Thermoluminescence Studies of Egyptian White Sand after Gamma Ray Exposure and Its Usability for Radiation Measurements

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ABSTRACT

Egyptian white sand (WS) samples from north Sinai that used in many applications such as glass industries, optical communications and building materials have been collected and prepared for the measurements of the present study. The thermoluminescence properties of WS namely; grain size, glow curve, dose response, batch homogeneity and fading effect have been studied by using the thermoluminescence technique (Harshaw-3500 series). The characterization of WS samples have been estimated using X-ray fluorescence (XRF), X-ray diffraction (XRD) and scanning electron microscopy (SEM). The results showed that WS samples have a high concentration of SiO₂ (97.96%) and XRD data showed presence of large amount of high crystalline quartz in form of silica that exhibit thermoluminescence. The glow curves of studied samples have been obtained after irradiation with various γ-doses of (Co-60), ranging from 10 Gy up to 30 kGy. The glow curve is consisted of three peaks at P₁=155 °C, P₂=203 °C and P₃=345 °C. The dose response curve is linear in the range from 600 Gy up to 10 kGy. A Small shift in the position of three peaks appeared with the change of doses. Slight decay is observed (≈14%) during store for 100 days. The previous data indicate that white sand could be used for high-doses dosimetry in several areas of applications of ionizing radiation.

Key Words: Thermoluminescence / Dosimetry / White Sand / Radiation.

INTRODUCTION

Thermoluminescence (TL), is known to be the result of the radiative recombination of electrons thermally released by trapping levels with holes and it is a method for measuring doses of ionizing radiation (1,2). Although different dosimetric techniques are available, the thermoluminescent dosimetry (TLD) is one of the most commonly used techniques, and is undoubtedly one of the main practical applications of the thermoluminescence (TL) (3). TL has reached a great development and a high acceptance degree in the dosimetry applications, among the international scientific community since the first works carried out by Daniels, Boyd and Saunders (4).

Many phosphors are used for dosimetry purpose and have been proved to be useful in TL-detectors. Since the nineties of the last century, sand, which is a natural material found in great amounts, has become an interesting material for its dosimetric properties (5,6,7). The most common constituent of sand is silica (silicon dioxide) that presents the phenomenon of thermoluminescence, because it is composed of mixture of quartz, feldspar and heavy minerals (8,9). The composition of sand is highly variable depending on the local rock sources and conditions (2), it also contains some other elements in minor quantities. The class of silicates is one of the most and important numerous in the mineral world (10).

Recently, some researchers have considered that sand can used as a radiation TL-dosimeter. Vaijapurkar and Bhatnagar (5), described the TL characteristics of sand from Rajasthan-
India and it has been presented, two TL-peaks at 80 °C and 220 °C. Teixeira and Caldas (11) studied sand from Brazilian beaches. Samples exposed to gamma doses of range from 5 Gy up to 80 kGy present two peaks at about 110 °C and 170 °C. R. Pitalúa et.al (3) described the TL characteristics of two sand samples coming from Colombian beaches, for to be used as dosimeter in therapeutic dose; the samples were exposed to gamma doses at 50 cGy up to 1000 cGy and they present two peaks at about 148 °C and 145 °C.

The objective of this work is to conduct a study of the main TL-characteristics made of the natural white sand collected from north Sinai, Egypt, and their usability for radiation measurements.

MATERIALS AND METHODS

Materials

In this work, natural white sand sample was collected from north Sinai, Egypt, at 10 cm of surface using plastic cup and then placed in plastic bags to prepare it for our study. Sinai is the biggest producer for white sand that has a high purity of silicon as shown in fig. (1).

Methods

The white sand sample was firstly washed with one Molar of hydrochloric (1M HCl) acid solution to remove the carbonate, and organic impurities then rinsed with distilled water to remove the HCl (1, 3). This previous procedure was repeated three times, with average 10 minute for each time. Then the wet sample was dried in open air at room temperature for 24 h.

Then the sample was sieved through several meshes [300, 250, 200, 150 and 75 µm] to determine the optimum grain size. All different sizes of the studied sample have placed in several lightproof capsules and exposed to test dose of 100 Gy from gamma source ⁶⁰Co.

The chemical analysis was carried out using X-ray fluorescence (XRF) at the Ceneteral Laboratory of Elemental and Isotopic Analysis at EAEA. Using Philips JSX-3222 equipment, at room temperature; (5g) powder of the sample was used to determine the chemical compositions.

The structural analysis carried out using X-ray diffraction (XRD), at the Egyptian Petroleum Research Institute (EPRI). At room temperature, the spectra were obtained in a diffractmeter Philips model (PW/1710), with Ni filter, Cu-Kα radiation (λ=1.542 Å) as incident radiation, at 40 kV of
voltage in the tube and a stream of 30 mA, varying the sweep angle among \(10^\circ < 2 \theta > 80^\circ\) every 0.02 degrees.

