Use of low-value personal objects for a rapid radiation triage with a portable Optically Stimulated Luminescence system

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Abstract–This work was carried out by the Istituto Superiore di Sanità (ISS) and the Ruđer Bošković Institute (RBI) in the framework of the BioPhyMeTRE project funded by the NATO Science for Peace and Security Programme. Low-value personal objects, which could be used as fortuitous dosimeters in case of a radiological/nuclear (R/N) accident involving a large number of civilians, were analysed by using optically stimulated luminescence (OSL). We proposed a model of a portable reader which allows for rapid analyses at the accident site. Items tested in the project were salty snacks, cigarettes, paper, cosmetics, medicines, dietary supplements, and others that could be found in the bags/pockets of civilians. Two protocols were developed for dose evaluation: one based on the use of a calibration curve and the other based on the single aliquot regenerative (SAR) dose procedure. Intra- and inter-laboratory tests were performed in parallel by each laboratory on salty crackers and dietary supplements that showed the best dosimetric properties. The results obtained with the crackers have already been published. In this paper, we provide a brief overview of the work carried out as part of the project.

Keywords: Radiological/nuclear emergency; Optically stimulated luminescence; Personal objects; Dose assessment; Radiation triage

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1. INTRODUCTION

In radiological or nuclear (R/N) emergencies, fast determination of the radiation exposure levels of potential victims makes it possible to distinguish between those who were unaffected and those who need medical assistance. Since the civilian population does not wear professional dosimeters, dose assessment using physical methods depends entirely on the objects that can be found at the place of the event, i.e. on fortuitous dosimeters. To this purpose, various materials from personal items (mobile phones, cards, clothing, etc.) have been successfully tested in recent decades using different physical techniques, such as electron paramagnetic resonance (EPR) and thermally or optically stimulated luminescence (TL/OSL), that allow the absorbed dose to be evaluated by measuring the radiation damage in the material structure (Kazakis et al., 2014; Sholom and McKeever, 2014, 2016; Bailiff et al., 2016; Nikiforov et al., 2016; Christiansson et al., 2017; McKeever and Sholom, 2019; Ekendahl and Reimitz, 2022; Fattibene et al., 2022). In the framework of the BioPhyMeTRE project, funded by the NATO Science for Peace and Security Programme, low-value personal objects, such as salty snacks, cigarettes, paper, cosmetics, medicines and dietary supplements, have been tested with a portable optically stimulated luminescence (OSL) reader that can be used at the accident site for rapid radiation triage of civilians. The advantages of this choice are: the speed of analysis (only 60 s per measurement), the availability of the instrument in many laboratories around the world as part of the irradiated food monitoring network, and the use of low-value personal items that people may be willing to donate in case of a radiological/nuclear emergency. Many different materials were examined, taken from personal objects that people may have in their bags/pockets or that can be found in the vicinity of the accident place (Testa et al., 2020). Very promising fortuitous dosimeters turned out to be, among others, salty crackers from a popular brand and magnesium-containing dietary supplements which were further investigated. Dose response in the 0.1–5 Gy range and signal stability within a week were studied. The results obtained from these studies for crackers have already been reported in Maltar-Strmečki et al. (2021). Two protocols for the dose evaluation were developed: one based on the use of a calibration curve and the other based on the Single Aliquot Regenerative (SAR) dose procedure (Murray and Wintle, 2003). Intra-laboratory tests were performed in parallel by each laboratory to establish the procedures. Based on the results of these tests, inter-laboratory exercises were organised involving two laboratories at ISS and at RBI. This paper provides a brief overview of the work carried out as part of the project.

2. MATERIALS AND METHODS

Different items, such as snacks, lunch bars, cosmetics, medicines, dietary supplements, salts, candies, dried fruit, cigarettes, banknotes, bandaid, panty lines, bus tickets, banknotes, disinfectant gel, blister, membership cards, soil, receipts, face masks, contact lenses, and glasses, were collected or purchased at local markets in Rome and Zagreb. The analyses were performed on non-irradiated samples and samples irradiated with doses in the range of 0.1–5 Gy. Irradiation was performed using Gammacell 40 Cs-137 (approximately 0.7 Gy min^{-1}) and Alcyion I CIS Biointernational Co-60 (0.12 Gy min^{-1}). The analyses were carried

