Characterization of Lithium Fluoride thermoluminescent detector dose response in the Harshaw 5500 reader for high gamma dose

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***Abstract*—When using lithium fluoride thermoluminescent detectors (TLDs), the dose response is usually linear up to doses of the order of 1 Gy. However, doses higher than this can be recorded. The effect on the linearity of the TLD-type (MCP-N, MTS-100, and MTT-100) and readout speed (10°C/s and 1°C/s) for a dose range of 0,05 to 50 Gy is evaluated.**

For MCP, at 1°C/s a dose response is linear within an uncertainty up to 10 Gy, at 10°C/s only to 1 Gy. From 10 Gy, the photomultiplier became saturated.

For MTS and MTT, the 10°C/s was slightly more accurate than the 1°C/s readout. The MTS dose response shows linear behavior up to 3 Gy. The MTT dose response only shows linear behavior up to 0.5 Gy. Correction factors for the protocols used at SCK CEN are suggested. A GlowFit analysis gave a better result for the MTT-type.

***Index Terms*—Enter Characterization, Thermoluminescence, TLD, Harshaw**

I. Introduction

Lithiumfluoride thermoluminescent detectors (LiF TLDs) are often used at SCK CEN e.g. to find dose gradients in phantom experiments or to assess staff and astronaut doses. These are small pill shaped detectors that store acquired dose in metastable vacancies in their structure. After heating, the detector's emitted light can be measured and should be linear with the acquired dose. During measurements, however doses can sometimes unexpectedly reach several grey, where the dose response is no longer linear. This is why the dose response needs to be characterized.

This light to dose relation is dependent on many factors, such as TLD-type, radiation energy and type [1]. These factors have been researched before. Previous research has also looked into the dose response of MCP-type TLD up to 5 Gy for different reheating speeds [2].

This article will expand on the effects of TLD-type, readout speed and dose range for gamma emission from Co-60 expressed as air kerma. The combined effect of the intrinsic dose response of the Harshaw 5500 and the non-linearity of the photomultiplier (PMT) will be taken into account. A GlowFit analysis to evaluate different peaks that make up the glow curve will be explored.

II. Methods

A. Used materials

Three types of TLD were irradiated: LiF;Mg,Cu,P (MCP), LiF;Mg,Ti (MTS) and LiF;Mg,Ti with modified activator composition (MTT). They have a diameter of 4.5 mm and a thickness of 0.6 mm. For each dose three detectors were used for each readout speed and each detector type.

B. TLD sensitivity

Before the experiment, the sensitivity or individual factor (IF) needs to be determined for each detector. This is done by comparing the reader output to the average of a reference plate with a dose of 50.0 mGy. To be able to express dose in air kerma, there is a 3 mm PMMA build-up plate in front to guarantee charged particle equilibrium.

C. Protocols used at SCK CEN

To reset the TLDs before irradiation, they are annealed. For MCP this means heating the TLDs to 240°C for 10 min and cooling at -10°C for 10 min. MTT and MTS are heated to 400°C for 1 h and then kept at 100°C for 2 h.

Then the TLDs can be irradiated. The dose range evaluated in this article is 0.05 to 50 Gy given by a Co-60 gamma source. This was done in the LNK calibration lab at SCK CEN. Doses up to 2 Gy were irradiated using the panoramic room with an air kerma of up to 822 mGy/h. Doses from 3 to 50 Gy were irradiated in a horizontal collimated beam with an air kerma up to 96.7 Gy/h.

Before the readout can start, the TLDs need to be preheated at 120°C for 30 min to eliminate fading effects due to the low temperature peaks [3]. Then, with the help of the Harshaw 5500 TLD reader from Thermo Fisher Scientific, the readout can begin. The glow curves for the TLDs are determined for a 10°C/s and 1°C/s readout speed. The MCP-type is heated up to a temperature of 255°C, the MTT and MTS are heated up to 400°C [1].

D. Linearity index

The linearity index LI will be determined to characterize the linearity of the dose response and to evaluate from which point on a correction is required. This was determined with the

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following equation.

$$LI = \frac{\left(\frac{light\ emission}{dose}\right)_{0.05\ Gy}}{\left(\frac{light\ emission}{dose}\right)_{x\ Gy}} \frac{1}{IF}$$

With x the point that will be analyzed. The uncertainty on the readout was evaluated by using the standard deviation doubled for the 95% certainty interval. The calibration certificates accredited with ISO 17025 the lab were used to determine the uncertainty on the dose.

E. Glow curve deconvolution

The glow curves will be analyzed through deconvolution of the different peaks with the GlowFit software developed by the IFJ. This method might improve the accuracy of the dose response over a larger interval.

