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Original Scientific Paper

LUMINESCENCE PROPERTIES AND APPLICABILITY OF TABLE SALT AS AN ACCIDENT DOSIMETER IN RADIOLOGICAL EMERGENCIES

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Abstract: In the event of a nuclear incident, it is important to assess the population's exposure thereto at individual level. In retrospective dosimetry, the absorbed dose is determined from materials that have wide application in everyday life. In the early stages after the accident, results obtained with retrospective dosimetry methods are used for triage and allow actions taken to focus on places where they are most needed, that is, they serve as support for making strategic decisions of action. Dosimetric data, in addition to assessment of individual doses, can also be used to assess long-term effects, as well as to improve epidemiological analyses. Materials suitable for examination with luminescent techniques are electronic components, building materials from which quartz can be isolated, porcelain, or dental ceramics.

Crystals characterized by good response to optically or thermally stimulated luminescence and widely distributed in the environment are very useful in retrospective dosimetry for dose estimates in nuclear incidents. When exposed to ionizing radiation, common salt, mainly comprised of NaCl, is a material that exhibits significantly greater luminescence than many other materials. The aim of this study is to investigate thermoluminescence (TL) and optically stimulated luminescence (OSL) characteristics of commercially available table salt.

A protocol for measuring luminescent properties in materials for retrospective dosimetry was applied. Both irradiated and non-irradiated samples showed satisfactory TL/OSL responses. A linear dose response was observed, identifying the material as suitable for retrospective dosimetry. Preheating and reading temperatures were determined, and the SAR method yielded highly accurate dose measurements.

Keywords: retrospective dosimetry, thermoluminescence, optically stimulated luminescence

ЛУМИНИСЦЕНТНИТЕ СВОЈСТВА И ПРИМЕНЛИВОСТ НА ГОТВАРСКА СОЛ (NACL) ЗА РЕТРОСПЕКТИВНА ДОЗИМЕТРИЈА

Апстракт: Во случај на нуклеарен инцидент, важно е да се направи проценка на изложеноста на населението на индивидуално ниво. Во ретроспективната дозиметрија, апсорбираната доза се одредува од материјали кои имаат широка примена во секојдневниот живот. Во раните фази по несреќата, резултатите добиени со ретроспективни дозиметриски методи се користат за тријажа и овозможуваат преземените постапки да се фокусираат на местата каде што им се најпотребни, односно служат како поддршка за носење стратешки одлуки на дејствување. Дозиметриските податоци, покрај проценката на индивидуалните дози, може да се користат и за проценка на долгорочни ефекти, како и за подобрување на епидемиолошките анализи. Материјали кои се погодни за испитување со луминисцентни техники се електронски компоненти, градежен материјал од кој може да се изолира кварц, порцелан, стоматолошка керамика, итн.

Кристалите кои имаат добар одговор на оптички стимулирана луминисценција или термолуминисценција и се широко распространети во околината во која живееме се многу корисни во ретроспективната дозиметрија за проценка на доза при нуклеарни инциденти. Готварската сол, која главно се состои од NaCl, е материјал што покажува значително поголема луминисценција од повеќето други материјали кога се изложени на јонизирачко зрачење. Целта на ова истражување е да се испитаат карактеристиките добиени при термолуминисценција (ТЛ) и оптички стимулирана луминисценција (ОСЛ) на комерцијално достапна готварска сол.

Применет е протокол за карактеризација на луминисцентните својства во материјалите погодни за ретроспективна дозиметрија. Од испитувањето на озрачените и неозрачените примероци се покажа задоволителни TL/OSL одговори. Од испитувањето забележан е линеарен одговор на дозата, идентификувајќи го материјалот како погоден за ретроспективна дозиметрија. Беа утврдени температурите за предзагревање и читање, а методот SAR даде многу прецизни мерења на дозата.

Клучни зборови: ретроспективна дозиметрија, термолуминисценција, оптички стимулирана луминисценција.

I. Introduction

DOSE reconstruction can include various physical and biological measurement methods as well as numerical analyses of radioactivity data records. Dose reconstruction based on dose measurements performed on individuals includes methods that estimate the absorbed dose by examining teeth, blood, and radionuclide activity in the body. For external exposure, the appropriate methods are usually based on persistent effects, such as free radicals or electrons trapped in defects (imperfections in crystal structure) in minerals, products of neutron activation, or changes in blood constituents. Measurements of radionuclides in the human body can be used for internal exposure.

Luminescent dose reconstruction methods are particularly suitable for determining doses to population groups caused by external exposure to gamma radiation. For individuals or population groups, additional modeling is required to transform the absorbed dose measured by luminescence methods.

Use of ionizing radiation, even in tightly controlled conditions, for example, in medical diagnostics or radiotherapy, is associated with certain risk of error and delivery of unwanted dose to the patient or personnel operating the equipment. In such cases, the delivered dose for patients and portion of support staff not covered by dosimetric monitoring can only be determined by retrospective dosimetric methods. Moreover, the threat of nuclear weapons use becomes a potential risk in the 21st century. The degree of risk of another nuclear power plant accident still exists, and with it, also the risk of mass radiation exposure. Even countries that nowadays use ionizing radiation only for peaceful purposes face the risk of mass contamination, in which case they would have to be prepared for rapid and accurate assessment of the dose received by the population in the event of a mass nuclear incident.