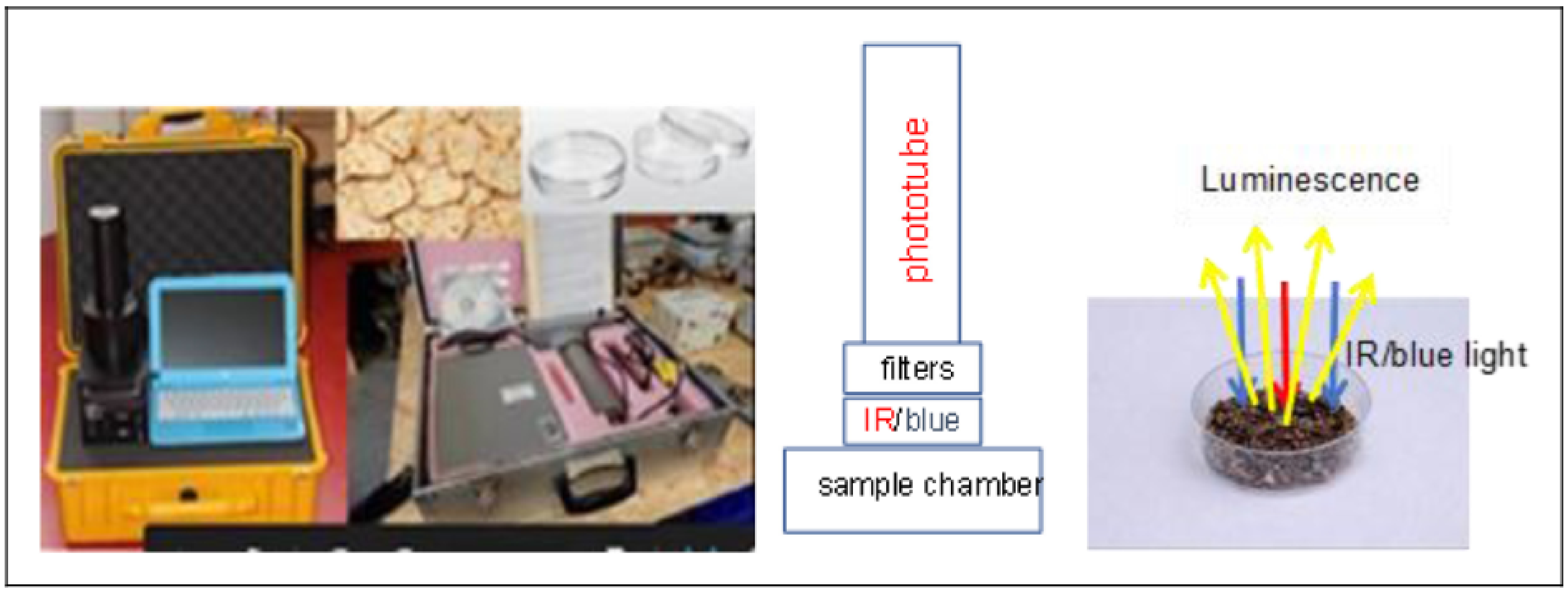

Fig. 1. OSL measurement. The sample is exposed to infrared radiation (IR, 890 nm) or blue light (470 nm) stimulation that induces the emission of the luminescence which is converted into electrical charge (counts) by the phototube.

out with a portable OSL system equipped with two stimulation sources, infrared (IR, 890 nm) and blue light (470 nm), provided by SUERC (Scotland, UK). For the OSL measurement, the samples were cut into small pieces or ground into powder and placed in Petri dishes (50-mm diameter) with the bottom of the dishes covered with a thin layer.

During the measurement, the sample was exposed to IR or blue light for 60 s, which induced the emission of luminescence from the crystalline components present in the sample (Fig. 1); the luminescence is converted into an electrical signal by the phototube, and the result is expressed in counts. All operations were carried out under red light to prevent the signal bleaching due to daylight. During storage, the samples were kept in the dark at room conditions. For dose evaluation two operational procedures were followed: one using a calibration curve and the other based on the SAR dose protocol. The SAR protocol used in this study, whose scheme is reported in Fig. 2, is a slightly modified version of the standard SAR dose protocol (Murray and Wintle, 2003).

To avoid undesirable effects of possible OSL residual signals, the SAR-like protocol was applied using two aliquots: one for the measurement of the OSL response to the unknown dose D and the other one for the evaluation of the OSL response to the calibration dose (1 Gy) obtained as the difference between the OSL responses of the two aliquots. To take into account the signal decrease (fading) due to the delay of the analysis, a correction factor was applied to the OSL response. The correction factors were obtained from the study of the OSL signal stability that was monitored at room conditions within a week on samples irradiated at 0.3, 1, and 5 Gy. For each dose, sets of 3–6 aliquots were irradiated altogether and measured each one at different times after irradiation. Each set was measured only once as the OSL measurement partially reduced the signal.

