Available online at www.sciencedirect.com

•• ScienceDirect

Radiation Measurements

Radiation Measurements vol (year) pp-pp

www.elsevier.com/locate/radmeas

Extensive fade study of Harshaw LiF TLD materials

Ling Z. Luo

Thermo Fisher Scientific, One Thermo Fisher Way, Oakwood Village, Ohio 44146, USA

Received DATE; received in revised form DATE; accepted DATE

Abstract

A Comprehensive and extensive fade study was conducted for Harshaw LiF TLD materials. This study covers the well established LiF:Mg,Ti and LiF:Mg,Cu,P materials in their different isotopes, sizes, forms and time-temperature readout schemes. Two parts of the fade study on the signal loss and the sensitivity loss were carried out in a long-term period of 500+ days at temperatures of 0^0C, 20^0C and 40^0C using more than 3500 dosemeters. Detailed results are presented and a summary is provided.

Keywords: thermoluminescent; Harshaw; TLD; Fade; LiF

1. Introduction

Fade is the process of gradually reducing the capability of producing the response due to radiation exposure. The fading rate of LiF based thermoluminescent (TL) material depends on many experimental parameters, such as, storage temperature, readout mechanism, anneal, radiation type or time. Based on the storage time before or after radiation, fade has two components. One is the signal loss (post-fade), which is the reduction of the response signal after the material has been irradiated, another is the sensitivity loss (pre-fade), which is the reduction of the capability to produce the response before the material is irradiated. The fade of LiF based material has been studied for years. Most studies were focused on the individual peaks, or the readout heating mechanism, or radiation type and radiation time stored at room temperature. To date, however, there is no systematic study on its fade due to the signal loss and the sensitivity loss for a prolonged period of time at various storing temperatures.

Do the signal loss and the sensitivity loss fade at the same rate? What effect does it have on the storage temperature that one should expect? Would the material differences such as isotope type, size and form affect their fade? What is the fade difference when using difference readout profiles? What is the long term fade? Harshaw TLD, in its previous work, has studied its LiF:Mg,Ti material and derived a generic fade function that applied to LiF:Mg,Ti material in all forms, at nor-mal room temperature (20^0C) with fade period of less than 120 days. Can this function extend to longer periods and include varying ambient temperatures? The present work is aimed at answering these questions.

2. Study and Setup

This study is designed to measure the fade associated with a various Harshaw TLDs. The TLD materials studied are Harshaw TLD LiF:Mg,Ti and LiF:Mg,Cu,P in the forms of card and extremity dosemeters. One TLD card holds four TL detectors. Each TL detector is encapsulated between 10 mg/cm^2 Teflon™ sheets. The TLD extremity dosemeter is in two styles, EXTRAD and DXTRAD. In the EXTRAD configuration, the TL detector is in the form of powder or a chip, bonded on a Kapton™ film of 0.165 mm thickness, 9.5 mm width and 24.2 mm long, in a circular area of 18 mm^2 located near one end. The remainder of the surface contains an identification bar code. In the DXTRAD configuration, the detector is in the form of powder or a chip bonded, on a 7 mm^2 area Kapton™ film based circular area and an annular shaped barcode of 4 mm ID x 7 mm OD surrounding the detector. The details of each type of dosemeter are described as following:

LiF:Mg,Ti Card (TLD-1776):

Four detectors are 0.32 x 0.32 mm^2 square LiF:Mg,Ti chips. The detector 1 is a 0.4 mm thick natural LiF element. Detectors 2 and 3 are both made of ^{7}Li-enriched material. They are 0.4 mm and 0.15 mm thickness, respectively. Detector 4 is a 0.4 mm thick ^{6}Li-enriched element.

LiF:Mg,Cu,P Card (TLD-1776H):

All four detectors are 3 mm diameter round LiF:Mg,Cu,P chips. The detector 1 is a 0.4 mm thick natural LiF element. Detectors 2 and 3 are made of ^{7}Li-enriched material. They are 0.4 mm and 0.25 mm thickness, respectively. Detector 4 is a 0.4 mm thick ^{6}Li-enriched element.

LiF:Mg,Ti EXTRAD Extremity (XD-700):

The detector is a 0.32 x 0.32 mm^2 square ^{7}Li-enriched LiF:Mg,Ti chip with a 0.4 mm thickness.