This paper focuses on characterization of widespread table salt, as well as nutritionally enriched salts that are increasingly used (magnesium chloride, potassium chloride, etc.).

In the last decade, different household salts have been subject of numerous optically stimulated luminescence (OSL) and thermoluminescence (TL) studies in respect to retrospective dosimetry purposes. Sea and rock salts are very well established as highly sensible material for (OSL) dosimetry. Existence of pre-established repository of well characterized materials, as fortuitus dosimeters, as well as a set of characterized instruments that collectively form a dosimetric system, assumes significant importance in facilitating prompt responsiveness during a nuclear incident. Thus far, extensive research efforts have been dedicated to investigating potential utilization of salt as retrospective dosimeter. Substantial variations in luminescent properties are observed, depending on the type of salt and its geographical origin. In almost all cases, examination of luminescent properties of salts by optically stimulated luminescence is accompanied by thermal processes of preheating or readout with heating.

Bailey et al. investigated OSL properties in respect to its applicability in dating and dosimetry of NaCl relative to dating and dosimetry of commercially obtained analytical quality NaCl, using a Risø TL DA-12 reader with blue, green, and IR continuous wave stimulation (CWS) light. They obtained linearity of OSL signal for doses up to 10 Gy. In their protocol, the salt is preheated to 200°C and read at 120°C [1]. Other research done by Go Okada et al. investigated OSL properties of Eu2+ doped NaCl single crystal using a lab-constructed automated system with CWS 450-550 nm. During the preparation process, the powder was dehydrated by heating at 500℃ overnight. The sample was irradiated with X-rays. They obtained linearity of OSL signal for doses up to 10 Gy [2]. TL properties were researched by Datz et al. on 10 brands of Israeli household salt (NaCl) using a Thermo 3500 manual reader with an IR filter. Readout temperature was between 50 and 350˚C at a linear heating rate of 1 and 5˚C s^{-1}. The samples, weighing 50 mg on average, were irradiated using a calibrated gamma-ray ^{137}Cs source with a dose ranging from 0.5 mGy to 300 Gy. Eight of the ten brands showed similar glow curves. They concluded that the salt with a higher dopant concentration is significantly more sensitive [3]. Alghamdi et al. have demonstrated that dosimetry using common salt with portable OSL reader is a rapid and effective means of determining dose below 100 μGy. For the purpose of dose response, experiments were made with photon irradiation in the range 20–500 μGy. Detection limits of 7 μGy have been successfully demonstrated for OSL measurements, while the other instruments examined had shown detection limits ranging from 30 to 340 μGy. The most sensitive systems were able to determine dose responses within the range of 0 to 500 μGy. These systems exhibited a linear response across this dose range, with a non-zero intercept indicating doses received from environmental sources since the salt's production. Measurements of salt samples that had been exposed to artificial daylight for 1 week showed luminescence signals significantly above the empty chamber, especially with 890 and 470 nm stimulation [4]. Majgier et al. investigated OSL properties of potassium chloride and its potential use in radiation dosimetry. In addition, these properties were compared to that of NaCl in the same type of physical forms. KCl was studied in three sample forms: powder, crystal and pellets, using a Risø TL/OSL-DA-15 reader with blue continuous wave simulation light with peek emission at 470 nm. Irradiations inside the TL/OSL reader were carried out using beta source with a dose rate of ~0.80mGy s^{-1}. All KCL samples (powder 60% 500–700 μm, crystal grains with grain sizes from 2 to 5 mm, and pellets 5mm diameter × 1mm thickness, ∼50 mg mass) were irradiated with an absorbed calibration dose (CD) of 0.44 Gy, stored for 150 s, and then OSL signal was read out at various temperatures from 25°C to 300°C. Heating to the set readout temperature was performed using a heating rate of 5°C/s. After that, a test dose of 0.044 Gy was administered and the corresponding OSL signal was acquired. For NaCl powder, readout settings were the following: preheating at 220°C and a 40 s OSL readout at 100°C with 40% of maximal continue wave blue LED stimulation power. Additional measurements were also made at room temperature and without preheat [5]. Janet Ayobami Ademola has shown that, within the limit of error, salt samples could be used as complementary emergency dosimeter in radiological accident situation (OSL and TL luminescence). Two samples were dried at room temperature and placed on plantchet sprayed lightly with silicon. The samples were irradiated with beta-irradiator (618 mGy) holding a calibrated $^{90}Sr/^{90}Y$ source. For irradiated samples (with heating rate of 5℃/s), TL peaks occurred at about 100℃, 240℃ and 280℃. OSL signals of irradiated samples (410 mGy) started to decay at about 0.49 s and decayed to negligible proportion after about 5 s. Two samples were used to test for fading, irradiated with 1000 mGy beta dose and stored in dark, at room temperature, for a period of 0 - 14 days. OSL measurements were done at stimulation temperature of 125℃ for 40 s, with a heating rate of 5℃/s. The samples were preheated to temperature of 190℃ at 5/s for 10 s before OSL measurements. The two samples exhibited little fading over 14 days, with more than 80% of the signal remaining [6].

