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ASSESSMENT OF EFFECTIVE DOSE TO AN INDIVIDUAL CARRYING MATERIALS USEFUL FOR RADIATION DOIMETRY BY OPTICALLY STIMULATED LUMINESCENCE

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***Abstract*:** Optically stimulated luminescence (OSL) from ordinary household salt has proven high potential for very low dose retrospective dosimetry. In the present paper other common place materials are considered and their dosimetric OSL-properties compared with household salt. The potential for assessment of the effective dose to an individual carrying such materials is investigated.

***Keywords*:** OSL, TLD, effective dose, RANDO phantom

1. Introduction

A radiological or nuclear (R/N) incident/accident where members of the public might have been exposed will require dose assessment of (unmonitored) members of the public for proper remedial actions, medical treatment and stress reduction. In order to assess the exposure of such persons and to estimate the risk of late health effects, methods to retrospectively determine the absorbed dose to various organs and effective dose are required. Several such methods, including biological, physical, and computational ones, have been suggested. Many of those methods, however, require high absorbed doses to provide a measureable response. One desirable property of such a method is that the response of the dosemeter is able to determine low absorbed doses, preferable down to a few mGy in order to accurately determine doses that are relevant for the human health (>50 mGy) and that applies to the Nordic emergency response reference levels (between 20 and 100 mSv during the first year) [1]. It is also desirable [2] to find a method to convert the dosemeter signal into a human radiation risk quantity such as the effective dose.

Specifically, optically stimulated luminescence (OSL) in crystalline materials has proven to be both cost effective and useful for such low dose determinations. In OSL, light with specific wave-length is used to stimulate an irradiated sample, which in turn emits luminescence light. The luminescence is proportional to the recombination, during deexcitation, of radiation induced trapped electrons. However, not all crystalline materials have properties that are suitable for low-dose determinations using the OSL method. Such materials must have the crystal structure of a semi-conductor. It is also desirable if these materials are worn or found close to man.

In the present paper several materials are investigated in terms of their OSL-sensitivity. The paper also describe how such OSL materials may be used in order to determine the effective dose to a person wearing such material on the body during exposure.

2. Material and methods

The dosimetric OSL properties of some materials commonly found in the immediate vicinity of people have been studied. The materials investigated were chosen based on three criteria: *i.*) known to have OSL properties [3-6], *ii.*) assumed to have OSL properties, and *iii.*) found close to man. All materials have been collected in homes and workplaces or purchased at local supermarkets and can thus be considered as commonly available. In total, fourteen such materials were included in the comparison to evaluate future dosimetry applications (Table 1). At this stage, the materials were only investigated in terms of their OSL sensitivity, without consideration of designing standardized read-out procedures for these materials.

To determine the specific sensitivity of the investigated materials, a test was carried out in a Risø TL/OSL reader (TL/OSL-DA-15, DTU, Risø Campus, Denmark) [7] using an internal ^{90}Sr/^{90}Y source of 20 MBq. Samples of each material, small in size enough to just barely cover a sample cup (~10 mg) of the reader, was portioned on 3-5 cups. No special preparation was carried out on the materials before they were exposed to radiation from the internal source and then evaluated. Irradiations of absorbed doses from a few mGy up to a few Gy were delivered to the individual dosemeters (sample cups in the read-out unit) to determine the specific sensitivity (cps mGy^{-1}). In addition, for the materials with the highest sensitivity, the minimum detectable dose (MDD) was determined. The MDD was defined as the absorbed dose corresponding to a signal equal to three times the standard deviation over the background signal [8].

