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Dose estimation based on OSL signal from banknotes in accident dosimetry

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HIGHLIGHTS

- Banknotes could be used as triage dosimeters in emergency situation.
- Some spots on banknote area showed relatively good dosimetric properties.
- Dose reconstruction is even possible after 48 h with 25% accuracy.

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ABSTRACT

Our work is focused on the optically stimulated luminescence (OSL) of paper currency of Polish zloty, especially 10 PLN and 20 PLN banknotes in regard to the dose reconstruction in an emergency situation involving radiation. 'New' Polish banknotes with enhanced anti-counterfeiting systems were investigated in comparison with 'old' banknotes which are still in circulation, as well as with 1 US dollar and 5 EURO banknotes. Similar dosimetric properties for 10 PLN and 20 PLN banknotes of 'old' and 'new' types were observed: relatively good repeatability of OSL signal, linear dose response in the dose range between 0.2 and 10 Gy, and fading reaching 65% of OSL signal after 5 h and remaining almost stable at the level of 45% after 48 h. Despite a high intrinsic initial signal of the 'new' type of Polish banknotes of 10 PLN and 20 PLN it is still possible to reconstruct the doses higher than 0.4 Gy two days after an incident with an accuracy better than 25%. In light of these results banknotes can be considered as potential triage dosimeters for retrospective dosimetry.

1. Introduction

In an emergency situation if uncontrolled radiation affected people or the environment the information about radiation doses allows for the prediction of the biological consequences. In such a situation when professional personel and environmental dosimeters are not available, objects of everyday use can be perceived as dosimeters. The electronic devices and plastic cards of different types, which are so common today, are considered especially interesting objects due to the fact that they contain luminescent Al_2O_3, SiO_2 and polymer–like materials.

Small electronic devices such as mobile phones have already been the object of several studies. Woda et al. (2012) studied the modules of chip cards; the glass displays from mobile phones were tested by Discher and Mrozik (Discher et al., 2013; Discher and Woda, 2013; Mrozik et al., 2014a,b; Discher et al., 2015); electronic components of personal devices were examined by Pascu et al. (2013) and Mrozik (Mrozik et al., 2014a,b). This investigation revealed that mobile phones contain some electronic components (e. g. resistors, inductors) and glass displays allowing the measurement of the doses of some mGy. Obtaining samples from a mobile phone, however, leads to its destruction. Moreover, in an emergency situation taking away and dismantling mobile phones can be stressful for the owners. It means that the potential victims have to give up their private mobile phones which leads to loss of contact with both the family and the world. Therefore there is a need to find other materials for the simple qualitative check whether there has been radiation or not.

It appears that such items as paper currency (banknotes); coins; plastic cards of different types (credit and debit cards, driver's licenses, membership cards, etc.), shoes and fabrics (Sholom and McKeever, 2014) are also sensitive to radiation due to the presence of some components in their structure which can emit

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luminescent light under stimulation. These materials can serve as evidence of their earlier irradiation. It seems that the banknotes of low denominations, which are often found in our pockets and whose loss is not painful, could be an interesting alternative.

Our work is focused on the optically stimulated luminescence (OSL) of paper currency of Polish zloty, especially 10 PLN and 20 PLN banknotes, their OSL signal and fading in regard to the dose reconstruction in emergency situations. This investigation was inspired by the change in Polish banknote protection systems which was implemented in Spring (2014) and concerned 4 of 5 types of banknotes (10, 20, 50 and 100 PLN). The last denomination worth 200 PLN was entered into circulation in February 2016. ‘New’ Polish banknotes with better protection (anti-counterfeiting systems) were tested in comparison with ‘old’ banknotes which are still in circulation, as well as with 1 USD dollar and 5 EURO banknotes. The aim of the work was to investigate the OSL properties of particular parts of the banknotes in regard to the presence of their intrinsic initial signal, their sensitivity to radiation, repeatability of OSL signal, dose response and fading; in terms of their potential application as triage dosimeters in emergency situations.

2. Materials and methods

Several ‘new type’10 PLN and 20 PLN banknotes as well their ‘old’ equivalents, 1 USD and 5 EUR banknotes were the objects of the study. Since Spring 2014 better protected Polish banknotes of denominations of 10, 20, 50 and 100 PLN have appeared in circulation slowly replacing the ‘old’ ones which will be in use until their natural destruction. Polish banknotes are made from cotton similar to EUR banknotes, whereas US dollar banknotes use paper that consists of 75% cotton and 25% linen (Sholom and McKeever., 2014).

80 - 100 spots were distinguished on the area of each banknote depending on the size of the banknote (a 10 PLN banknote is smaller than a 20 PLN one). OSL signal was checked on both sides of the banknote (obverse and reverse), but the presented results were received from the obverse side. The location of the spots representative for 10 PLN and for 20 PLN banknotes are presented in Fig. 1a and b, respectively.

