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Optically stimulated luminescence of natural NaCl mineral from Dead Sea exposed to gamma radiation

J. Roman-Lopez[a,*], Y.I. Piña López[b], E. Cruz-Zaragoza[c], J. Marcazzó[d]

[a] CONACYT-Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, A.P.70-543, 04510 Ciudad de México, México
[b] Facultad de Ciencias, Universidad Nacional Autónoma de México, 04510 Ciudad de México, México
[c] Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, A.P.70-543, 04510 Ciudad de México, México
[d] Instituto de Física Arroyo Seco (UNCPBA) and CIFICEN (UNCPBA-CICPBA-CONICET), Pinto 399, 7000 Tandil, Argentina

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ABSTRACT

In this work, the continuous wave - optically stimulated luminescence (CW-OSL) emissions of natural salt minerals, collected from Dead Sea in summer of 2015, were studied. The CW-OSL dose response of natural salt showed a linear range between 0.5 Gy and 10 Gy of gamma radiation of ^{60}Co. Samples exposed at 3 Gy exhibited good repeatability with a variation coefficient of 4.6%. The CW-OSL response as function of the preheating temperature (50–250 °C) was analyzed. An increase of 15% of the CW-OSL response was observed in NaCl samples during storage period of 336 h. The results showed that the natural Dead Sea salt minerals could be applied as natural dosimeter of gamma radiation.

1. Introduction

The luminescence of natural (halite) and synthetic NaCl (pure and doped) minerals have been extensively studied due to both their radiation sensitivity and TL and OSL properties for applications in retrospective dosimetry, geological dating and identification of irradiated food (Timar-Gabor and Trandafir, 2013; Spooner et al., 2012; Bailey et al., 2000; Zhang et al., 2005; Cruz-Zaragoza et al., 2006; Fuochi et al., 2008). In this sense, Hunter et al. (2012) investigated the emission spectra, using thermoluminescence (TL) of commercial salts from Australia, Europe, Asia and America. They found that the most samples presented strong TL emissions at 590 nm and proposed the NaCl as an adaptable retrospective dosimeter with the restriction of use samples without exposure to daylight, due to that approximately 90% of the peak at 260 °C was bleached after 10 min of exposure to light. However, Druzhyna et al. (2016) observed in Israeli NaCl samples an optical bleaching of the TL intensity of around 30% for one day of exposure. On the other hand, the optically stimulated luminescence (OSL) response of natural halite presented several effects which must be considered for the use of these minerals as retrospective and accident dosimeter in radiological events. Such effects are: the appearing of anomalous fading, sensitivity changes caused by thermal and optical influence, regeneration of the OSL intensity effect, caused for subsequent OSL readouts after a delay time, and strong optical bleaching conditioned the application of sealed samples. The optical sensitization of the CW-OSL response in halite samples was studied by Biernacka et al. (2016) using blue and green light for bleaching of samples after readout. When the samples were bleaching with blue light the sensitization of the OSL response was higher than observed using green light beaching. A regeneration effect for both types of bleaching light was also observed with maxima of OSL intensity at delay time of 10^4 s. In this sense, Christiansson et al. (2014) investigated the CW-OSL response of four distinct brands of salt under laboratory and field conditions (light, temperature and type of container). It was found a variance in measurements of absorbed dose of ± 7% between the four brands and a difference of ± 15% in samples mixed in the container compared to samples located at the center of the container, and an inverse fading of 17–31% after 142 days of storage. This work is focusing in determine the CW-OSL dosimetric properties of natural NaCl samples, collected in the Dead Sea, and exposed to ^{60}Co gamma rays for its application as natural dosimeter. The dosimetric properties studied were dose-response in the range 0.2–20 Gy, repeatability of the OSL signal after ten cycles of irradiation-readout and preheating stability from 50 °C up to 230 °C. In addition, structural and chemical characterization was performed by X-Ray Diffraction (XRD) and Energy Dispersive Spectroscopy (EDS).