In order to relate the radiation induced signal in an OSL sensitive material to the effective dose to an adult individual from external exposure, irradiation with well-determined photon beams of the investigated materials, positioned on a physical anthropomorphic dosimetry phantom was carried out. For this purpose the male version of the RANDO phantom (Alderson, The phantom laboratory, Salem, NY, USA) was used. The organ positions were defined and outlined in a previous project [9, 10]. The sampling schedule covered all risk organs [11] with thermoluminescent (TL) chips of lithiumflouride (LiF), in total 362 individual LiF chips. The phantom was also prepared with an electronic dosemeter (EPD, Siemens) and ordinary TL dosemeters (TLDs), positioned on the phantoms chests, for measurement of the personal dose equivalent, $H_p(10)$ (mSv). Furthermore, ordinary household salt in a small salt package, commonly found in fast food restaurants, was positioned on the phantoms front leg in height of the trouser pocket (Fig. 1). The phantom was then exposed in a ^{60}Co beam in AP-, PA-, and ROT-exposure geometries (Fig. 2) at a distance of 5.5 m to provide a parallel photon beam over the phantom. After exposure, the TL-signals from the LiF chips and the OSL-signal from the salt were read-out in the TL/OSL-reader. For each exposure, six salt sample cups were read-out and individually calibrated using a specially designed SAR-protocol [12] enabling a signal uncertainty of less than 3% for the individual read-outs.

Fig. 1. The Alderson RANDO Phantom positioned on a rotating table for allowing exposure in AP-, PA- and ROT ^{60}Co-exposure geometries. TLDs and an EPD were positioned on the phantom in chest height. A portion bag with salt was put at the height of the trouser pocket on the front side of the leg.

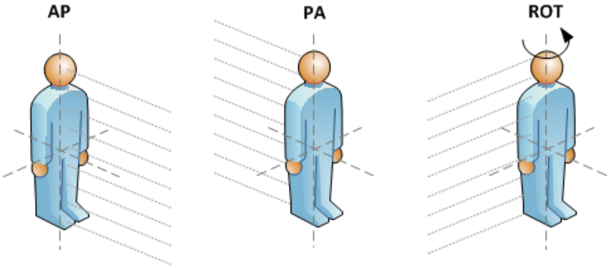

Fig. 2. Exposure geometries AP (anterior-posterior), PA (posterior-anterior) and ROT (rotational invariant) used with the RANDO phantom in the parallell ^{60}Co photon beam.

3. Results and discussion

3.1 Comparison of potential OSL materials

The dosimetric parameters assessed for the comparison of the OSL properties of the investigated materials are shown in Table 1. All of the investigated materials show a signal response to optical stimulation after exposure to ionising radiation, except for the salty candy. The absence of OSL response for the candies is supposed to be due to the salted coating that consists of a compound that does not fulfill the crystal properties required for OSL.

The sensitivities as measured by the standard protocol optimized for quartz and shown in Table 1 are given as luminescence (cps) per given absorbed dose (mGy). A range in sensitivity is provided when various forms of the same material has been tested in different forms *e.g.* desiccants of silica gel, bentonite clay, $AlNa_{12}SiO_5$, SiO_2, Al_2O_3. The sensitivity of an OSL material is one of the parameters that typically determines the future use of the material as a retrospective dosemeter. From Table 1 the investigated materials may be divided into two groups based on their sensitivity: materials 1-5 and materials 6-14. The materials in the latter group (Nr. 6-14) showed a markedly lower OSL signal after exposure to ionising radiation compared to the first group. The low sensitivity may be increased by adjusting the read-out protocol and by applying individual calibration procedures to the individual samples of the material [12]. However, in the present study we have only compared the sensitivity of the investigated materials using a standard read-out protocol. Further improvements of read-out protocols for the specific materials are to be done in a separate study.

The here used definition of the MDD have been determined for the first group of highly OSL sensitive materials. Hence, the MDD of the materials in the second group (Nr. 6-14) have not been considered as the read-out protocols must be further optimized. The other materials (Nr. 1-5) indicate very low MDDs (0.2-20 mGy). The higher values of the MDD of materials Nr. 4 and 5 suggest that both desiccants and dental repair materials should be sorted, arranged and carefully selected into sub-samples before estimating low absorbed doses.

Table 1. Summary of the studied materials and their OSL dosimetry properties, indicating if an OSL signal was acquired (Y) or not (N). The sensitivity (cps mGy^{-1}) is provided together with the minimum detectable dose (mGy) if less than 500 mGy. Given is also the number of different samples of the same material (No.).