LiF:Mg,Ti DXTRAD Extremity (DXT-100):

The detector is a DXTRAD of 3 mm diameter round natural LiF:Mg,Ti chip in 0.4 mm thickness.

LiF:Mg,Cu,P EXTRAD Extremity (XD-707H):

The detector is made of ^{7}Li-enriched LiF:Mg,Cu,P powder with a mass thickness of 0.07 mg/cm^2.

LiF:Mg,Cu,P DXTRAD Extremity (DXT-707H):

The detector is made of ^{7}Li-enriched LiF:Mg,Cu,P powder with a mass thickness of 0.07 mg/cm^2.

The study is conducted on the two fade types: Signal loss and Sensitivity loss. For each fade type, three storage temperatures are operated: standard laboratory temperature 20^{0}C; low temperature 0^{0}C and high temperature 40^{0}C (note: only one temperature (20^{0}C) is carried out for the extremity dosemeters). For readout, the standard Harshaw TLD Time-Temperature Profiles (TTPs) are used, see table 1. In total, there are 18 permutations in cards and 8 permutations in extremities for each type of detector.

All dosemeters are annealed at the beginning of the study and then, for cards, divided to three large groups. Each large group is stored at one of three temperatures. Extremity is stored at 20^{0}C only. Each large group is then divided into two small groups. Each of these small groups is then divided into 20 sets of 5 dosemeters each. The dosemeters in the first small group are not irradiated until one week before they are to be read, in order to measure loss of sensitivity due to time between anneal and irradiation. All of the dosemeters in the second small group are irradiated 2 days after they are annealed and then read at increasing weekly/monthly intervals to measure loss of signal between irradiation and readout. Control dosemeters (3 per set) are also annealed at the same time and read at the same time as the Test dosemeters. See table 2 for test scheduling, it is scheduled to collect data weekly for first four weeks and then monthly up to 12 months, beyond that, the frequency is reduced to 2 months. There are about 3000 cards and 650 extremities used in this one and half years study.

To reduce unnecessary background signals, all dosemeters are wrapped, by group, using aluminum foil. Standard laboratory temperature is con-trolled at 20^{0}C ± 2^{0}C; A refrigerator is used to achieve the low temperature between 0^{0}C and 3^{0}C; and an incubator keeps the high temperature dosemeters between 36^{0}C to 42^{0}C.

All readouts are carried out according to the schedule in table 2. Readouts are performed on a Harshaw Model 8800 TLD reader. Irradiations are obtained by using a ^{90}Sr/Y source, built in to the reader. The dose level is set to 3 mSv. The reader is calibrated for all seven TTPs before every readout. Three sets of dosemeters, (controls, signal loss and sensitivity loss types), from each storing temperature, are read at the same time.

3. Results and Discussion

Fade tests are carried out for 17 months on cards and 6 months for extremities. Results of detailed glow curves changes, from front to back, are illustrated in Figure 1, where both Signal loss and Sensitivity loss for each type of detector at each storing temperature are plotted side by side. The first glow curve at top front is ‘zero’ fade, which is achieved by using the AutoCal feature of the TLD reader. (AutoCal commands the reader to clear the dosemeter, expose the dosemeter and then performs the readout in succession.) The intensity on y-axis is in the unit of nA. TL response is the total charge collected, or the integral of the curve, over the period of heating time. Background signals are subtracted but the curves are not normalized to its base curve, yet. Therefore, there are a few cases where the main peaks appear higher, even though the TL value is less. To better understand the TL value fade, Figure 2 shows the TL response change compared to the baseline versus the fade time. In this study, the baseline is defined as 2-day fade: one day Signal loss and one day Sensitivity loss.

The dosimetric peak temperatures of LiF material are between 150 to 240^{0}C. They are known as peaks 3, 4 and 5 for LiF:Mg,Ti and peaks 3 and 4 for LiF:Mg,Cu,P. These are stable peaks. The low temperature peaks are the major players in the fade process. Hence, the readout TTP, which starts at 50^{0}C will experience more fade than the TTP that starts at 165^{0}C. Let us look at the cases of a no-preheat TTP. At 0^{0}C storing temperature, the signal (loss) fades faster than the sensitivity does as shown in Figure 2, i-a and ii-a. This is due to the fact that peak 2 is still preserved before the irradiation (sensitivity loss) and can be seen in Figure 1, i-a and ii-a. As the storing temperature increases to 20^{0}C, in the first 30 days, the signal loss out weighs the sensitivity loss. Beyond 60-80 days, the sensitivity loss increases at a faster rate since peak 2 has completely faded, see figures 1 (i-b and ii-b) and 2 (i-b). This ‘flip’ is illustrated clearly in figure 2 (iv-b and i-b Rescale). However, this is not notable for LiF:Mg,Cu,P (figure 2, ii-b). When the temperature is raised up to 40^{0}C, peak 2 fades away in days, hence, the sensitivity loss now out weighs the signal loss, see figures 1 (i-c and ii-c) and 2 (i-c and ii-b).

