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Lower Limit of Detection Study and Uncertainty Analysis of Harshaw LiF TLD Material

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Abstract

In measurement systems, there is a net signal level above which a true reading will be detected with a high confidence and a positive result will be reported qualitatively. This level is referred to as the lower limit of detection (LLD). The LLD varies as a function of the environment for a typical dosimetry system. Presented is a long term study of the LLD and uncertainty analysis of various LiF materials at various storing temperatures. The study is carried out over a period of 24 months at storage temperatures of 0˚C, 20˚C and 40˚C using more than 3500 dosimeters. The length and variations of this study may be the most comprehensive study to date. The materials are Harshaw LiF based TLD cards and extremities, which include LiF:Mg,Ti and LiF:Mg,Cu,P materials in their different isotopes, sizes and forms. Different time-temperature readout schemes are also included in the study. The results show that LLD increases over the storage time and the Harshaw TLD™ LiF:Mg,Cu,P provide better LLD compares to LiF:Mg,Ti.

Introduction

The ability to measure a dose at low dose levels and the confidence of this measurement are considered as important characteristic properties for a dosimetry system. This low dose detection ability is recognized by the lower limit of detection (LLD) and the confidence is characterized by its uncertainty.

The commonly accepted definition of LLD, derived by Roberson and Carlson, is expressed as:

$$LLD = \frac{2\left(t_n s_0 + t_m^2 s_\mu^2 H_B\right)}{1 - t_m^2 s_\mu^2} \qquad (1)$$

Where,
t_n or t_m = student's t value corresponding to 95% confidence and (n-1) or (*m-1*) degrees of freedom
s_o = standard deviation of n background dosimeters
s_μ = relative standard deviation ofmirradiated dosimeters
H_B = average measurement of background (induced and non-induced radiation)

LLD depends on not only the deviation and sample size of the irradiated and non-irradiated samples, but also the background H . As the monitoring period goes longer, the background builds up so that the LLD is expected to increase. In addition, the environmental temperature affects the delectability as well.

"The uncertainty of the result of a measurement generally consists of several components which, in the CIPM approach, may be grouped into two categories according to the method used to estimate their numerical values:
A. those which are evaluated by statistical methods; and
B. those which are evaluated by other means."

The Type A is associated with uncertainty arising from a random effect and its evaluation can be based on any valid statistical method for treating data.

The Type B is from a systematic effect and its evaluation is usually based on scientific judgment using all the relevant information available, which may include:
- *previous measurement data,*
- *experience with, or general knowledge of, the behavior and property of relevant materials and instruments,*
- *manufacturer's specifications,*
- *data provided in calibration and other reports, and*
- *uncertainties assigned to reference data taken from handbooks.*

The total uncertainty is:

$$U_{Total} = \sqrt{U_A^2 + U_B^2} \qquad (2)$$

Presented here is a continuous work of Luo. It covers a systematic study of Harshaw LiF TLD material of its LLD, at various temperatures over long period, and an uncertainty analysis for the fading study from the previous work.

Setup, Study and Results

A detailed setup was described in the previous Luo's paper. Three storage temperatures are implemented: standard laboratory temperature ; low temperature 0˚C and high temperature 40˚C. Five dosimeters are irradiated to 3-mSv at either the beginning or the end of the monitoring period and a set of three un-dosed dosimeters serving as the background samples are processed together with irradiated samples. All dosimeters are wrapped using aluminum foil to reduce any unnecessary irradiation during the storage. In this work, only TLD cards are studied. These cards are LiF based LiF:Mg,Ti and LiF:Mg,Cu,P detectors in natural, Li-7 enriched and Li-6 enriched.

System Uncertainty

To minimize the overall uncertainty, the same TLD Reader and irradiator are used throughout this study. Therefore the uncertainty from the system is the same. This system uncertainty (Usys) is mainly B type sources related to the instrument. One overall dosimeter variation, an A type, is estimated from the element correction coefficients (ECC) of the 3000 dosimeters used in the study. The sources of the system uncertainty are listed and summarized in Table 1:

Total System Uncertainty

Source of Uncertainty	Type A	Type B	
Dosimeter Variation: (ECC)	**5.15%**		
Radiation Source: Sr-90			**0.3%**
Reader: Harshaw Model 8800			**1.3%**
		Reference Light	0.5%
		High Voltage	0.0%
		Heating Temperature	0.3%
		Dark Current	0.0%
		Linearity	1.0%
		Reader Correction Factor	0.5%
Total Type	**5.15%**		**1.3%**
Total System U_{sys} =	**5.3%**		

Background

At each data point, three background measurements are taken. They are the average TL readout of three un-irradiated dosimeters stored at 0˚C, 20˚C and 40˚C, respectively. The uncertainty of this A type background,U_{Bkg}, is calculated by: $t_{n-1}/\sqrt{n}$ multiplying its standard deviation s_o. Then the total uncertainty is the combination of U_{Bkg} and U_{sys}. The accumulated background and its uncertainty over the two years are plotted in the figures 1 and 2.

