Residual Optically Stimulated Luminescent (OSL) Signals for Al_2O_3:C and a Readout System with Reproducible Partial Signal Clearance

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Abstract

Optically stimulated luminescent dosimeters (OSLDs) are devices that, when stimulated with light, emit light in proportion to the integrated ionizing radiation dose. The stimulation of OSL material results in the loss of a small fraction of signal stored within the dosimetric traps. Previous studies have investigated the signal loss due to readout stimulation, and the optical annealing of OSLs. This study builds on former research by examining the behavior of OSL signal after annealing, exploring the functionality of a previously developed signal loss model, and comparing uncertainties for dosimeters reused with or without annealing. For a completely annealed dosimeter, the minimum signal level was 56 ± 8 counts, and readings followed a Gaussian distribution. For dosimeters above this signal level, the fractional signal loss due to the reading process has a linear relationship with the calculated signal. At low signal levels (below 20,000 counts) in this OSL system, calculated signal percent errors increase significantly but otherwise are on average 0.72 ± 0.27%, 0.40 ± 0.19%, 0.33±0.12%, and 0.24±0.07% for 30, 75, 150, and 300 readings. Theoretical calculations of uncertainties showed that annealing before reusing dosimeters allows for dose errors below 1% with as few as 30 readings. Reusing dosimeters without annealing leads to extremely large increases in error if only 30 or 150 readings are taken, thus 300 readings would be necessary keep dose errors below 1%. Note that these dose errors do not include the error associated with the signal-to-dose conversion factor.

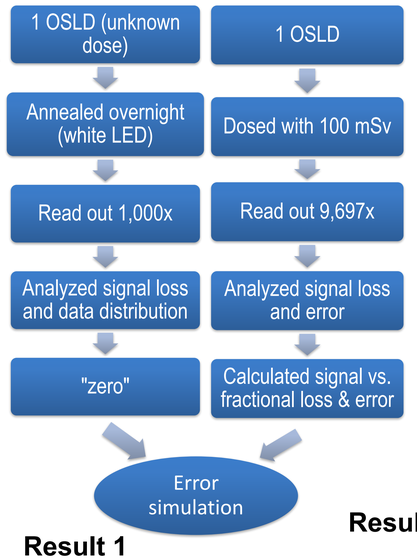
Objectives:

- What is "zero" or maximum depletion of OSL signal?
- What is the relationship between calculated signal and fractional loss due to the readout of dosimeters?
- What is the relationship between calculated signal and its error?
- How can these relationships be used to estimate the propagation of error if dosimeters are to be reused without annealing?
- How does annealing between reuses impact the error?

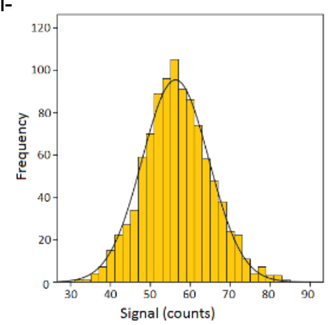
Introduction:

- OSLDs are devices that measure absorbed doses of ionizing radiation.
- When stimulated by light, OSLDs emit visible light proportional to their absorbed ionizing radiation dose. A PMT captures the emitted light and converts it to an electrical signal (counts).
- Re-reading a dosimeter can help improved confidence and the statistics regarding a measurement (Abraham et al. 2017a).
- Upon stimulation with light in most OSL systems, the dosimeters lose a small fraction of the signal stored in dosimetric traps.
- The response of an OSL due to a given irradiation can be calculated by subtracting the residuals from the response. The uncertainty in determining the dose includes uncertainty in the determination of the residual signal.
- Alternatively, OSLs can be optically annealed beforehand using light sources with the proper spectra (Abraham et al. 2017b).

Methods



Result 1



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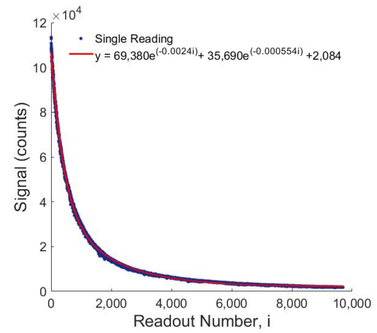
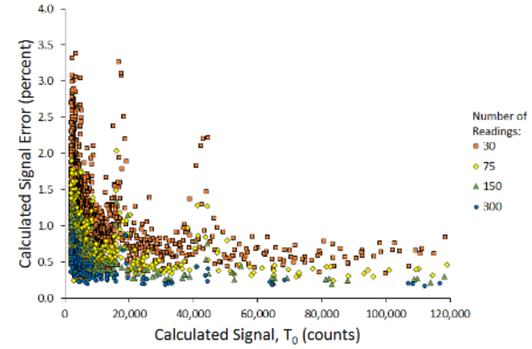


Result 3



Signal loss correction formula:
The loss of signal arising as a result of the readout process was corrected for using the mathematical model:

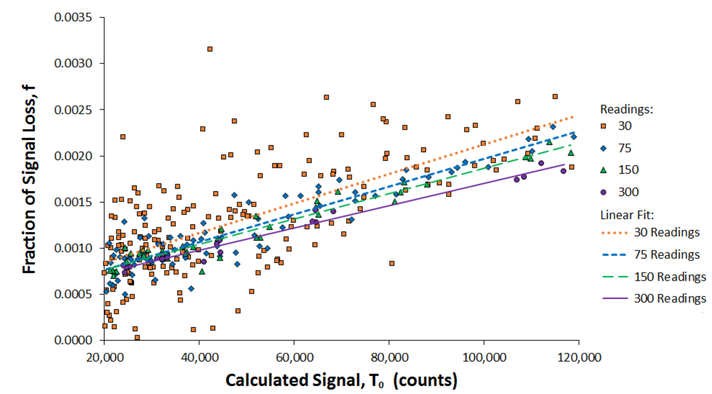
$$S_i = T_0(1-f)^i$$

where i is the readout number, S_i is the signal for the ith reading, f is a dimensionless fitted parameter that estimates the fraction of signal lost in the reading process, and T_0 is a fitted parameter that hypothetically represents the signal at the time of the first reading if f were zero (Abraham et al. 2017a). For the dosimeter interrogated 9,697 times, the data were analyzed in sections of varying sample sizes.

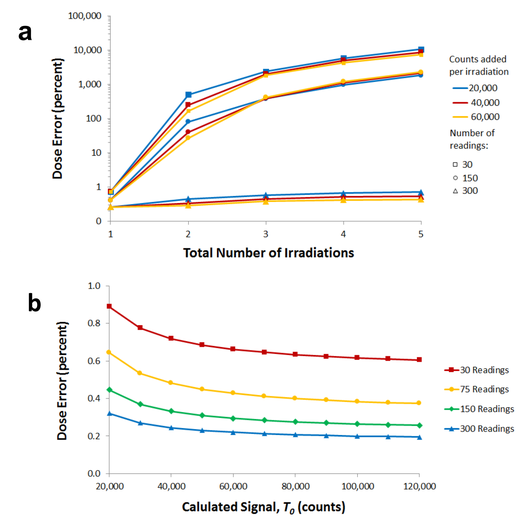
Key Results:

1. The baseline "zero" for a fully annealed dosimeter was 56 ± 8 counts in this particular OSL dosimetry system. Data followed a Gaussian distribution (black curve).
2. The signal depletion due to 9,676 readouts was the sum of two exponentials plus a constant.
3. Fractional loss f increases linearly with calculated signal T_0. When 300 readings are taken, $f = (1.20 \times 10^{-8})T_0 + 0.000497$ with $R^2 = 0.98$.
4. Calculated signal error increases significantly at lower signal levels and when fewer readings are taken. At higher signal levels, the calculated signal percent error was 0.72 ± 0.27% when 30 readings were taken; this decreased for increased number of readings.
5. Based on simulations: to achieve relative errors below 1%, 300 readings would be necessary when not annealing (a), whereas as few as 30 readings are needed if annealing between irradiations (b).

Result 4



Result 5



Conclusions

OSLDs are radiation detection devices that lose a small amount of signal with each readout stimulation. Once an OSL is annealed, it no longer exhibits this signal loss with readout, and multiple readings follow a Gaussian distribution. For a completely annealed commercially available Al_2O_3:C dosimeter, the minimum signal level detected by a commercial reader was 56.24 ± 8.24 counts. Note that the effects of dosimeter history or accumulated dose on the minimum signal level was not evaluated in this work. Minimum signal levels may vary for OSL readers due to differences in background noise levels and stimulation methods. The fractional signal loss due to the reading process with this reader has a linear relationship with the calculated signal for dosimeters that have not been completely annealed. When readout 300 times, the fractional loss parameter corresponds to the equation $f=(1.20\times10^{-8})T_0+0.000497$ with a R-squared value of 0.98. Above noisy low signal levels, the calculated signal percent errors are on average 0.72 ± 0.27%, 0.40 ± 0.19%, 0.33±0.12%, and 0.24±0.07% for 30, 75, 150, and 300 readings with the OSL system tested here. Simulations following error propagation rules showed that annealing before reusing dosimeters theoretically permits dose errors below 1% with as few as 30 readings. Reusing dosimeters without annealing leads to extremely large errors for only 30 or 150 readouts, thus theoretically around 300 readings would be necessary to achieve errors below 1%.

Acknowledgements

The authors wish to thank Tobias J. Buth, Alexander S. Dawson, Rebecca A. Lynch, Hien Nguyen, and Travis Smith, who performed data collection. This work was funded in part by the Consortium for Verification Technology under the Department of Energy National Nuclear Security Administration, award number DE-NA0002534.

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Abraham SA, Frank SJ, Kearfott KJ. An efficient, affordable optically stimulated luminescent (OSL) annealer. Health Phys 113:2-12; 2017b. DOI: 10.1097/HP.0000000000000677.

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