3. RESULTS AND DISCUSSION

Preliminary tests were performed to check the luminescence properties and radiation sensitivity of all materials selected for the study. Both laboratories obtained similar results, although with different total counts due to the instrumental characteristics (phototube

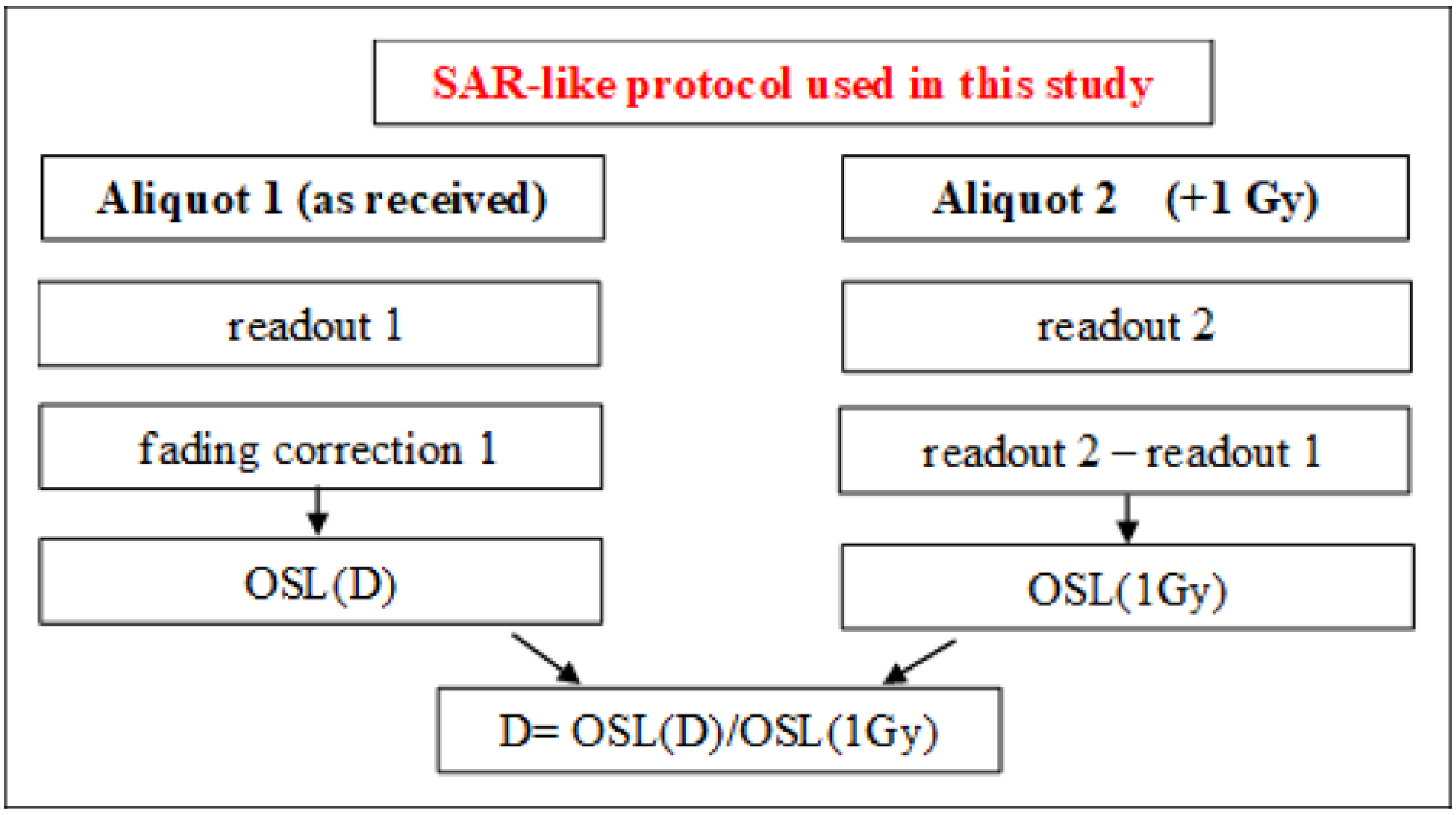

Fig. 2. SAR-like protocol proposed for the dose reconstruction test using the OSL technique.

Table 1. OSL response (total counts in 60 s) of cosmetics and foods.