When the TLD is preheated to the temperature that eliminates the fast fade peaks in its readout, the fade should be reduced. This can be observed in figure 2 (iii-b) at 20^{0}C storing temperature where there is no significant fade. However, at 0^{0}C storing temperature, the response appears to increase, figure 2 (iii-a). It cannot be explained in the present work. At 40^{0}C, more sensitivity loss than signal loss is noticed, see figure 2 (iii-c).

Work has been done to develop a series fade function for each case based on these experimental data. The basic function form is:

$$F = a * \ln(T) + b$$

where F is the fade factor and T is the time period from anneal to readout in days. Parameters *a* and *b* of each type are provided in table 3.

Previous work had derived a generic fade function in the condition of standard laboratory temperature. It is expressed as:

$$F = e^{-0.00331*(\frac{T}{2}-8)}$$

This fade function is based on an 8-day Signal loss and an 8-days Sensitivity loss. It has been used for years for LiF:Mg,Ti material, in all forms, with the limit of no more than 120 days. From figure 2 (iv-b and i-b Rescale), one can see that these two fade functions are comparable between 20 to 120 days.

4. Summary and Future Plan

An extensive long term fade study of Harshaw LiF based TLD has been performed. The results are highlighted below:

1. The Signal loss and the Sensitivity loss do not fade at the same rate and are dependant on the storage temperature.
2. At thelow temperature, Signal loss is faster than the Sensitivity loss due to the preservation of low temperature peak 2.
3. There is a transition period, when peak 2 is completely faded. At this point, the sensitivity starts to fade faster than the signal.
4. The readout TTP, with preheat, reduces the fade. There is no significant fade for LiF:Mg,Cu,P during in 17 months period.
5. Different material isotopes, sizes and forms have insignificant effect on fade.
6. The currently used fade function is valid within its limits.

Further work to quantify each peak and to better understand the fade is planned

Acknowledgments

Author would like to acknowledge her friends and colleges Joe Rotunda and Ken Velbeck for their many advises, and to her co-workers for countless support.

References

McKeever, S.W.S, Moscovitch, M. and Townsend, P.D, Thermolumniescence Dosimetry Materials: Properties and Uses, Nuclear Technology Publishing, ISBN 1 870965 19 1

Moscovitch, M., 1986. Automatic Method for Evaluating Elapsed Time Between Irradiation and Readout in LiF-TLD, Radiat. Prot Dosim. 17, 165-169.

M. Moscovitch, A. Szalanczy, W.W. Bruml, K.J. Velbeck and R.A. Tawil, 1990. A TLD System Based on Gas Heat-ing with Linear Time-Temperature Profile, Radiat. Prot Dosim. 34, 361-364.

Harshaw TLD User's Manual, Publication No. ALGM-D-U, 2000

Luo, L.Z., 2007. The Study Of New Calibration Features In The Harshaw TLD System, Radiat. Prot Dosim. Ad-vance Access published on January 12, 2007; doi: doi:10.1093/rpd/ncl542

Luo, L.Z., Velbeck, K.J., Moscovitch, M. and Rotunda, J.E., 2006. LiF:Mg,Cu,P Glow Curve Shape Dependence On Heating Rate, Radiat. Prot Dosim. 119: 184 – 190.