Fig 1 Background accumulation for LiF:Mg,Ti at temp(s) 0˚C, 20˚C and 40˚C

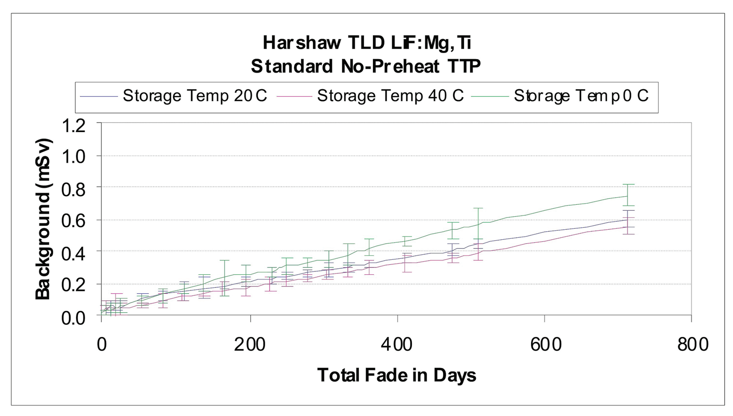
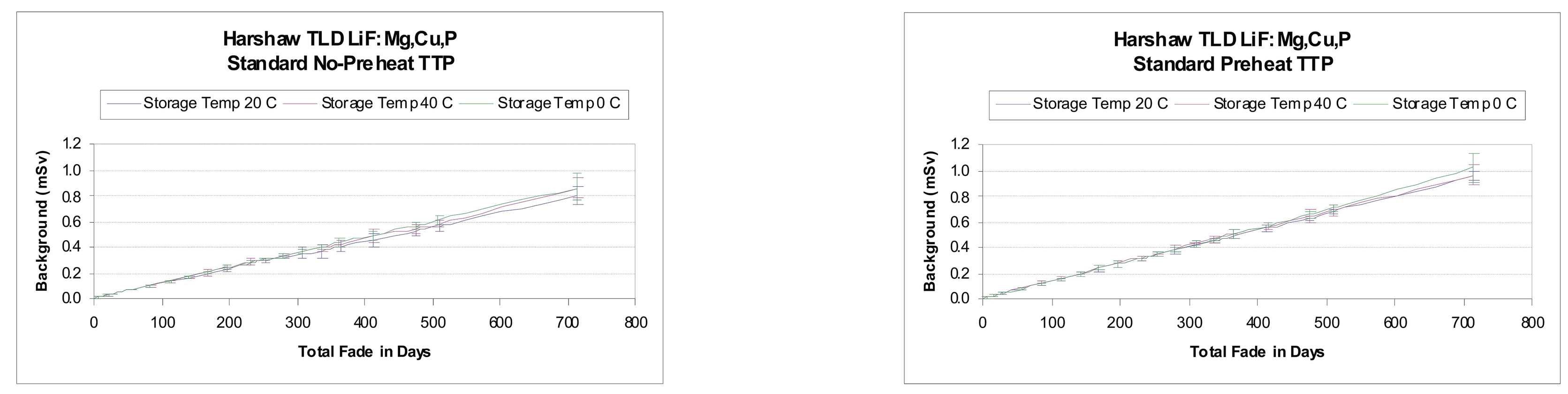


Fig 2 Background accumulation for LiF:Mg,Cu,P at temp(s) 0˚C, 20˚C and 40˚C for no-preheat and preheat TTPs



For LiF:Mg,Ti, the background is accumulated faster at the lower storage temperature, figure 1. The material is more sensitive at lower temperatures due to the slower fading of low temperature peaks (peak 2 and 3). However, for LiF:Mg,Cu,P, the storage temperature does not affect the accumulation rate of the background but the PreheatTTPhas a higher background, figure 2.