Cosmetics	NI* IR	5 Gy IR	NI* Blue	5 Gy Blue	Foods	NI* IR	5 Gy IR	NI* Blue	5 Gy Blue
Face cream	-	-	529	557	Crackers	433	1619717	1746	1831732
Face powder	763	979	5272	7459	Candies	401	420	-	-
Face blush	-	-	145045	151888	Dried fruit	-	-	757	1764
Lip pencil	757	1764	-	-	Lunch bar	-	-	423	804
Lip gloss	423	804	-		Sea salt[†]	-	-	1007	260892089
					Sea salt[‡]	-	-	10481	91845413
					Sea salt[§]	-	-	3395	85191003

[*]NI, non-irradiated.
[†]Reduced sodium sea salt.
[‡]Potassium-enriched sea salt.
[§]Calcium- and magnesium-enriched sea salt.

sensitivity and type of detection band filter). Tables 1–3 show the results for cosmetics and food, supplements and medicines, and other household goods, respectively.

For most samples, there were no significant differences between the OSL responses of non-irradiated and irradiated samples, so irradiation cannot be detected for these materials. However, irradiated salty crackers, salts, and some dietary supplements yielded much higher total counts (orders of magnitude) than those of non-irradiated samples, suggesting promising properties as fortuitous dosimeters. The high radiation sensitivity of these samples is due to the presence of specific crystalline components: salt (crackers) and magnesium compounds (dietary supplements). For a few materials (lip pencil, dried fruit, and tobacco), the differences appeared not negligible as the OSL responses of irradiated samples are more or less

Table 2. OSL response (total counts in 60 s) of supplements and medicines.

Supplements†	Mg	NI* IR	5 Gy IR	NI* Blue	5 Gy Blue	Medicines	NI* IR	5 Gy IR	NI* Blue	5 Gy Blue
1	Yes	-	-	1166	326890	Acetylsalicylic acid	-	-	569	576
2	Yes	375	4752	303	18203	Paracetamol	342	368	342	782
3	Yes	-	-	913	663380	Antiacid drug	-	-	775	764
4	Not	-	-	-	1326	Atenol + chlor-thalidone	-	-	645	784
5	Not	-	-	964	1145	Probiotics	-	-	1148	797
6	Yes	-	-	550	20787	Laxative	375	939	-	574
7	Yes	-	-	951	31347					

*NI, non-irradiated.
†All the products contain different minerals and vitamins except supplement 1 that contains only magnesium compounds.

Table 3. OSL response (total counts in 60 s) of various materials.

Samples	NI* IR	5 Gy IR	NI* blue	5 Gy blue	Samples	NI* IR	5 Gy IR	NI* blue	5 Gy blue
Cigarette tobacco	463	1339	-	-	Banknote 1	-	-	502	631
Membership card	368	783	4100	2634	Banknote 2	-	-	481	709
Bus ticket	-	-	2796	3322	Blister	-	-	789	1126
Shop receipt	494	932	20165	21460	Disinfectant gel	-	-	-	607
Bank receipt	669	604	-	-	Face mask (white)	-	-	472	591
Panty liners	-	-	718	859	Face mask (blue)	-	-	814	666
Bandaid	-	-	558	479	Soil under shoes	-	-	3089	1665
					Contact lenses	-	-	507	471
					Glass lenses	-	-	424	518

*NI, non-irradiated.