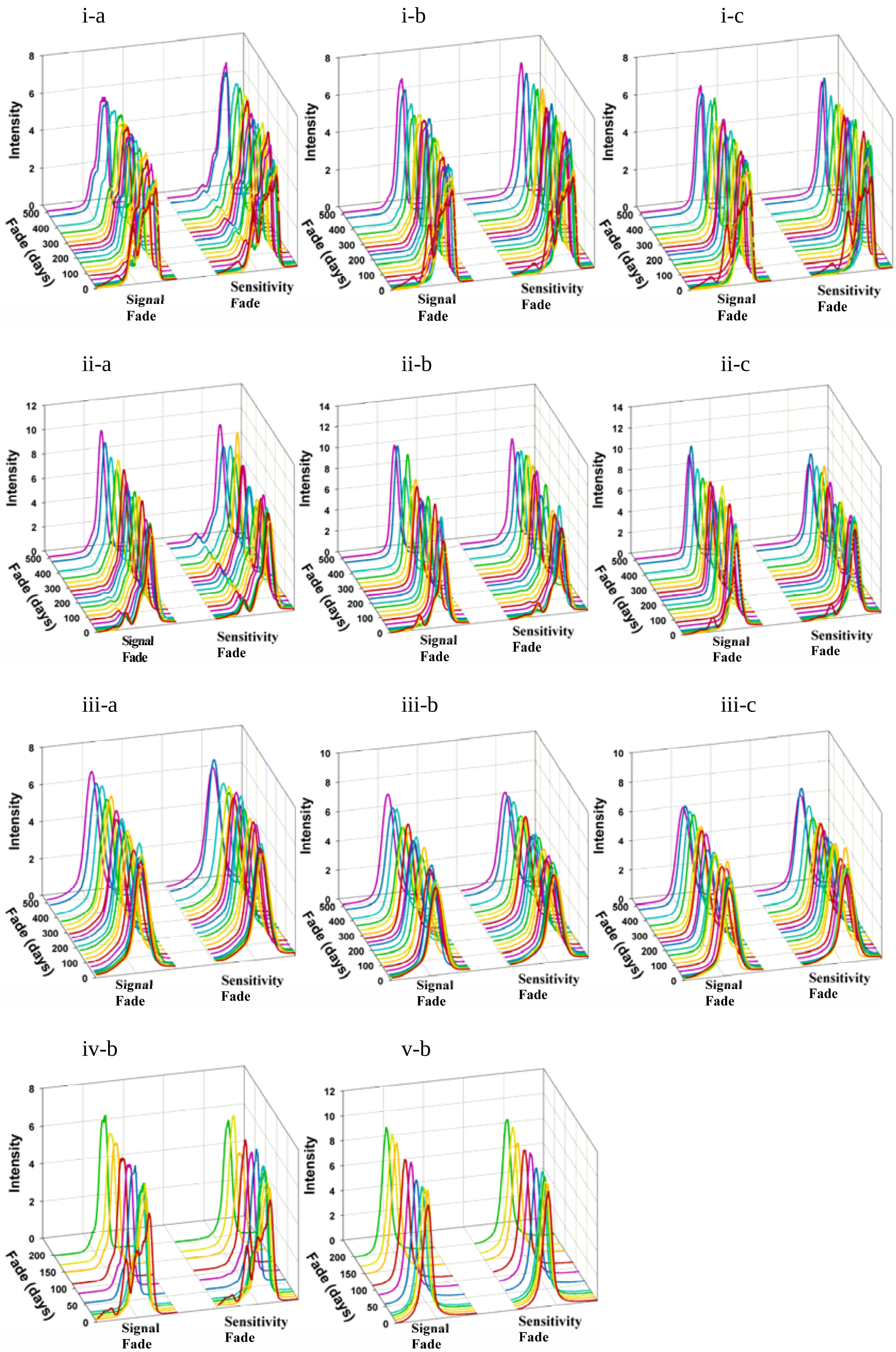

Fig 1. Illustration in glow curve changes for the Signal loss and Sensitivity loss of Harshaw LiF based TLD at storing temperature of: a. 0^0C; b. 20^0C and c. 40^0C. The material and readout temperature: i - LiF:Mg,Ti 50^0C to 300^0C; ii - LiF:Mg,Cu,P 50^0C to 260^0C; iii - LiF:Mg,Cu,P 165^0C to 260^0C; iv - LiF:Mg,Ti extremity 50^0C to 300^0C and v - LiF:Mg,Cu,P extremity 165^0C to 255^0C.