Katarzyna et al. demonstrated OSL dosimetric properties of dietary supplements containing potassium chloride (KCl). CW-OSL measurements were performed using a Helios OSL reader with green continuous wave simulation light. Equal samples weighing 100 ± 3 mg with similar surface area were prepared and irradiated with a dose of 2.5 Gy before reading CW-OSL signal. Dose response characteristics were observed in a range from 0.05 Gy to 11.65 Gy immediately after irradiation and 24 h after irradiation. The dose recovery test was performed for doses: 0.61 Gy, 1.84 Gy and 3.07 Gy, representing the radiation dose triage levels. Linearity in the dose response was present in two ranges: 0.05-0.9 Gy and 0.9 to 9.5 Gy [7].

Bernhardsson et al. have investigated the potential of a selection of household salt as retrospective dosemeter for ionizing radiation using optically stimulated luminescence (OSL). The salt was carefully mixed in a dark room and was irradiated at distances of 5.5 and 0.5 m, with dose rates of 21 $\mu Gy\ s^{-1}$ and 2 $mGy\ s^{-1}$. Following the irradiation, the salt was kept inside light-sealed tubes for 24 h before readout. A linear dose response relationship was found in the dose range from 1 mGy to about 100 mGy, while above that level, the relationship becomes moderately supra-linear, at least up to 9 Gy. The two sea salts and the dissolved mine salt showed dominating glow peak at around 100°C [8].

Fujita et al. investigated optically stimulated luminescence (OSL) and violet thermoluminescence (VTL) characteristics of "Aji-Shio" (Ajinomoto), Japanese commercial salt. An automated Risø TL/OSL DA15-B reader was used in all OSL and violet TL (VTL) measurements, using blue continuous simulation lights with maximum emission at 470 ± 30 nm. The SAR (single-aliquot regenerative-dose) protocol (using blue-LED simulation) was established. The samples were first irradiated with a dose of 2 Gy and then preheated to 160˚C for 10 s. OSL measurements were then carried out at 60˚C for 40 s. A test dose of 0.5 Gy was then given, followed by second preheating done at 100˚C for 30 s. OSL simulation was done again at 60˚C for 40 s, and afterwards the samples were illuminated for 40 s at 160˚C [9]. Fuochi et al. studied Gamma-irradiated NaCl samples of different origin using PSL technique. Irradiation was performed with ^{60}Co gamma rays. The dose rate at the sample location was 0.6 Gy/min, with an uncertainty in dose delivery of about 2% at 1 SD. The number of photon counts recorded in 60 s was taken as PSL measurement result. PSL response increases linearly with sample mass up to about 10 g and saturates at about 20 – 25 g. High PSL positive results of rock salt suggest that the material has stored the natural radiation background on a geological time scale. This information was lost during the industrial preparation process of refined table rock salt which led to negative PSL classification. To reset the geological PSL signal to zero, all salt samples were annealed at 150℃ for 1 h before irradiation. The irradiation doses were limited to 0.5 and 1 Gy, since the very high geological signal of rock salt suggested its high sensitivity. Dose response behavior of sea salt and refined rock salt was studied in the 0.1 – 2 Gy range. Doses were limited to 2 Gy to avoid counter overflow. Measurements were performed 24 h after irradiation. Even the samples kept in dark under normal laboratory conditions showed a fast decay within the first few days. After 20 days of storage, PSL readings decreased to about 20% of the initial values. TL measurements were made on about 30 mg aliquots in the range 70℃ – 380℃, with a heating rate of 6℃/s. The glow curve of rock salt presents a peak in the high temperature region, typical of geological signals [10].

Lopez et al. investigated CW-OSL dosimetric properties of natural NaCl samples, collected in the Dead Sea, using a custom-made OSL equipment with blue continuous simulation light, with maximum emission at 455 ± 25 nm. Luminescence of the stimulated sample was observed trough two U 340 filters. CW-OSL dose response was analyzed from 0.2 up to 20 Gy of ^{60}Co gamma radiation. Natural NaCl minerals showed a linear CW-OSL dose response range between 0.5 and 10 Gy, obtained at room temperature (~25 ˚C). The samples exhibited an enhancement of sensitivity when preheated between 130˚C and 190˚C, as well as an increase of CW-OSL response when stored in a time period of 336 h [11]. Spooner et al. studied NaCl samples, analyzing its high sensitivity to ionizing radiation, by thermoluminescence (TL), optically-stimulated luminescence (OSL) and infrared-stimulated luminescence (IRSL). 8 mg of sample grains were loaded onto stainless discs and preheated at 2K/s to each of 8 different temperatures spaced in 10℃ increments from 190℃ to 260℃ and irradiated with 0.13 Gy $^{90}Sr/^{90}Y$ beta radiation. Preheating to 300℃ and higher temperatures created a significant new 100℃ TL peak in the UV (370 nm) emission band while desensitizing the 590 nm TL emission. The Pulse anneal analysis of OSL and IRSL was done in two stages. Firstly, the samples were irradiated with 0.26Gy, and OSL was measured using 12s exposure. Secondly, measurements were made to reveal thermal draining of the traps by increasingly high temperature preheating. 0.26 Gy dose was administered to each disc, the first illumination was done at 30℃ for 0.2 s. Temperature was incremented in 20℃ steps until 140℃, then in 10℃ steps to 300℃, between each the sample was returned to 30℃ and monitor exposure was being made. OSL showed a slight increase in sensitivity as the annealing temperature approached 100℃, then dropped at a rate paralleling thermal erosion of 100℃ TL peak. There is no significant source of OSL or IRSL (room temperature readout) that survives heating to temperatures beyond about 240℃. TL, OSL and IRSL sensitivity changes, confirmed activation of sensitivity change by exposure to temperatures exceeding 160℃ [12].