Quartz minerals observed using scanning electron microscope (SEM) for morphological studies, in the Egyptian Nuclear and Radiological Regulatory Authority (ENRRA), using JEOL JSM 2300 LV SEM. The advantage of this technique (low vacuum, LV-SEM) is the possibility of working with uncoated samples.

The irradiation was carried out at room temperature by using gamma cell of \([\text{Dose rate 21.88 Gy/min at March 2013}]\), at the Cyclotron Project, the National Research Center, EAEA. Then the sample of white sand with approximately (150-75) \(\mu\text{m}\) of grain size irradiated by different gamma doses \((^{60}\text{Co})\) from 10 Gy to 30 KGY, to study the effect of gamma dose on the TL-signal. The readings were carried out by TLD reader \([\text{Harshaw-3500 series}]\) with a rate of 5 \(^\circ\text{C/s}\) until reaching a maximum temperature of 450 \(^\circ\text{C}\).

### RESULTS AND DISCUSSION

1. Grain Size Effect

This effect has been studied by plotting the relation between the grain size of white sand and its corresponding TL-intensity, as showing in Fig. (2). It could be observed that, when the grain sizes of (WS) sample decrease, the TL-intensity increases. Therefore, the grain size in range \([150-75 \, \mu\text{m}]\) has been chosen to complete the study.

![Fig. (2): Relation between TL-Intensity of (WS) and Different Grain Size](image)

2. Characterization

2.1. X-Ray Diffraction (XRD)

The structural analysis was carried out by X-ray diffraction at room temperature and varying sweep angle among \((10^\circ < 2 \theta > 80^\circ)\) every (0.02) degrees.

Fig. (3) shows the XRD pattern of white sand from north Sinai, which proves the crystallinity of used samples. In addition, it reveals the presence of a large amount of highly crystalline quartz in the form of silica and other minerals.
The height and sharpness peaks refer to the main compound of the studied sample [Quartz(Q)], that exhibits TL- signal at position [20.80 and 26.60] of (2 \( \theta \)) axis. However, it is understood that the height and sharpness of the XRD peaks are not only a measure of the quantity of the minerals, but also for its higher crystallinity.

**Fig. 4(a):** Angular grain to sub round with smoothed edges and sides.

2.2. Scanning Electron Microscopy (SEM).

The surface morphology of the studied sample is given in Fig. 4 (a & b). The SEM pattern of WS showed that the quartz grains are angular to sub rounded marked by peeling of surface as a result of intense chemical weathering, angular grain with smoothed edges and sides, weathered, and conchoidal blockage with smoothed surface were created by mechanical abrasion and chemical processes.

**Fig. 4(b):** Peeling of surface as a result of intense Chemical weathering.
2.3. X-Ray Fluorescence (XRF).

The chemical analysis of the studied sample was carried out using XRF. Where 5gm of WS sample powdered and prepared to determine the chemical compositions. Table (1) shows high concentrations of SiO$_2$ (97.96\%), while some other compounds concentrations of REEs, are shown in Table (2).

![XRF Pattern of White Sand from North Sinai.](image)

**Fig. (5): XRF Pattern of White Sand from North Sinai.**

**Table (1): Chemical Compositions of (WS) Sample.**

<table>
<thead>
<tr>
<th>constituents</th>
<th>SiO$_2$</th>
<th>Fe$_2$O$_3$</th>
<th>Cr$_2$O$_3$</th>
<th>NiO</th>
<th>CuO</th>
<th>MnO</th>
<th>ZrO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt, %</td>
<td>97.961</td>
<td>1.125</td>
<td>0.242</td>
<td>0.041</td>
<td>0.016</td>
<td>0.011</td>
<td>0.008</td>
</tr>
</tbody>
</table>

**Table (2): Concentrations of Other Compounds of REEs.**

<table>
<thead>
<tr>
<th>constituents</th>
<th>Th$_4$O$_7$</th>
<th>CeO$_2$</th>
<th>Nd$<em>6$O$</em>{11}$</th>
<th>Dy$_2$O$_3$</th>
<th>Sm$_2$O$_3$</th>
<th>Gd$_2$O$_3$</th>
<th>Tm$_2$O$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt, %</td>
<td>0.158</td>
<td>0.149</td>
<td>0.074</td>
<td>0.058</td>
<td>0.057</td>
<td>0.056</td>
<td>0.021</td>
</tr>
</tbody>
</table>

3. Glow Curve Analysis

The glow curves of white sand samples are presented in Fig. 5(a, b). It is noticed in figure 5(a) that the natural accumulated glow curve of WS, consists of one peak at 334 °C. In addition, it is observed that, the shallower peaks did not appear in the natural glow curve; this is may be due to the
thermal fading of the ambient atmosphere with the time and this intensity of the natural glow curve has accumulated from the environmental background radiation by time.

