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Comparison of commercial thermoluminescent readers regarding high-dose high-temperature measurements

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HIGHLIGHTS

- Three different TLD systems, Harshaw 3500, Risø DA-20 and RA'94 have been compared.
- The temperature profiles and effects of different spectral sensitivity were studied.
- Harshaw 3500 shows the best thermal stability considering the peak maximum position.
- Harshaw 3500 shows the highest detection limit under the typical readout parameters.
- Differences in spectral characteristics influence the shape of TL glow curves.

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ABSTRACT

Three different thermoluminescent measuring systems have been compared with respect to the differences in temperature profiles, spectral sensitivities, as well as characteristics for high intensities of TL light. The comparison was performed using the Harshaw 3500, Risø DA-20 and RA'94 TLD readers. The instruments were tested for the readouts of highly irradiated LiF:Mg,Cu,P (MCP) TL detectors, which require readout up to 550 °C, in case of doses exceeding 1 kGy. It was found that the Harshaw 3500 can be used, without any additional light attenuation, for the measurements of MCP detectors exposed to doses up to about 5 Gy. For the other two readers the upper dose limit is about 10 times lower. It was also found that the Harshaw 3500 shows the best thermal stability considering the peak maximum position. For the ultra-high doses the differences in the spectral characteristics of the applied optical filters and photomultipliers, in conjunction with an evolution of the MCP TL emission spectrum with increasing dose, significantly influence the shape of TL glow curves measured with the DA-20 reader. The detailed characteristic of the compared TLD readers at high-dose high-temperature range is discussed.

1. Introduction

Typical, commercial thermoluminescent (TL) readers are usually designed to measure TL light intensity at the lowest possible level. In radiation protection, which is the most widespread application of thermoluminescence, the reason for this is a trend to obtain the lowest achievable dose detection limit. In TL dating and in material research this is caused by low sensitivity of the studied samples. However, there are situations, when there is a need to measure high intensity TL signals (e.g. for high doses in industrial dosimetry or even at lower doses, when an ultra-sensitive TL detectors are used). If readers are optimized for low light measurements, the question arises, what is their performance for high TL light intensities, close to the photomultiplier (PMT) detection limit? Some of readers offer a possibility to apply a neutral filter in order to avoid such conditions of work and to extend the measuring range. However, this is not always an acceptable solution, e.g. when in a series of measurements, TLDs exposed both to low and high doses are present, so a wide dynamic range is needed.

Most of the standard TLD readers are also usually designed to perform measurements in the temperature range up to 400 °C, what corresponds to the glow curves of common TL detectors. Moreover, the attention is mostly paid to the range below 300 °C, where main dosimetric peaks typically occur. Nowadays, there are several commercial TLD readers with the extended temperature range, even up to 600 °C, and there are applications, which really require measurements at such high temperatures. However, performance of these readers at the highest working temperatures has not been studied so far.

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The aim of this work was to investigate and to compare three different TLD measurement systems with respect to high-dose and high-temperature measurements. Studies were realized using the RA'94, Harshaw 3500 and Risø DA-20 TLD readers. The motivation to undertake this work was the recently discovered thermoluminescence of LiF:Mg,Cu,P, at the high-dose and high-temperature range (Bilski et al., 2008; Obryk et al., 2009), and based on these effects the developed method of ultra–high dose measurements, in the kGy range (Obryk et al., 2011a; Obryk, 2013). The shape of the LiF:Mg,Cu,P TL glow curve undergoes a complete alteration after irradiation above 1 kGy (a typical TL signal saturation level). These changes are related to the growth of high-temperature TL peaks, including so called peak "B", with maximum located at temperatures as high as 450 °C or even higher (Obryk et al., 2010, 2011b), what makes measurements even up to temperature of 550 °C necessary. Furthermore, some significant changes in the LiF:Mg,Cu,P TL emission spectrum were also observed (Mandowska et al., 2010; Gieszczyk et al., 2013a, 2013b). These changes in the emission spectrum rise questions about influence of spectral sensitivity of readers on high-dose measurements, and this issue was also addressed in the work.

The investigations were realized using the LiF:Mg,Cu,P (MCP) detectors due to their high-sensitivity and presence of the above described high-temperature thermoluminescence. However, the observed effects and drawn conclusions are of a general kind and concern also other TL materials.