Spooner et al. studied TL, OSL and IRSL (infrared-stimulated luminescence) properties of 19 NaCl samples and their potential use in retrospective dosimetry. Sample characterization was done using the University of Adelaide Fourier-Transform thermoluminescence spectrometer to measure natural TL (NTL) and artificially-dosed TL (ATL) emissions. Kinetic analysis was done on each sample, whose sizes varied between 180-250μm grains, with a modified Alldred glow oven using an EMI 9635QA PMT colour glass filter. OSL, IRSL and TL dose response curves for UV and blue-to-orange emissions were constructed following beta irradiation (90Sr/90Y) for doses of 0, 0.14, 0.27, 0.54, 1.1, 2.2, 4.4, 8.7, 17.5 and 35 Gy. These experiments were performed using a Risø TL/OSL DA-20 reader with an EMI 9235QB PMT filter, with a heating rate at 2K/s in flowing nitrogen. Luminescence sensitivity of 590nm TL and blue-stimulated UV OSL was sufficient to enable dose detection limits of < 1mGy to be readily achievable for reported samples [13]. Tanır et al. studied infrared stimulated luminescence (IRSL) decay from NaCl using only one aliquot irradiated with a range of 2Gy to 200Gy β-radiation doses. The dose rate given to samples was 0.034Gy/s. The bleaching is carried out by exposing to daylight (or LED) and controlled by measuring signals from the sample. A single aliquot prepared from NaCl sample was given the β-radiation dose, preheated at 200 C for 1 min/IRSL was measured/it was bleached. These procedures were repeated for 2, 4, 6, 10, 15, 20, 30, 50, 75, 100 and 200 Gy doses for the same aliquot. Continuous decrease at low doses (2, 4 and 6 Gy) and an initial increase in intensity at high radiation doses (10 Gy) was observed. IRSL from NaCl has shown that the initial dose dependence at low doses is linear, followed by an approach to saturation at high doses. IRSL dose response from NaCl was saturated at ~ 50Gy. IRSL signal of NaCl has been shown to be decayed as being dose-dependent [14].

To carry out these investigations, it is first necessary to establish a protocol for luminescent reading of various materials, as well as to determine the linear region of the luminescent response suitable for use in dosimetry, and to apply the established protocol. In addition, the characteristics of investigated materials are provided by using deconvolution methods. Deconvoluted thermoluminescent curves determined some characteristics of the crystal structure of investigated materials. An assessment of measurement uncertainty for the reconstructed dose was also made.

II. Theoretical Background

Electrons of a single atom are allowed to exist in certain discrete energy levels. When a number of atoms form a solid, bands of allowed energy states are formed, separated by forbidden energy bands.

When defects (imperfections) are present in the crystal structure of a solid, electrons can move between valence and conduction band, leaving free electrons in the conduction band and free holes in the valence band. By this, new localized energy levels in the band gap are formed. When minerals are exposed to ionizing radiation, electrons may gain enough energy to leave their energy band and remain trapped in some imperfections of the crystal lattice. When this material is later exposed to optical or thermal stimulation, trapped electrons may gain enough energy to release and recombine with holes. The result of such re-combinations is emission of photons.

Thermoluminescence is the phenomenon of emission of light from irradiated solids when exposed to thermal stimulation, while optically stimulated luminescence is the phenomenon of emission of light from irradiated solids when stimulated with light of certain wavelengths. When TL- or OSL-sensitive material is exposed to ionizing radiation, electron-hole pairs are formed and move freely through the conductance and valence band. Some of them may be trapped in some active points. Electrons remain in this state until they gain enough energy from the stimulation to be released, after which they recombine with holes.

Luminescence signal is detected by photon counting method.

III. Materials and Methods

This study analyzes table salt found on the open Macedonian market. The declared composition of the examined salt is 99.9% table salt, potassium iodate and E 535 (sodium ferrocyanide). The examined salt sample contains KIO_3, in the amount of 20 to 30 mg of iodine per 1kg of salt.

Measurements are performed with the Riso TL/OSL reader, model DA-20, at the Radiation Physics Laboratory (RAD-LAB) within the Faculty of Electrical Engineering and Information Technologies in Skopje.

The apparatus is comprised of sample carousel and sensitive photomultiplier. The sample is placed on heater plate and then heated by thermocouple. Emitted light is focused towards the photomultiplier through a filter. Main parts of the TL/OSL reader used are sample chamber with sample holder that holds samples for measurement in certain position, heating system that controls sample temperature, light stimulation system that provides light sources for OSL, photomultiplier tube that detects emitted luminescence, filter system which filters out unwanted wavelengths, and control/data acquisition system software that manages operations and data.

A schematic diagram of the instrument is shown in Figure 1.