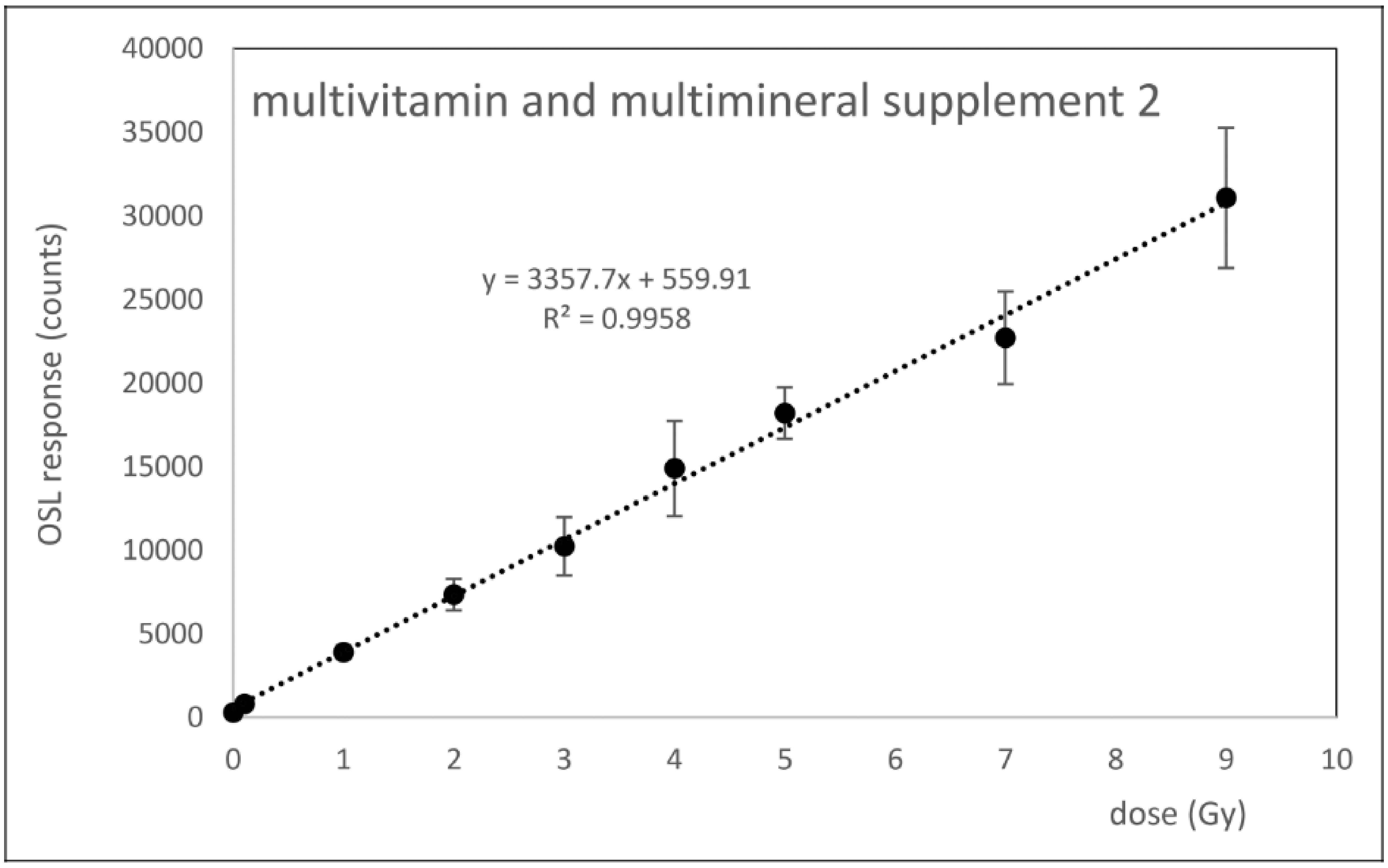

Fig. 3. Dose–response curve of multivitamin and multimineral dietary supplement 2 obtained using the blue light stimulation; each dose point is the average of the OSL responses of 3 tablets, and the error is the standard deviation.

doubled of those of the non-irradiated ones; nevertheless, they do not allow to distinguish them as the uncertainty of the OSL measurement is very high (up to 70%) due to the high batch variability. The luminescent components, in fact, are generally present in low and uncontrolled percentages in these materials, and their distribution inside the material is not necessarily uniform so that different aliquots of the same sample possibly provide very different OSL responses. As for the stimulation sources, blue light was generally more efficient in producing luminescence and was used for further studies on salty crackers and supplements: the dose response in the range of 0.1–5 Gy (and over) and the OSL signal fading studies. All selected materials showed a linear increase in the OSL signal with dose in the investigated range. The results obtained with salty crackers have already been published in Maltar-Strmečki et al. (2021). Here, as an example, the dose response curve of the multivitamin and multimineral supplement 2 is reported in Fig. 3. Regarding the signal stability, all samples showed a similar behaviour: a strong signal decrease in the first 2 days due to thermal effects. From these data, a correction factor was calculated to be applied to the OSL response recorded hours/days after irradiation (accident).

Intra- and inter-laboratory tests were performed by the two laboratories on the same samples. Both protocols provided accurate dose evaluations, although the SAR protocol, that requires re-irradiation of the sample, has higher uncertainties in the estimated doses due to the numerous sources of error in the procedure. The data analysis is still ongoing, but the preliminary evaluations showed that the magnesium-containing dietary supplements are a very promising material for fortuitous dosimetry. The results were very satisfactory, as both procedures provided accurate dose values that allowed the identification of the radiation triage category.

4. CONCLUSIONS

Different materials were examined as fortuitous dosimeters. Among them, salty crackers and magnesium-containing dietary supplements showed very good dosimetric properties: high radiation sensitivity, linear dose response in the range of 0.1–5 Gy, and reproducible signal fading over time. The dose evaluation tests performed by the two laboratories provided very good results for the magnesium-containing supplements, allowing identification of the triage category and accurate dose assessments. Recently, an inter-laboratory comparison exercise was organised at ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) on the same products, in which biological laboratories were also involved. The data analysis is still ongoing, but the preliminary results are promising and seem to confirm the results of the intra- and inter-laboratory tests.

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