2. Materials and methods

Natural NaCl minerals were collected, at a depth of approximately

* Corresponding author.
E-mail address: jesus.roman@nucleares.unam.mx (J. Roman-Lopez).

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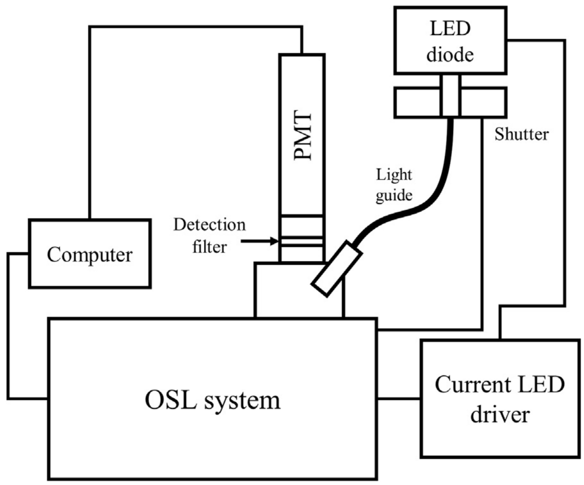

Fig. 1. Custom-made OSL schematic diagram. The light stimulation is centered on the samples using a light guide (Marcazzó et al., 2011).

1 m, in the Dead Sea lake. Previously to irradiation and CW-OSL analysis the NaCl minerals were kept into a beaker at room temperature (20–25 °C) for 1 week and then they were grinding to fine powder carefully to avoid a spurious luminescence response. The NaCl minerals were chemically characterized by Energy Dispersive Spectroscopy (EDS) using a JEOL JSM-5900 with oxford INCA 200 detector. X-ray Diffraction (XRD) was carry out by D8-advance Bruker diffractometer with Cu-Kα radiation (λ = 1.5406 Å) for study the structural characteristics of the natural NaCl. The XRD measurements were taken from 10° up to 100° (2θ) with steps of 0.0197°. Samples of approximately 10 mg of natural NaCl were weighed and mounted on aluminum discs for ^{60}Co gamma irradiation and CW-OSL luminescence study. The aliquots were exposed to ^{60}Co gamma rays using a Gammacell-200 irradiator with a dose rate of 0.1426 Gy/min at sample position. A custom-made OSL equipment was used to perform the CW-OSL decay measurements. Fig. 1 shows a schematic diagram of custom-made OSL equipment which is composed by a OSL system, current LED driver, LED diode, computer and a detection unit (PMT). The details of the parts were reported in Marcazzó et al. (2011). The optical stimulation of the NaCl minerals was made using a Luxeon V Star blue Lambertian light emitting diode (LED) with maximum emission at 455 ± 25 nm and provide a luminous flux of 700 mW. The current of the LED, during the sample stimulation was controlled with a Newport laser diode driver model 525B. Between the stimulation light and the sample two long-pass Schott GG-420 filters, with maximum transmission of 0.91 for wavelengths higher than 420 nm and a transmission less than 10^{-6} at shorter wavelengths, were placed. The luminescence of the stimulated sample was observed trough two optical bandpass filters Hoya U-340 and detected by a photon counting Hamamatsu H9319-02 photomultiplier tube (PMT) that cover a spectral range of 300–850 nm.

3. Results

3.1. Sample characterization

The structure and chemical composition of natural NaCl minerals were analyzed by XRD and EDS. In Fig. 2 is shown the diffraction pattern and reflection planes associated to NaCl structure. The NaCl minerals presented a cubic system with a space group *Fm*3*m* and cell parameters of a = b = c = 5.6 Å. These values were compared with diffraction patterns, R070292 and R070534, of natural NaCl minerals obtained from RRUFF data base.