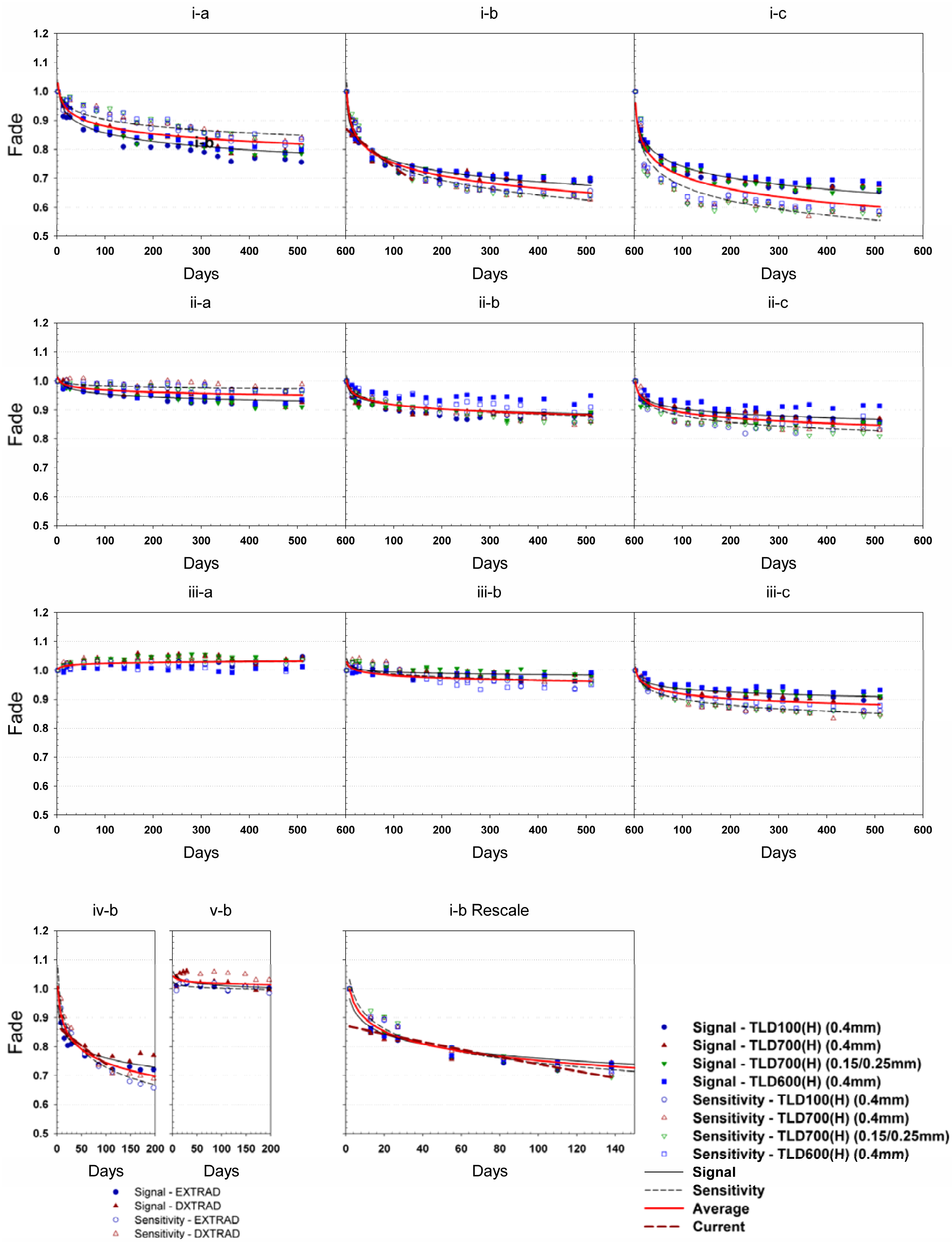

Fig 2. Relative Signal loss and Sensitivity loss of Harshaw LiF based TLD, based on 2-day fade, at storing temperature of: a. 0^0C; b. 20^0C and c. 40^0C. The material and readout temperature: i - LiF:Mg,Ti 50^0C to 300^0C; ii - LiF:Mg,Cu,P 50^0C to 260^0C; iii - LiF:Mg,Cu,P 165^0C to 260^0C; iv - LiF:Mg,Ti extremity 50^0C to 300^0C and v - LiF:Mg,Cu,P extremity 165^0C to 255^0C.

Table 1: Time-Temperature Profiles. Note: * is for ^{6}LiF-enriched element.

