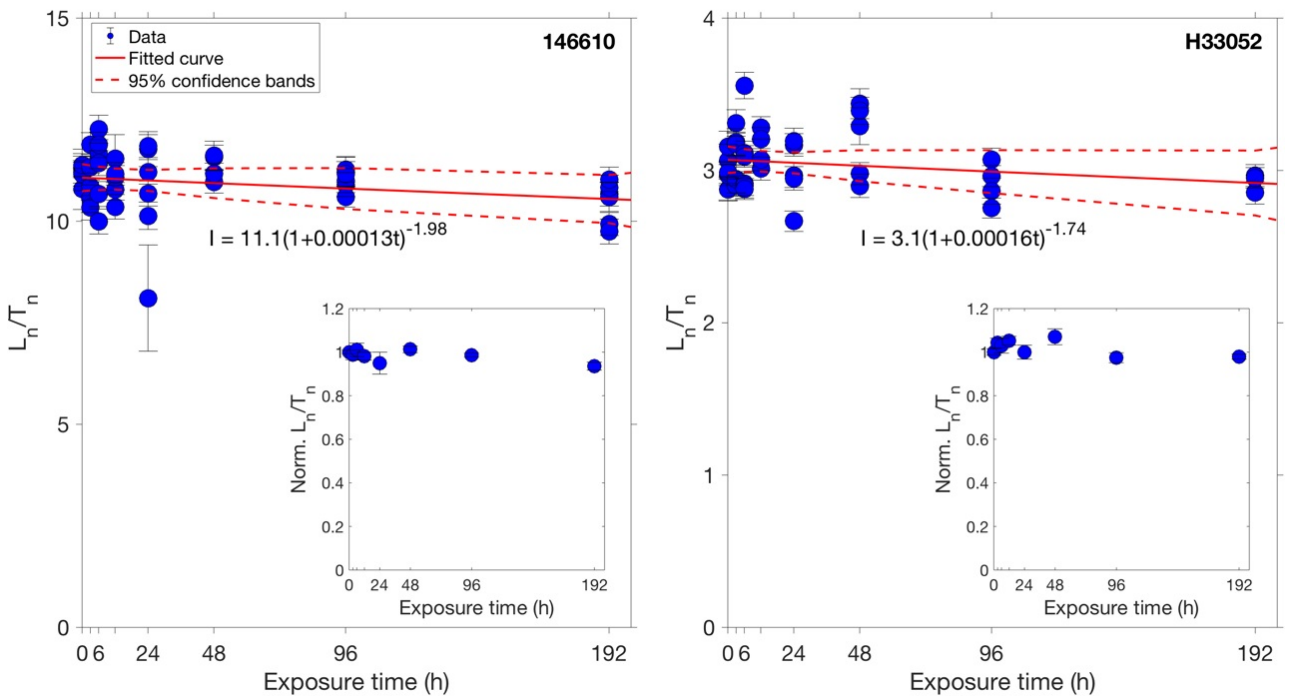


Figure 3. The same data as in Figure 2 excluding the outliers. Solid lines represent the best fit of the model by [Bailiff & Barnett \(1994\)](#) in the form of $I = I_0 (1+Bt)^{-P}$ to the data, and the dashed lines indicate the 95% confidence bands. The insets show the same data as in the main figures averaged and normalised to the corresponding data at $t = 0$.

Table 1. Summary of the samples, the best-fit parameter values, the goodness-of-fit statistics and the calculated signal loss after 48 h of exposure to the lamp. CB: confidence bounds, SSE: the sum of squares due to error, DFE: degrees of freedom, RMSE: root mean squared error.

Sample name	Dose + se (Gy)	Grain size (μm)	I_0 [95% CB]	B [95% CB]	P [95% CB]	Predicted signal loss in % [95% CB]	Goodness-of-fit statistics [SSE, R-square, DFE, Adjusted R-square, RMSE]	Reference
146610	18.5 ± 4	40–63	11.07 [10.74, 11.41]	0.0001297 [-0.0518, 0.05206]	1.983 [-782.7, 786.7]	1.22 [-3.32, 3.37]	[2.1029, 0.0590, 42, 0.0142, 0.2238]	Sohbati et al. 2016
H33052	4.81 ± 0.07	180–250	3.07 [2.983, 3.158]	0.0001553 [-0.0522, 0.05251]	1.735 [-575.7, 579.1]	1.28 [-3.35, 3.37]	[0.4164, 0.0546, 36, 0.0021, 0.1076]	Hansen et al. 2018

exposure times. It is notable that the observed signal loss in 146610 and H33052 after 192 h (i.e. 8 days) of exposure is only $6.48 \pm 2.02\%$ ($n = 6$) and $2.16 \pm 1.9\%$ ($n = 3$), and the corresponding values after 48 h are $-1.24 \pm 1.6\%$ ($n = 4$) and $-7.09 \pm 3.75\%$ ($n = 5$), respectively. Obviously, a more accurate and precise estimate of the bleaching rate requires substantially more datapoints, at much longer exposure times up to a few years; this was deemed neither practicable nor necessary for the purposes of this study.

5. Conclusions

Our new bleaching tests demonstrate that 48 h of exposure to the new laboratory lamp emitting at 594 nm with a power density of $\sim 0.2 \mu\text{W}\cdot\text{cm}^{-2}$ at the sample position results in a loss of $\sim 1\%$ in the IR_{50} signal from the K-rich feldspar samples investigated here. The loss of quartz OSL and K-feldspar pIRIR signals is anticipated to be even smaller than 1%, as they have a lower bleaching rate at the peak emission wavelength of the lamp (Sohbati et al., 2017). This is in line with the earlier conclusion by Sohbati et al. (2017), who established that such lighting conditions in OSL dating laboratories are optimum, as they are both safe for samples and provide a clear visibility for operators.

It is noteworthy that the $1\%/48 \text{ h}/0.2 \mu\text{W}\cdot\text{cm}^{-2}$ IR_{50} signal loss calculated above is derived from clean K-rich feldspar grains that were directly exposed to the lamp. The signal reduction in dirty bulk samples and coated sand grains during the early steps of sample preparation such as sieving and HCl acid treatment is anticipated to be even lower. Furthermore, the total cumulative exposure time to laboratory light during most routine sample preparation procedures is usually much shorter than 48 h. Thus, if necessary, the operator could afford using higher power densities (e.g. by up to a factor of 2) for shorter durations, during high-risk sample preparation steps such as HF treatment. Finally, regardless of how small the bleaching effect of a safelight, the common-sense advice is to keep the exposure of OSL samples to any light source to an absolute minimum prior to measurement of the natural signal.

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Reviewer

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