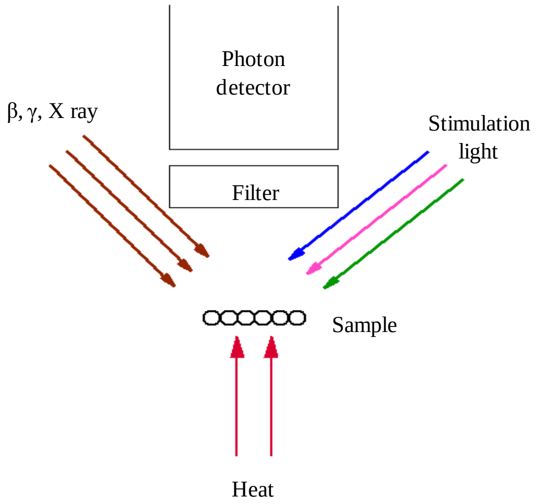

Fig. 1. Schematic diagram of the Riso TL/OSL reader

By using filters, the sample may be stimulated with light of different wavelengths. Intensity of the stimulating light is approximately 1018 times higher than the intensity of the light emitted from the sample. 90Sr beta source is used as source of radiation, embedded in the instrument. The beta source is characterized by activity of 1.48GBq (~0.1 Gy/s) and maximum energy of 2.27MeV. The beta dose actually comes from the decay of 90Sr, i.e., 90Y.

Figure 2 shows the protocol for determining luminescent characteristics regarding the material's application in retrospective dosimetry.

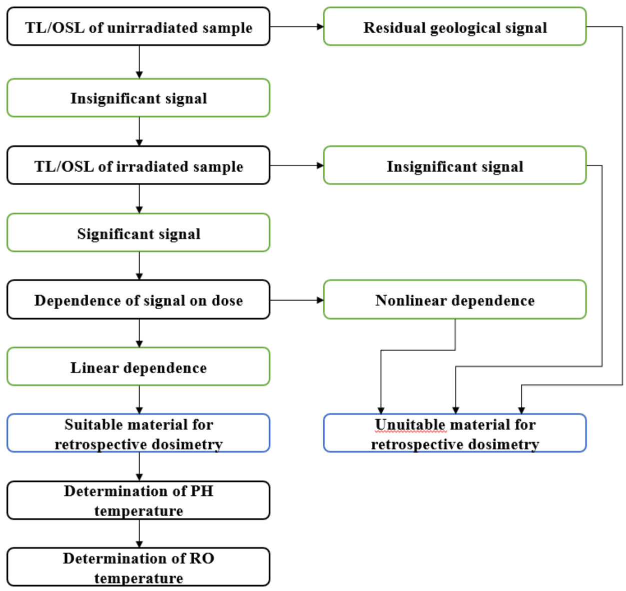

Fig. 2. Protocol for determining luminescent characteristics for the material's application in retrospective dosimetry

The protocol connects measurement procedures - marked with black outline, interpretation of the results obtained from measurement procedures - marked with green outline, and conclusions about the material's acceptability as retrospective dosimeter - marked with blue outline. Measurement procedures and interpretations are explained in detail below.

A. Deconvolution

For deconvolution of TL glow curves of irradiated samples, the software TL/OSL glow curve analyzer was used. By analyzing glow curves, some kinetic parameters of the samples could be calculated. New software for automatic glow curve deconvolution was used. The program provides values of kinetic parameters, glow peak area, and FOM as summing discrete (FOK, GOK) or continuous distribution of traps [15].

B. Results

Measurements were made for table salt samples from the open Macedonian market.

Beta source in the Riso TL/OSL reader is calibrated by sensitized quartz grains with dimensions in the interval 180-250μm, irradiated with 137Cs source with a dose of 4.81Gy from the Nordic Center for Luminescence Research. From the calibration curve obtained, it was calculated that the source's dose rate is 0.085Gy/s.

Measurements with TL and OSL were made on non-irradiated table salt sample and irradiated sample, with a dose of 300 mGy.

TL glow curves of non-irradiated, irradiated, and irradiated sample after illumination are shown in Figure 3. TL testing was performed with temperatures up to 400°C, with a heating rate of 5°C/s using U-340 optical filter. Measurements were conducted on non-irradiated salt sample, and two different irradiated salt samples: one exposed to a dose of 300 mGy and the other exposed to the same dose, but subjected to blue light illumination prior to TL measurement. TL signal emitted by the non-irradiated salt sample proved to be negligible, indicating absence of residual geological signals, making the salt suitable for retrospective dosimetry applications. Analysis of TL glow curve revealed three prominent peaks occurring at approximately 90°C, 200°C, and 220°C (Fig.2 for irradiated sample). Notably, the third peak is attributed to light-insensitive loop, as evidenced by the persistence of discernible TL signal even after illumination.

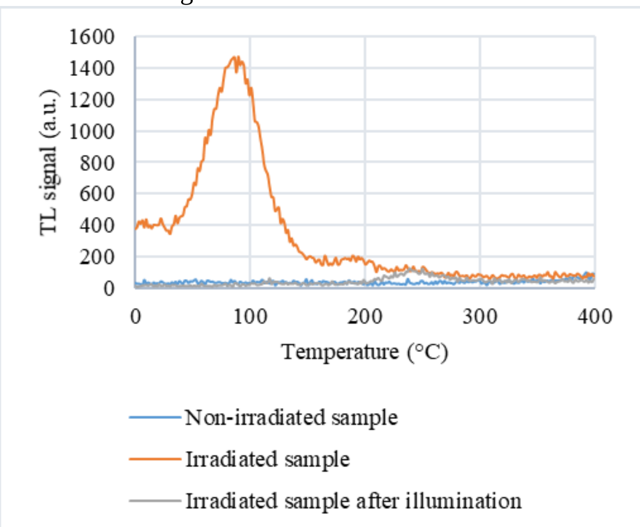

Fig. 3. TL signals of non-irradiated, irradiated sample (300 mGy), and irradiated sample (300 mGy) after illumination

Emission of OSL signal is presented in Figure 4. OSL measurement was performed with blue light at 60% power, without preheating. Measurements were conducted on non-irradiated salt sample and irradiated salt sample exposed to a dose of 300 mGy. OSL signal emitted by the non-irradiated salt sample proved to be negligible as in TL investigation. OSL signal of irradiated sample dropped to an insignificant level already after two seconds of illumination.