Dosemeter	TLD-1776	TLD-1776H		XD-700	DXT-100	XD-707H	DXT-707H
TTP Name	StdMT	StdMCP_NoPH	StdMCP_PH	StdMT_Ext	StdMT_Ring	StdMCP_Ext	StdMCP_Ring
Pre-Heat (^{0}C)	50	50	165	50	50	165	165
Time (s)	0	0	10	0	0	10	10
Rate (^{0}C/s)	25	15	15	15	15	255	255
Max Temp (^{0}C)	300	260	260	300	300	15	15
Acq. Time (s)	13 (16*)	23 (26*)	13 (16*)	20	20	13	13
Anneal Temp (^{0}C)	300	260	260	300	300	255	255
Time (s)	0	10	10	0	0	10	10

Table 2: Test schedule. Weekly for four weeks, monthly to 12 months and then two-month up to 17 months. Above: Sensitivity loss and anneal. Below: Signal loss.

	Start	WK0	WK1	WK2	WK3	WK4	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M14	M16	M17
Set1	Anneal	Irrad	Read																		
Set2	Anneal		Irrad	Read																	
Set3	Anneal			Irrad	Read																
Set4	Anneal				Irrad	Read															
Set5	Anneal					Irrad	Read														
Set6	Anneal						Irrad	Read													
Set7	Anneal							Irrad	Read												
Set8	Anneal								Irrad	Read											
Set9	Anneal									Irrad	Read										
Set10	Anneal										Irrad	Read									
Set11	Anneal											Irrad	Read								
Set12	Anneal												Irrad	Read							
Set13	Anneal													Irrad	Read						
Set14	Anneal														Irrad	Read					
Set15	Anneal															Irrad	Read				
Set16	Anneal																Irrad	Read			
Set17	Anneal																	Irrad	Read		
Set18	Anneal																		Irrad	Read	
Set19	Anneal																			Irrad	Read
Set20	Anneal																				Irrad
Controls	Anneal		Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read

	Start	WK0	WK1	WK2	WK3	WK4	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M14	M16	M17
Set1	Anneal	Irrad	Read																		
Set2	Anneal	Irrad		Read																	
Set3	Anneal	Irrad			Read																
Set4	Anneal	Irrad				Read															
Set5	Anneal	Irrad					Read														
Set6	Anneal	Irrad						Read													
Set7	Anneal	Irrad							Read												
Set8	Anneal	Irrad								Read											
Set9	Anneal	Irrad									Read										
Set10	Anneal	Irrad										Read									
Set11	Anneal	Irrad											Read								
Set12	Anneal	Irrad												Read							
Set13	Anneal	Irrad													Read						
Set14	Anneal	Irrad														Read					
Set15	Anneal	Irrad															Read				
Set16	Anneal	Irrad																Read			
Set17	Anneal	Irrad																	Read		
Set18	Anneal	Irrad																		Read	
Set19	Anneal	Irrad																			Read
Set20	Anneal	Irrad																			

Table 3: Summary of *a* and *b* parameters for Fade Function $F = a * \ln(T) + b$

	0^0C			20^0C			40^0C		
LiF:Mg,Ti Card	Signal Loss	Sensitivity Loss	Average	Signal Loss	Sensitivity Loss	Average	Signal Loss	Sensitivity Loss	Average
a	-0.0425	-0.0333	-0.0379	-0.0524	-0.0736	-0.063	-0.0569	-0.0726	-0.0647
b	1.0531	1.0568	1.055	1.0018	1.0832	1.0425	1.003	1.0075	1.0053
LiF:Mg,Ti Extremity									
a				-0.0464	-0.0878	-0.0671			
b				0.9749	1.1332	1.0541			
LiF:Mg,Cu,P Card									
a	-0.0153	-0.006	-0.0107	-0.0187	-0.0249	-0.0218	-0.0225	-0.0315	-0.027
b	1.0256	1.0111	1.0183	1.0032	1.0339	1.0186	1.0073	1.024	1.0156
LiF:Mg,Cu,P Card									
a	0.0056	0.0043	0.0049	-0.0065	-0.0139	-0.0102	-0.0165	-0.0292	-0.0228
b	0.9992	1.0033	1.0012	1.0243	1.0513	1.0378	1.0122	1.0343	1.0233
LiF:Mg,Cu,P Extremity									
a				-0.0118	-0.006	-0.0062			
b				1.0663	1.029	1.0476			