III. RESULTS AND DISCUSSION

A. MCP linearity

Figure 1 shows the linearity of the MCP TLD-type for 1°C/s readout. Up to 10 Gy every value of the linearity index contains 1 in its uncertainty interval apart from 2 Gy. After 10 Gy, the voltage was lowered, since the PMT at 10°C/s readout became saturated. For the 1°C/s readout, the dose response remained linear up to 13 Gy, but more research needs to be done to determine the reliability at a lower voltage.

The linearity of the dose response for 10°C/s, as seen in figure 2 becomes superlinear starting at 1 Gy. At 10 Gy, the PMT was saturated. The top of the peak of the glow curve got cut off and the reader stopped. This means the dose would be underestimated. Further research could investigate the effect of the saturation and the drop in superlinearity starting at 5 Gy.

[2] used a readout speed of 2°C/s instead of 1°C/s, and only went up to 5 Gy. A similar result was found for the lower readout speed. At 10°C/s the value of the superlinearity was lower. In [2] the linearity index at 10°C/s at 5 Gy was 1.10 ± 0.04. in this research the same point is 1.56 ± 0.07. On Figure 2 a correction factor is suggested, however, the values from [2] and this research vary too much for this to be reliable.

A GlowFit deconvolution was done for the 1°C/s readout using the parameters from [1]. The results did not improve. This is in line with [4], where it is concluded that the shape of the MCP glow curve does not change below 1 kGy.

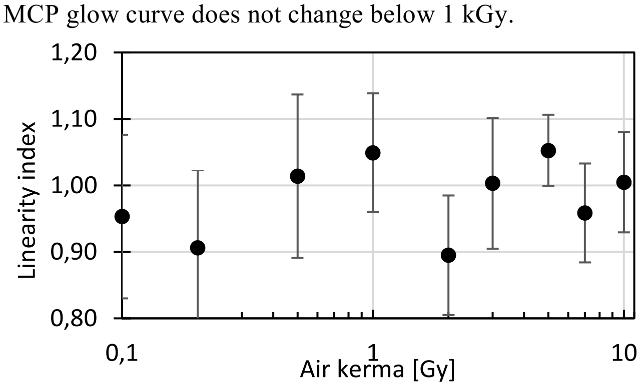

Figure 1: Linearity index for MCP at 1°C/s

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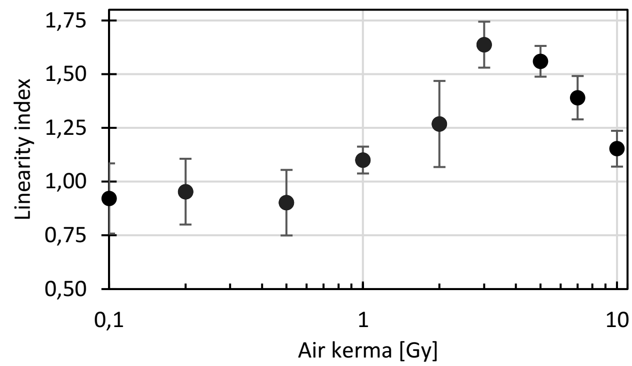

Figure 2: Linearity index for MCP at 10°C/s

B. MTS linearity

Figure 3 and 4 show the dose response for 1 and 10°C/s for the MTS-type detector. This type is optimized for gamma radiation [5]. For 1°C/s, the only points considered linear are 0.1, 0.2, 3, and 5 Gy; 0.5, 1 and 2 Gy are not. At 10°C/s the dose response is linear up to 3 Gy, except for 1 Gy. At 50 Gy the light emission in the reader was nearly saturated at 1°C/s and completely saturated at 10°C/s. So, these points should not be used.

A GlowFit analysis was done using the parameters from [6]. The deconvolution method did not seem reliable for this TLD-type.

[4] only reports on peaks 4 and 5 of the deconvoluted result. While this research focuses on the region of interest around these peaks and [4] has no values published. However, the graphs show a very similar result.