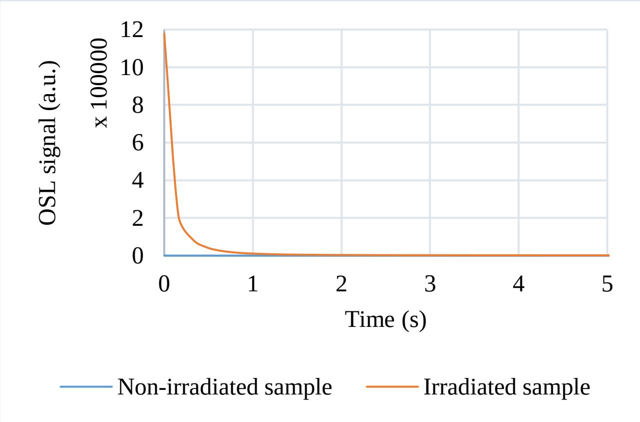

Fig. 4. OSL signals of non-irradiated sample and irradiated sample (300 mGy)

Dependence of the luminescent response is an important condition for the investigated material to be used as dosimeter. The luminescent signal response was measured by TL and OSL at doses from 100 mGy to 2600 mGy (Fig.5). The integral of the glow curve from 60°C to 300°C is considered as response for TL measurements, while for OSL measurements, an integral up to 1.5 s is taken as response.

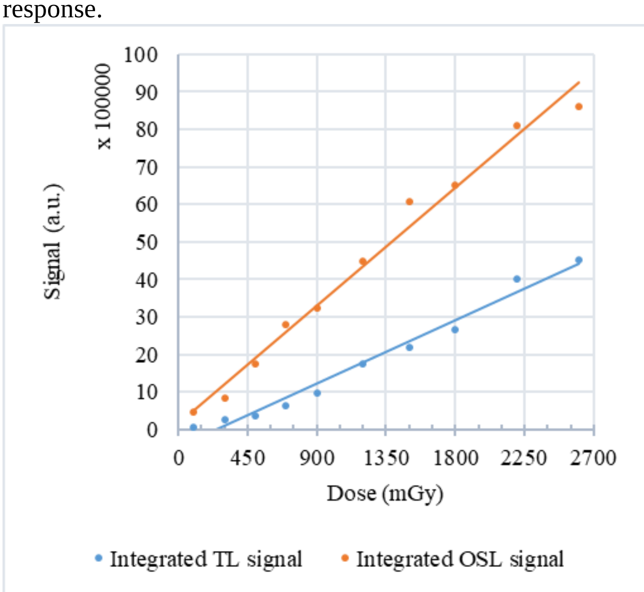

Fig. 5. Dependence of the luminescence signal on the dose

Comparison of preheating temperature TPh dependence of OSL response with TL glow curve is shown in Figure 6. Optimal preheating temperature is determined from the results. Stability of OSL signal is examined depending on the preheating temperature. The following test sequences were used:

1. Irradiation of each sample with a dose of 300 mGy;
2. Preheating at TPhi °C (heating rate 5°C/s) for 10 s;
3. OSL stimulation at 125°C (heating rate 5 °C/s) for 40 s;
4. Repeating sequences (1) to (3) from TPh1 = 60°C with increasing preheat temperature TPhi by 20°C.

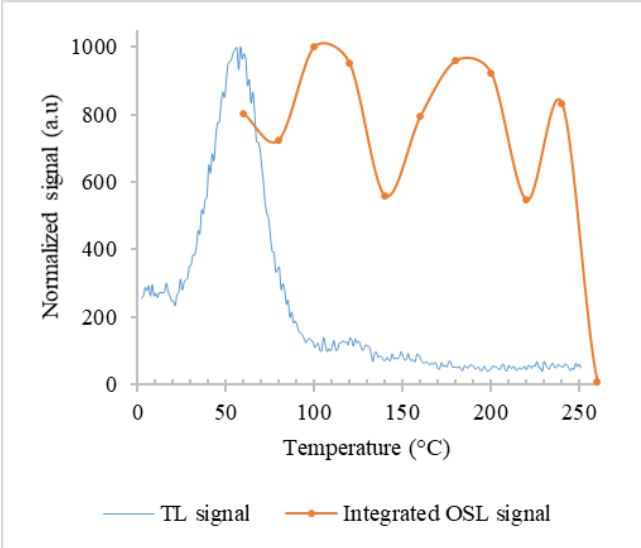

Fig. 6. Comparison of preheating temperature dependence of OSL response with TL glow curve

Each measurement was performed with a new aliquot of the same mass to eliminate the change in sensitivity due to heating.