![Natural Glow Curve ofWs](image)

**Fig. 5(a):** The normal glow curve of the Egyptian white sand, at long-term exposure of environmental background radiation

Fig. 5(b) shows the characteristic glow curves of the WS sample which has a size in range [150-75 µm] after exposed to different gamma doses ranging from 10Gy up to 30kGy. It could be noticed that this glow curve consists of three peaks at (155, 203, 345 °C) and the prominent peak ($P_3=346$ °C) is considered the dosimetric peak.

![Glow Curve ofWs](image)

**Fig. 5(b):** The characteristic glow curves of white sand at different doses.
4. Dose Response Curve

The white sand sample was irradiated to various γ-doses (Co-60) in the range between 10 Gy to 30 kGy. The Measurements have been taken by the TL-reader (H-3500). Dose response curve was obtained and presented in Fig. (6). The intensity of WS sample is linear within the range from 600 Gy up to 10 kGy, after that it becomes supra linear from 10 kGy to 20 kGy and finally became saturation.

![Dose Response Curve](image)

**Fig. (6):** The dose response curve of white sand sample

5. Peak Positions

The positions of the three peaks, which characterized the WS sample, plotted against the variation of doses and the revealed plots shown in Fig. (7). There is slightly increasing of peak position at low doses in the range from 10 Gy to 100 Gy, after that, the three peaks are stable and this stability is due to the purity and crystallinity of the studied sample.

![Peak Positions](image)

**Fig. (7):** The peak positions of WS at different doses.
6. Batch Homogeneity (\( \Delta \))

The TL response of samples of the same material that have undergone the same treatment may not necessarily be the same. The recommendation of the International Electrochemical Commission (IEC), however, is that the evaluated value for any dosimeter in a batch shall not differ from the evaluated value of any other in the same batch by more than 30% (IEC).\(^{(14)}\)

This has verified for the optimum grain size (150-75) \( \mu m \) of the white sand sample, using (10) samples from the same batch by irradiation and read out with (TLD-3500) reader.

Then, 
\[
\Delta = \left[ \frac{M_{\text{max}} - M_{\text{min}}}{M_{\text{min}}} \right] \times 100 
\]

Where: \( M_{\text{max}} \) and \( M_{\text{min}} \) represent the maximal and minimal recorded values, respectively.

Then, 
\[
\Delta = \left[ \frac{8.154 - 6.777}{6.777} \right] \times 100 = 20.318\% 
\]

So that the calculated value of \( \Delta \) is 20.318\%, which is lower than upper limit recommended by IEC. This shows, the homogeneity of the white sand sample used.

7. Fading Effect

The white sand sample exposed to gamma dose of 1kGy, after that it was stored in ambient temperature. Several TL-reading evaluated after different intervals of time up to 100 days. Figure (8), shows the relative TL response of the white sand as a function of storage time (where \( F_0 \) is the first read out intensity and \( F \) are the intensities after several intervals). From this Figure, it observed that the total TL-signal of the WS sample which represented by solid line No.1 has faded during 100 days about 14 \%. In addition, the dosimetric peak (peak three) of WS the which represented by dot line No.2 showed TL- stability over 100 days with fading rate of 4 \%.

![Figure 8](image-url)

**Fig. (8):** The relative TL response of WS as a function of storage time. The solid line for the total area under the curve and the dote line for the dosimetric peak (peak three).
CONCLUSIONS

The obtained results of the structural and chemical analysis showed that the white sand consists of quartz and minerals that exhibit TL signals. The XRD analysis showed that WS consists of large amount of crystalline quartz and has a high silica concentration (97.96%). This quartz is the major component that exhibit TL-signals, other minerals and rare earths behave as a TL-sensitizer. The glow curve of the sample has three peaks at 155, 203 and 345 °C. The shallower peaks did not appear in the natural glow curve, this may be due to the thermal fading of the ambient atmosphere. The third peak at 345 °C is the highest one and it is consider the dosimetry peak, as well as the position of it is stable for the different doses. The intensity of WS sample is linear within the range from 600 Gy up to 10 kGy, after that, it become supra linear and then become saturated. The WS sample showed TL- stability through three months and the rate of fading during this period was 14 %. In addition, the main dosimetric peak of WS showed stability over 3 months was 4 %. The WS sample properties reveals the capability of using it as high dose or accident radiation dosimetry.

REFERENCES

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