Fig. 3 shows the EDS analysis of NaCl minerals composed by Sodium (Na), Chloride (Cl) and Oxygen (O) elements with atomic percentage (average of 15 measurements) of 37.88%, 46.29% and 15.82%,

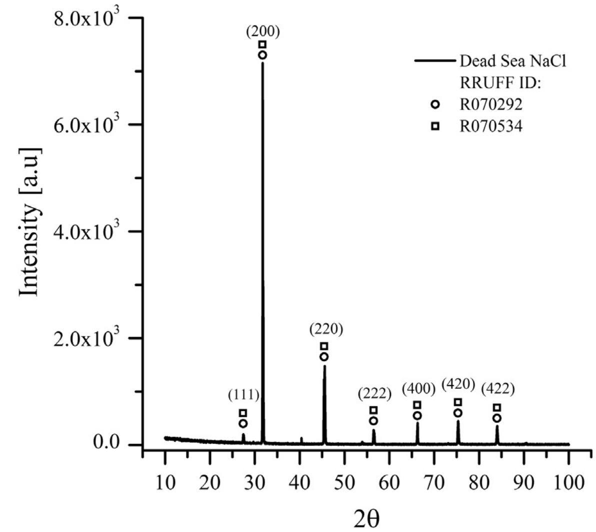

Fig. 2. X-ray diffraction pattern of Dead Sea Salt minerals. The symbols represent the NaCl reflections corresponding to diffraction card R070292 and R070534 of the RRUFF database.

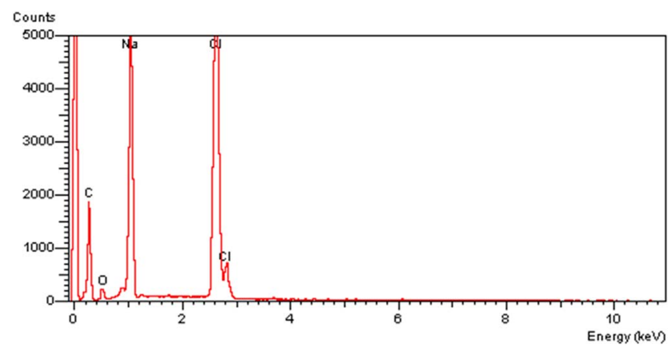

Fig. 3. EDS spectra with the chemical composition of Dead Sea NaCl minerals.

respectively. The incorporation of O ions could be related with the adding of water in the sample due to humidity environment of the sea.

3.2. CW-OSL response

Continuous CW-OSL response of natural NaCl minerals was measured using the followed conditions: blue light at 455 nm with 497 mA of current intensity and a stimulation time of 120 s. In Fig. 4 is shown the as-obtained (natural response) and irradiated (0.2 Gy of ^{60}Co) CW-OSL response of Dead Sea minerals. At two seconds of light stimulation the CW-OSL intensity decayed 58% and for 20 s the intensity decreased 70.3%. After that, the CW-OSL intensity exhibited a slow decay up to a time of 120 s. These behaviors can be related with three different decay components.

In this sense, the CW-OSL decay curve was fitted applying the Eq. (1) that describe the summation of three decay exponentials due to the stimulated light release electrons from more than one trap. Therefore, the OSL response of each exponential decay can be produced by one electron and hole trap via conduction band transport, the recombination of electrons at hole traps (concentration *m*) is carry out without re-tramping and assuming a quasi-stationary free electron density (quasi equilibrium approximation) (McKeever et al., 1997; Bøtter-Jensen et al., 2003; Yukihara and McKeever, 2011):

$$I_{OSL} = -\frac{dm}{dt} = \frac{dn_1}{dt} + \frac{dn_2}{dt} + \frac{dn_3}{dt} = I_{10}\exp\left(-\frac{t}{\tau_1}\right) + I_{20}\exp\left(-\frac{t}{\tau_2}\right) + I_{30}\exp\left(-\frac{t}{\tau_3}\right) \quad (1)$$