The results obtained show two local minima of the integrated OSL signal with a value of about 600 normalized units at 140°C and 220°C. The value 140°C was chosen for preheating temperature.

In order to determine the optimal readout temperature T_{Ro}, an examination of OSL signal's dependence on the readout temperature was made (Fig.7.).

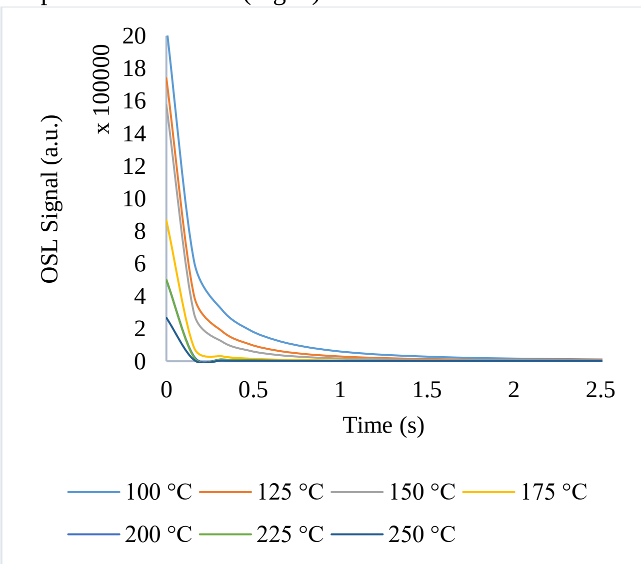

Fig. 7. Dependence of OSL signal on the readout temperature

The following test sequences were used:
1. Irradiation of each sample with a dose of 300 mGy;
2. Preheating at 140°C (heating rate 5°C/s) for 10 s;
3. OSL stimulation at T_{Roi} °C (heating rate 5°C/s) for 40 s;
4. Repeating sequences (1) to (3) from TRo1=100 °C with increasing readout temperature T_{Roi} by 25°C.

From OSL signals obtained, the readout temperature (T_{Ro}) is selected for which the signal has the highest intensity and the lowest decay rate. In this case, it is the temperature of 100°C.

The dose response determined using a single-aliquot regenerative dose methodology on five samples is shown in Figure 8, with the maximum deviation from the set dose (1 Gy) at less than 10%.

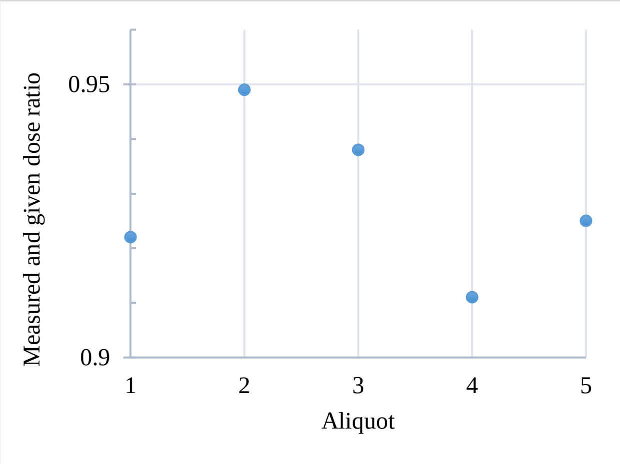

Fig. 8. SAR measurement of for dose recovery test for a laboratory given accident dose of 1 Gy.

An example of deconvolution results is shown in Figure 9. The thick solid line shows the best fit curve of experimental results (crosses), and the thin solid lines represent peaks used for deconvolution.

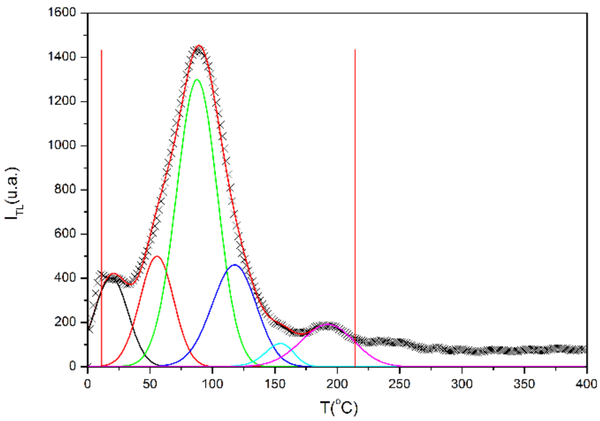

Fig. 9. Fitted glow curve by deconvolution with the TL/OSL glow curve analyzer

This study was developed using six peaks, taking into account the First Order Kinetic (FOK) approach and the continuous trap distribution (using the Gaussian expression).

Deconvolution results are summarized in Table 1. These results include activation energy *E*, intensity of the maximum I_{max}, temperature of the maximum T_{max}, and frequency factor σ.

TABLE I
KINETIC PARAMETERS OBTAINED BY DECONVOLUTION

	E (eV)	I_{max} (a.u.)	T_{max} (°C)	σ
Peak I	1.36	393.03	21.65	0.058
Peak II	1.61	488.08	58.29	0.059
Peak III	1.64	1265.76	91.01	0.067
Peak IV	1.48	447.98	121.41	0.057
Peak V	1.93	103.65	156.32	0.034
Peak VI	1.83	186.11	196.91	0.072

IV. CONCLUSION

Luminescence properties of common salt (NaCl) widely used on the open Macedonian market were investigated. A protocol with measurement procedures that can be used to determine luminescent properties of materials for application in retrospective dosimetry was applied. First, TL/OSL response of an irradiated and non-irradiated sample was investigated, with satisfactory results obtained. From examination of the dose response, linear response was obtained for the entire examined area. This material was identified as having potential for use in retrospective dosimetry. Preheating and reading temperatures were determined, to which SAR method for dose determination was applied, yielding high accuracy results.