Nr.	Material	No.	OSL-signal	Sensitivity (cps mGy^{-1})	MDD (mGy)
1.	Household salt	1	Y	1500	0.2
2.	Salty snacks	10	Y	4-1300	1
3.	Resistors	1	Y	19	14*
4.	Desiccants	11	Y	0.3-13	8-450
5.	Dental repair materials	4	Y	0.8-31	20-180
6.	Coffee	1	Y	<0.9	-
7.	Medical pills	1	Y	0.8	-
8.	Chewing gum	1	Y	0.6	-
9.	Sugar	1	Y	0.2	-
10.	Plaster wall	1	Y	0.2	-
11.	Egg shell	1	Y	0.2	-
12.	Nail file/sand paper	2	Y	0.2	-
13.	Hair	1	Y	0.1	-
14.	Salty candy	1	N	-	-

**Immediately after exposure.*

It is interesting to note that the high sensitivity observed in household salt may also be found in some types of common salty snacks. Snacks that is covered with salt in its purest form *e.g.* salty sticks and salted cashew nuts show a very high sensitivity to ionising radiation. If individual read-out protocols are developed for such salty snacks the sensitivity will be improved and may potentially be higher than for the household salt used in the present study.

3.2 Determination of effective dose using the OSL from salt

Among the investigated materials (Table 1) the highest sensitivity to ionising radiation was found for ordinary household salt (NaCl). In a second step of investigating OSL for retrospective dosimetry, the household salt (Nr. 1 in Table 1) has been tested for estimation of the effective dose to an individual when worn on the body during exposure.

The effective doses for the three exposure geometries (AP, PA and ROT), as calculated from the organ absorbed doses, are given in Table 2. Provided are also the personal dose equivalent as measured with an EPD and TLDs (mSv), and the absorbed dose (mGy) estimated from the OSL signal in a salt (NaCl) package when kept on the front side of the leg of the phantom.

In terms of the individual dosemeters response, the absorbed dose in the salt follows the effective dose and the personal dose equivalent measured with the EPD, except for the PA exposure geometry. In the PA geometry the salt underestimates the effective dose by about 50%. In the same geometry the EPD also underestimates (<25%) the effective dose. This may be explained by the attenuating tissue between the source and the dosemeters in this particular irradiation geometry: for the EPD it consists of lung tissue (>16 cm) and soft tissue (>6 cm), and for the salt it is mainly soft tissue (>22 cm). Hence, the reduced average energy of the beam reaching the salt package on the leg indicate a lower sensitivity for the salt at lower photon energies.

Table 2. Effective dose (mSv) to the anthropomorphic Alderson RANDO phantom when exposed in a ^{60}Co beam ($\dot{K}_{air}$ = 40.7 mGy h^{-1}) in AP-, PA- and ROT geometries. Provided is also the personal dose equivalent as determined by an electronic dosemeter (EPD, mSv), TLDs ($H_p(10)$, mSv), and the absorbed dose (mGy) as determined by the OSL signal in a salt package on the front side of the trouser pocket of the phantom, in the same geometries.

Exposure geometry	E (mSv)	EPD (mSv)	TLD (mSv)	OSL(NaCl) (mGy)
AP	35	39	51	36
PA	27	21	28	14
ROT	25	25	29	30

With the ^{60}Co exposure conditions used in this study the OSL conversion coefficients to effective dose are 0.98, 1.98 and 0.85 Sv Gy^{-1} for AP-, PA- and ROT geometries, respectively. For AP-geometry this conversion may be applied for all energies between 0.1-1.0 MeV, whereas the PA and ROT conversion coefficients are expected to reduce with about 20% from 1.2 MeV to 0.1 MeV [13].

4. Conclusions

Among the fourteen different materials tested, all except one showed an OSL signal after exposure to ionising radiation. For the materials with non-optimized read-out protocols the sensitivity was below 1 cps mGy^{-1} and the MDD was not determined. For the materials with optimized read-out protocols the sensitivity was much higher, up to 1500 cps mGy^{-1}. After selecting an OSL sensitive material it is important to separate equal samples of that specific material and use the parts with the highest sensitivity. By doing so it is possible to achieve a minimum detectable dose of less than 1 mGy for household salt. It is also shown possible to estimate the human effective dose from an OSL sensitive material after exposure to external radiation.

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