LLD

Five cards are irradiated and three cards are not. Each card has four detectors. This results in m=20 and n=12. Applying to the equation 1, the LLD at each data point is determined. The uncertainty is calculated using same method as described above. The results are shown in the figures 3 and 4. The Harshaw LiF material's LLD increases linearly from 5 μSv for LiF:Mg,Cu,P and 50 μSv for LiF:Mg,Ti to ~0.1 mSv in two years.

Fig 3 LLD for LiF:Mg,Ti at temperatures 0˚C, 20˚C and 40˚C

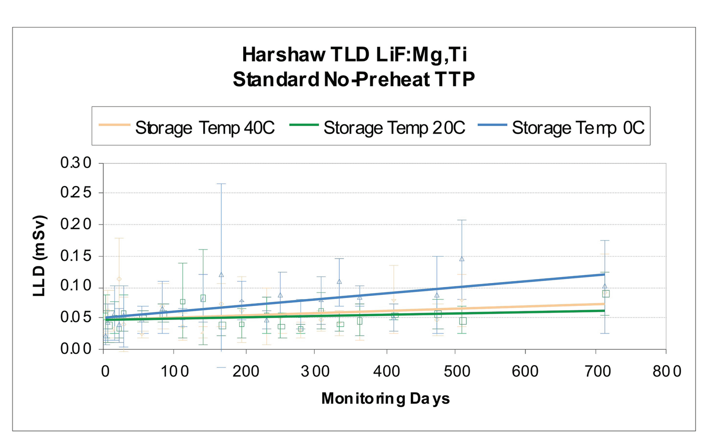
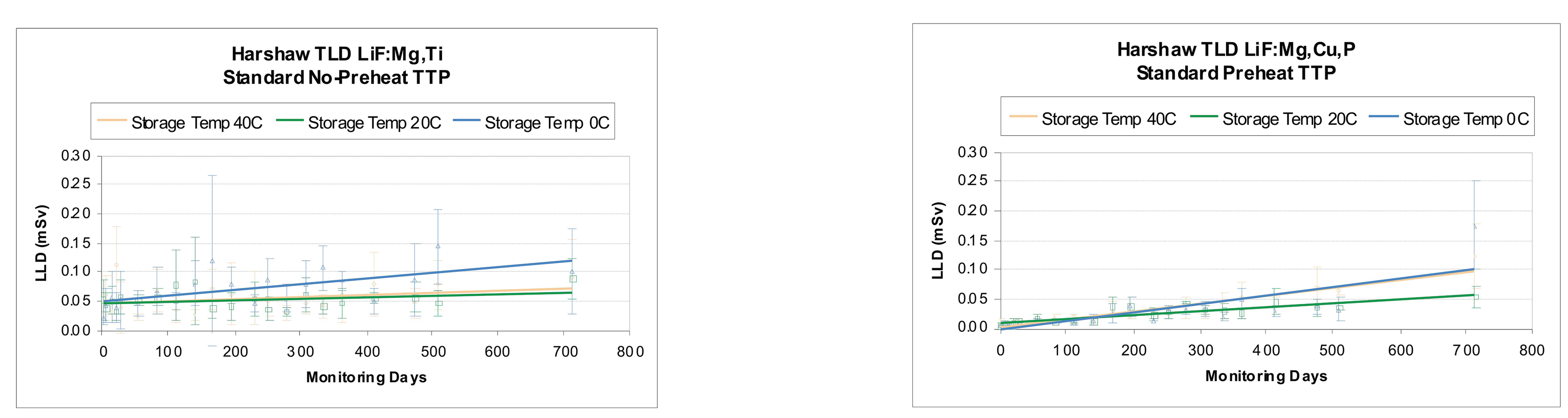


Fig 4 LLD for LiF:Mg,Cu, P at temperatures 0˚C, 20˚C & 40˚C for nopreheat and preheat TTPs