2. Materials and methods

2.1. TLD readers specification

Three different measurement devices, the Harshaw model 3500 (Thermo Scientific, USA), Risø model TL/OSL DA-20 (Risø DTU, Denmark) and RA'94 (Mikrolab, Poland) have been compared. All these readers are able to measure TL signal up to the temperature of 600 °C or even 700 °C (in case of the DA-20). The readers are equipped with photomultiplier tubes, metal resistance heaters and gas connections, which make it possible to measure TL signal in the neutral gas atmosphere. While the PMT tubes applied in the Harshaw 3500 and RA'94 are operated in continuous current mode, the one mounted in the DA-20 performs measurements in photon counting mode. Except for the differences in spectral sensitivities of different types of photomultipliers, the main difference between the studied devices is the heating method. In case of the Harshaw 3500 and RA'94 a sample is heated directly by a contact with the heating planchette. The DA-20 heats the sample indirectly via the stainless steel cup. This difference may cause some shifts of the measured TL glow curves towards higher temperatures. The another difference, important only from the practical point of view, is that the Harshaw 3500 and RA'94 are designed for a single detector measurements, while the DA-20 is equipped with the carousel, which allows to read out up to 48 detectors during one sequence. The readers are delivered with U340, BG39 (DA-20) and BG12 (RA'94) detection filters. The standard detection filter, in case of the Harshaw 3500, is not specified by the producer. The reference light in the form of ^{14}C isotope combined with a scintillator, in the RA'94, has been replaced by the LED diode in the other two readers. The most important characteristics of the studied devices are given in the Table 1.

2.2. Irradiation and readout conditions

All TL measurements were performed using virgin LiF:Mg,Cu,P TL detectors, manufactured at the Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN), Krakow, Poland. The detectors in the form of sintered pellets of 4.5 mm diameter and 0.9 mm thickness were used. Before the irradiations a standard annealing procedure of 10 min at 240 °C was applied. High-dose irradiations have been implemented at the Institute of Applied Radiation Chemistry, Lodz University of Technology, Lodz, Poland. The dose was delivered using the linear electron accelerator at the dose rate of about 1.7 kGy/min. Dosimetry was performed during the irradiations by the usage of radiochromic foils. The applied doses were ranging from 0.5 to 1215 kGy. Low-dose irradiations (doses below 0.5 kGy) have been realized at the IFJ PAN, Krakow using Sr-90/Y-90 beta source, mounted inside the DA-20 (Bøtter-Jensen et al., 2000), as well as an external Cs-137 gamma-ray source. The relative TL efficiency of MCP detectors, for all applied radiation qualities, is practically the same. Readouts were realized at the IFJ PAN, Krakow using three measurement systems, described in details in the previous section. In all cases the samples were heated up to temperature of 550 °C with the constant heating rate of 2 °C/s. MCP detectors after the readout up to 550 °C were no longer used. In order to attenuate too high intensities of luminescence, at some of high-dose measurements, additional suppressing filters were applied. This was realized by the usage of the diaphragm with a hole of 0.5 mm diameter, in case of the DA-20 and RA'94. In case of the Harshaw 3500 the neutral density optical filter (Melles Griot ND-200) was utilized.

Table 1
The studied TLD readers specification.

	Harshaw 3500	Risø TL/OSL-DA-20	RA'94
Photomultiplier (PMT)	bialkali ETE 9125B	bialkali EMI 9235QB	bialkali EMI 9789QB
PMT mode	Continuous current	Photon counting	Continuous current
Standard filters	Unspecified	U340, BG39	BG12
Heating method	Contact, direct	Contact, indirect	Contact, direct
Heating range [°C]	RT – 600	RT – 700	40–600
Number of samples in one sequence	1	Up to 48	1
Reference light	LED	LED	^{14}C + scintillator
Built-in irradiator	No	Yes	No

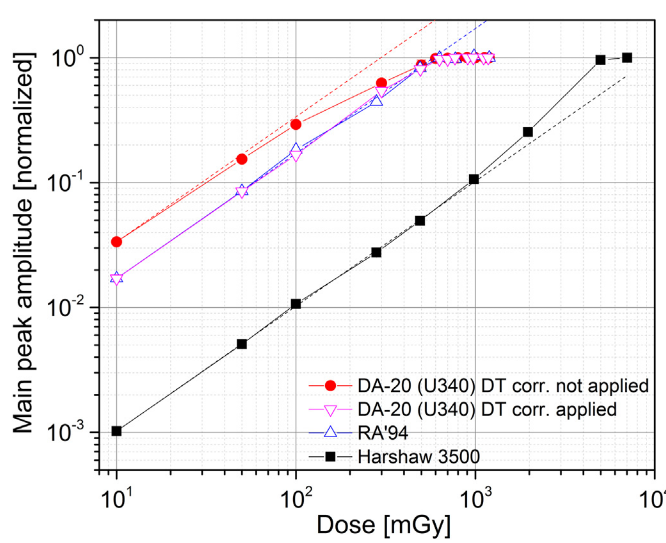

Fig. 1. TLD readers response (LiF:Mg,Cu,P main peak height) in the range from the low doses up to the photomultiplier detection limit. "DT corr." means "dead time correction".