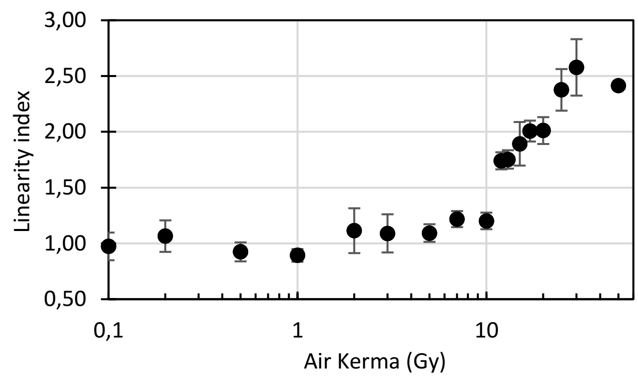

Figure 3: Linearity index for MTS at 1°C/s

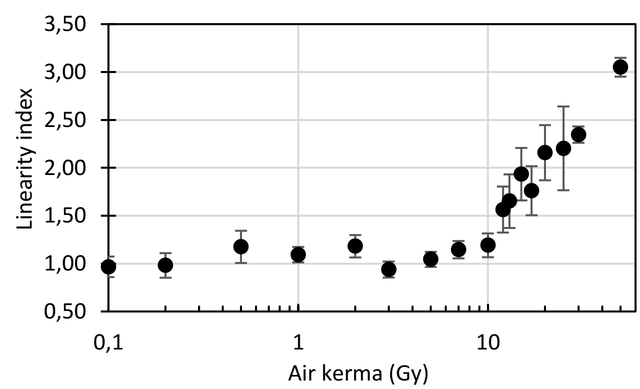

Figure 4: Linearity index for MTS at 10°C/s

C. MTT linearity

Due to a shortage of these detectors and to avoid using TLDs that have been irradiated with more than 1 Gy, there are less datapoints for the MTT-type. Due to the same dopants being used in MTS as in MTT, a similar result is expected. However, MTT is designed with a high LET in mind, which is not the case here [5].

Figure 5 shows the linearity for the dose response at 1°C/s. Figure 6 shows that at 10°C/s. The dose response is similar for the 1 and 10°C/s readout speed. Contrary to the MCP results, the 10°C/s readout has a better result than the 1°C/s. The first is linear up to 0.5 Gy, the latter only up to 0.2 Gy. Above this both graphs become superlinear.

The suggested correction function assumes a power function. Further research might be needed to confirm if this relation is the best fit for the given interval.

Previous research only looked at the deconvoluted results of peaks 4 and 5 [4]. It is difficult to compare as both peaks show a very different dose response.

A GlowFit analysis was done using the parameters from [1]. The rise in linearity was much slower than when using the ROI. However, the results did not seem reproducible, so a correction function will not be given.

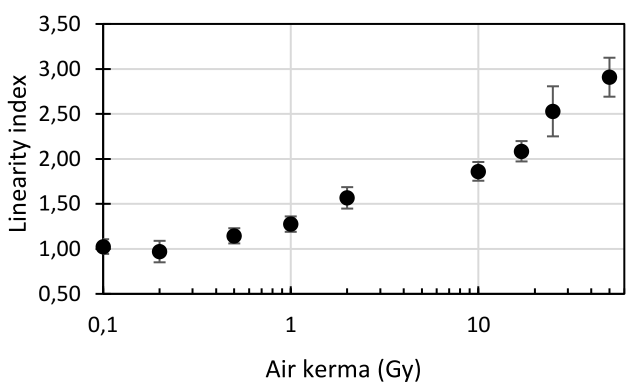

Figure 5: Linearity index for MTT at 1°/s

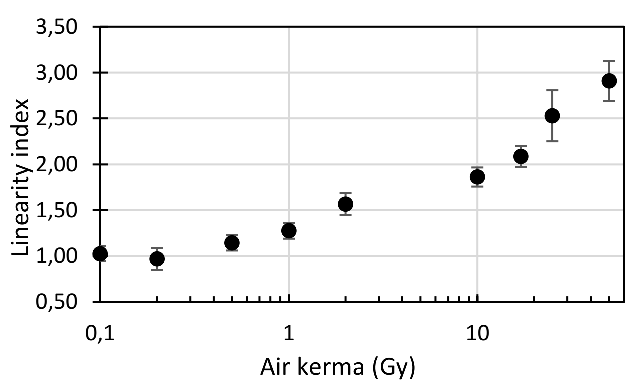

Figure 6: Linearity index for MTT at 10°C/s

IV. Conclusions

For the three types of detectors, LiF;Mg,Cu,P (MCP), LiF;Mg,Ti (MTS) and LiF;Mg,Ti (MTT), the linearity index was evaluated.

For MCP the 1°C/s readout is significantly more linear than that of 10°C/s. So, for an accurate dose reading above 1 Gy, the MCP TLD should be read out at 1°C/s. A dose higher than 10 Gy will need to be read out with a lower voltage, or another solution could be applied, like using a diaphragm. A GlowFit analysis is not required.

For MTS, the difference between 1 and 10°C/s was less extreme. In this research the latter was more accurate. Corrections are needed above 3 Gy. A GlowFit analysis has improved linearity in other research but did not give a reliable result here.

Like MTS, for MTT the 10°C/s readout was slightly more accurate than the 1°C/s. Corrections are needed above 0.5 Gy. These corrections use a power function instead of a linear function. Further research might be beneficial to confirm this relation. A GlowFit analysis improved the result.

References

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