The diameter of the spots was of 8 mm, adequate to the dimension of the cups in an OSL reader. The luminescence of the samples (particular parts of the banknotes) was investigated with OSL method in an automated luminescent TL/OSL reader (model DA-20) produced by Risoe National Laboratory, Denmark. OSL measurements were done using blue diodes (470 nm ± 30 nm) with a total power of 80 mW/cm^2 at the sample position. The readouts were performed with U340 optical filter transmitting 250–400 nm light wavelength. The Risoe reader is equipped with a beta irradiator holding ^{90}Sr/^{90}Y source and maximum energy of 2.27 MeV for irradiation of the samples with a dose rate of about 64.6 mGy. The calibration of ^{90}Sr/^{90}Y source was performed using MCP dosimeters in regard to ^{137}Cs gamma-ray reference source calibrated in terms of kerma in air. Between irradiation and readout the samples were kept in darkness assuming that the banknotes are usually stored in a wallet protected from light.

The preliminary investigation relied on the irradiation and readouts of the spots of banknotes in order to plot maps of the intrinsic initial native signal and with sensitivity to the ionizing radiation of particular parts of the banknotes. From each banknote (‘new’ and ‘old’ 10 and 20 PLN, 1 USD and 5 EUR) some spots were selected for further study of repeatability, linearity and fading.

The intrinsic initial native signal is an OSL signal which can be measured during the first readout on the samples untreated by any irradiation but only in the new type of polish banknotes. The old type does not have any initial intrinsic signal. Initial signal comes from the banknote's origin, chemical composition, treatment, printing ink and different collaterals. Initial signal is an undesirable phenomenon and distorts the radiation induced signal. Cleaning didn't remove any initial signal in banknotes. Initial signal is irretrievably erased during the first OSL readout. All systematic investigations of repeatability, dose response and fading were carried out on samples after their first OSL readout (which means without initial signal). The use of a ‘fresh’ sample with initial signal is always clearly marked in the text.

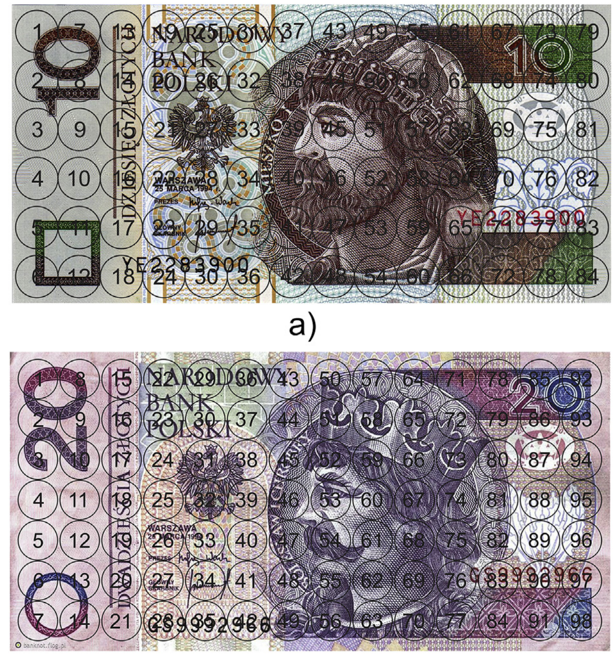

Fig. 1. The ‘new’ 10 PLN (a) and 20 PLN (b) banknotes with the location of investigated spots.

At the beginning of our experiments the repeatability of the signal of selected areas from different banknotes was checked. Generally, the same areas of the banknotes (28± 1 mm^2) presented similar properties but some deviation was noticed, therefore each spot should be treated individually. This individual approach means that the calibration should be performed and calculated for each separate spot. These deviations can arise from the individual attributes of the banknotes which are caused by its wear rate.

OSL signal was read out for 300 s while recording the signal every 0.1 s. For calculation the sum of the first 5 points (recorded in first 0.5 s) minus last 5 points (last 0.5 s between 299.6 and 300.0 s) was taken. This method was always applied except in Chapter 3.7 where another signal calculation method was implemented (see text).

3. Results and discussion

3.1. OSL signal of particular spots

In the first step of the investigation OSL signal was checked for some spots randomly chosen from the banknotes. The exemplary results for the ‘old’ type of 20 PLN banknote are presented in Fig. 2A and for the ‘new’ type in Fig. 2B. Routinely, each spot taken from a “fresh” banknote was at first irradiated with 1 Gy and then read out (curve a). Next the background level (the second readout of the same sample) was measured (curve b). The second irradiation performed on the same spot gives only a signal coming from