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REFERENCES

[1] Bailey, R. M.; Adamiec, G.; Rhodes, E. J. OSL. "Properties of NaCl Relative to Dating and Dosimetry". Radiat. Meas. 2000, 32 (5), 717–723. https://doi.org/https://doi.org/10.1016/S1350-4487(00)00087-1.

[2] Okada, G.; Motoki, S.; Sakamoto, M.; Kusano, E.; Yada, R.; Fujimoto, Y.; Yanagida, T.; Nanto, H. "Characterization of Optically-Stimulated Luminescence Properties by NaCl:Eu2+ Crystal and the Thermal Response". J. Alloys Compd. 2021, 863, 158561. https://doi.org/https://doi.org/10.1016/j.jallcom.2020.158561.

[3] Datz, H.; Druzhyna, S.; Oster, L.; Orion, I.; Horowitz, Y. "Study of the Suitability of Israeli Household Salt for Retrospective Dosimetry". Radiat. Prot. Dosimetry 2016, 170 (1–4), 407–411. https://doi.org/10.1093/rpd/ncv517.

[4] Alghamdi, H.; Sanderson, D.; Carmichael, L.; Cresswell, A.; Martin, L. "The Use of Portable OSL and IRSL Measurements of NaCl in Low Dose Assessments Following a Radiological or Nuclear Emergency". Frontiers in Public Health, 2022.

[5] Majgier, R.; Rääf, C. L.; Mandowski, A.; Bernhardsson, C. "OSL Properties in Various Forms of KCl and NaCl Samples after Exposure to Ionizing Radiation". Radiat. Prot. Dosimetry 2019, 184 (1), 90–97. https://doi.org/10.1093/rpd/ncy189.

[6] Ademola, J. A. "Luminescence Properties of Common Salt (NaCl) Available in Nigeria for Use as Accident Dosimeter in Radiological Emergency Situation". J. Radiat. Res. Appl. Sci. 2017, 10 (2), 117–121. https://doi.org/https://doi.org/10.1016/j.jrras.2017.01.003.

[7] Szufa, K. M.; Majgier, R. "Optically Stimulated Luminescence Properties of Commercially Available KCL Dietary Supplements as

Retrospective Dosimeters". Luminescence 2022, n/a. https://doi.org/https://doi.org/10.1002/bio.4355.

[8] Bernhardsson, C.; Christiansson, M.; Mattsson, S.; Rääf, C. L. "Household Salt as a Retrospective Dosemeter Using Optically Stimulated Luminescence". Radiat. Environ. Biophys. 2009, 48 (1), 21–28. https://doi.org/10.1007/s00411-008-0191-y.

[9] Fujita, H.; Jain, M.; Murray, A. S. "Utilization of OSL from Table Salt in Retrospective Dosimetry". Japanese J. Heal. Phys. 2011, 46, 60–65.

[10] Fuochi, P.; Alberti, A.; Bortolin, E.; Corda, U.; Civita, S. La; Onori, S. "PSL Study of Irradiated Food: NaCl as Possible Reference Material". Radiat. Meas. 2008, 43, 483–486.

[11] Roman-Lopez, J.; Piña López, Y. I.; Cruz-Zaragoza, E.; Marcazzó, J. "Optically Stimulated Luminescence of Natural NaCl Mineral from Dead Sea Exposed to Gamma Radiation". Appl. Radiat. Isot. 2018, 138, 60–64. https://doi.org/https://doi.org/10.1016/j.apradiso.2017.05.001.

[12] Spooner, N. A.; Smith, B. W.; Creighton, D. F.; Questiaux, D.; Hunter, P. G. "Luminescence from NaCl for Application to Retrospective Dosimetry". Radiat. Meas. 2012, 47 (9), 883–889. https://doi.org/10.1016/j.radmeas.2012.05.005.

[13] Spooner, N. A.; Smith, B. W.; Williams, O. M.; Creighton, D. F.; McCulloch, I.; Hunter, P. G.; Questiaux, D. G.; Prescott, J. R. "Analysis of Luminescence from Common Salt (NaCl) for Application to Retrospective Dosimetry". Radiat. Meas. 2011, 46 (12), 1856–1861. https://doi.org/10.1016/j.radmeas.2011.06.069.

[14] Tanir, G.; Bolukdemir, M. H. "Infrared Stimulated Luminescence-Decay Shape from NaCl as a Function of Radiation Doses". Radiat. Meas. 2007, 42 (10), 1723–1726. https://doi.org/10.1016/j.radmeas.2007.07.003.

[15] Benavente, J.F.; Gómez-Ros, J.M; Romero, A.M. "Thermoluminescence Glow Curve Deconvolution for Discrete and Continuous Trap Distributions". Applied Radiation and Isotopes. 2019, 153. https://doi.org/10.1016/j.apradiso.2019.108843.