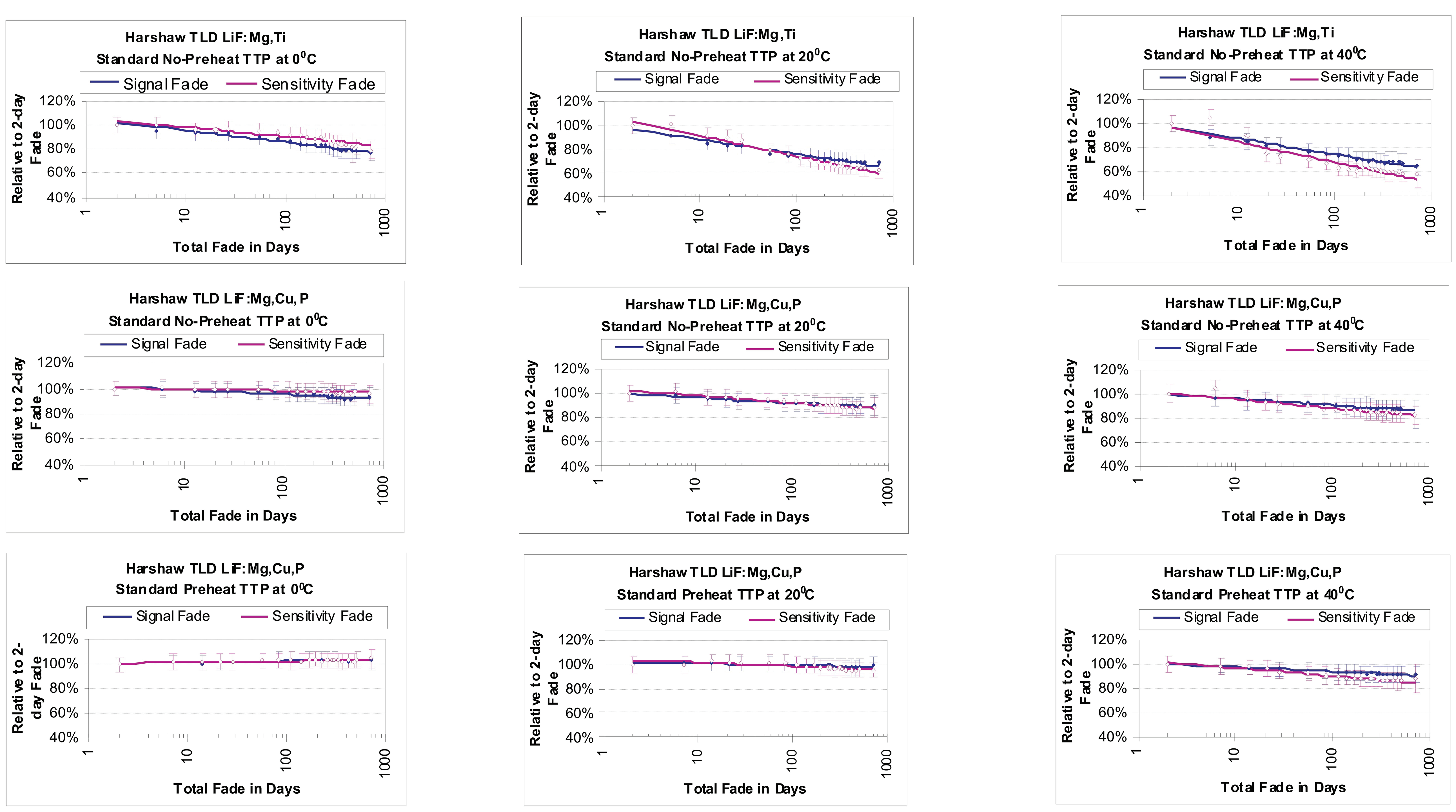


Fade

Previous Luo's work describes in detail the fading in signal and in sensitivity of Harshaw LiFTLD at different temperatures. The fading function f = a + ln(b) x is provided in each case. No effort was made to provide the uncertainty of the results at that time. Now the uncertainty is determined for each fade curve. The same technique is used. The statistical uncertainty of each point U_μ is combined with the system uncertainty U_{sys}, where U_μ. $U_\mu = \frac{t_{5-1}}{\sqrt{5}} s_\mu$. This resultant total uncertainty is $U_{Total} = \sqrt{\sum U_\mu^2 + U_{sys}^2}$

The fade curves of figure 2 in Luo's paper are now re-plotted in a logarithmic time scale. The fading in signal and sensitivity are shown in figure 5. Note that all fade curves are plotted using the derived fading function. The uncertainty is based on the real data points. It is shown that all the fade curves are within the uncertainty range, except the sensitivity fade for LiF:Mg,Ti at 40˚C.

Fig 5 Relative signal loss and sensitivity loss of Harshaw LiF based TLD, based on 2-day fade, at storing temperature of 0˚C, 20˚C, 40˚C



Summary

Presented is a work of a systematic study of Harshaw LiF TLD and its lower limit of detection at different temperatures over a long time period. Uncertainty analysis is also provided for the system and for the previous fade study results.

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