1. Introduction

Unfortunately, even if all conditions have been made to secure nuclear or radiological facilities but accidents sometimes occur, because of operational faults (i.e. Chernobyl), natural disasters (i.e. Fukushima), or even terrorism. In the case of nuclear accidents or radiological occurrence, it is possible that a large number of members of the public are significantly exposed to radiation. In this situation, the attention is focused on measurement and assessment of the radiation-absorbed dose that relates to radiation deterministic effects on cells and tissues. Depend on the exposure and absorbed dose; authorities can be able to determine the appropriate action to activate the proper emergency plan.

In radioactive accident conditions, finding a method for measuring the radiation dose for individuals is not an easy question. As likely members of the public being exposed to radiation in the accident, do not have dose-measuring equipment such as sensitive films or radiation measuring devices. Therefore, attention was sought to finding a way to estimate the radiation dose by using materials gathered from the scene or the belongings of the affected population to visualize the level of radiation exposure at the stage.

Many physical dosimetry techniques, such as electron paramagnetic resonance (EPR), thermoluminescence (TL) and, optically stimulated luminescence (OSL), were applied to determine radiation dose following radiological events (Bailiff, Sholom, & McKeever, 2016). TL technique was our concern in this work.

Recently, many authors were headed toward the study and testing of natural and industrial materials as retrospective materials by using the TL technique. TL signals measured from natural samples can deliver information about the radiation-absorbed dose; it had been used as a dosimeter for decades (Gomaa & Eid, 1982; McKeever, Chen, & Halliburton, 1985). So that TL technique allows evaluates the radiation dose absorbed by measuring TL signals from materials that may be found all around the accident. As retrospective or accident dosimeter, the probable TL materials must consider several characteristics, such as high-temperature glow curves, stable peaks, and high-enough sensitivity.

For this seeking, TL sensitivity for various materials was investigated as retrospective dosimetry such as, red sand (Hafez, Sheha, Abd-Elmageed, & Sayed, 2019), silicates contained in dust (Bortolin et al., 2010), natural barite (Sharma et al., 2015), Nigerian clay with different heating rate methods (Olise, Ola, & Balogun, 2018), touch screen glasses, electronic component of mobile phones (Discher, Bortolin, & Woda, 2016; Oks et al., 2011), and electronic porcelain insulators (Mesterházy, Osvay, Kovács, & Kelemen, 2012).

‘Halite’ the mineral form of sodium chloride (NaCl) commonly named as rock salt. Halite crystals are iso-metric and typically, colorless or white but sometimes found in different colors depending on the amounts of impurities. It is formed by salty water vaporization, which...
contains dissolved sodium ions and chlorine ions. Table salt and rock salt (Halite) also gained attention in many studies recently (Ademola, 2017; Amer, 2017; Druzhyna, Datz, Horowitz, Oster, & Orion, 2016; Elashmawy, 2018; Khazal & Abul-Hail, 2010; Roman-Lopez, López, Cruz-Zaragoza, & Marcuzzo, 2018; Spooner, Smith, Creighton, Questiaux, & Hunter, 2012; Spooner et al., 2011; Yüce & Engin, 2017) as accidental and retrospective dosimetry as it is readily available anywhere and does not require unique treatments before measurement.

This study aims to make reference TL measurements of natural NaCl minerals (halite) extracted from the Egyptian west desert where Egypt’s nuclear power production project will start in future. TL sensitivity was studied for five (NaCl) samples: three natural rock salts and two commercial salts (Table salt and Analytical NaCl). This study tries to demonstrate a linear dose–response function for the investigated halite samples, which connects the radiological events TL signals with its same dose. More investigations have to be carried out in the future after the power plant project starting in work.

2. Material and methods

Five salt samples, as shown in Figure 1, were collected, three natural rock salts from Fayoum Governorate, Qattara Depression, and Siwa Oasis (three regions are known for their salt mining in Egypt), one common Table salt from market (commercial name in Egypt called Bono) and one Analytical NaCl, then they were grinding by mill and sieved to 106–210 μm grain. Samples were kept in the laboratory condition without any special treatment before the investigation. Energy Dispersive Spectroscopy (EDX) chemically characterized all Samples. The samples exposed to 60Co gamma rays using a Gamma cell (Medical sterilizer-Cm20 at June 2001) irradiator.

TL-measurements were performed using TL-Reader Harshaw model 3500 with linear heating rate 5°C/s from 25°C up to 400°C. Five mg of the salt sample was uniformly distributed on the sample tray to assure good thermal contact with the heater during TL measurements. All measurements were taken after 24 h from irradiation to uniform the decay period and decrease the error in reading according to low-temperature peak. To study the changes in the TL intensity with time (fading), all investigated salts were irradiated with 100 Gy of gamma-ray from 60Co cell. They were stored in the dark in laboratory condition and measure the TL intensity at different intervals for 30 days.

3. Results and discussion

3.1. Sample characterization

The chemical compositions of Table salt, Fayoum Governorate, Qattara Depression, Analytical NaCl, and Siwa halite were determined by energy dispersive X-ray analysis (EDX). Results show the presence of minor traces of elements such as O, Cu, Ca, Zn, Re, and Si with difference concentration beside main element Na and Cl in the investigated samples. Whether

Figure 1. Google image shows three regions known for their salt mining in Egypt Fayoum Governorate, Qattara Depression, and Siwa Oasis with images of their samples and two images for the other investigated samples Table salt (bono) and Analytical NaCl.
in Siwa halite there is a minor trace of Ca element with 0.13% only beside the main element Na and Cl. The difference in the concentration of the chemical composition of each type of salt may be due to a geological region that the sample was collected from it. The comparison between the chemical compositions of all investigated samples determined by EDX is listed in Table 1.

### 3.2. Characteristic glow curve

The characteristic glow curves for Table salt, Fayoum Governorate, Qattara Depression, Analytical NaCl, and Siwa halite, respectively, after exposed to different gamma-doses from $^{60}$Co (25, 50, 100, 500 Gy) are shown in Figure 2(a) through 2(e). From these figures, we can observe that the number and position of glow peaks separate the samples into two groups.

The first group includes, Qattara Depression, Analytical NaCl and Siwa halite has three peaks (P1, P2 and P3) at average values 95°C- 181°C- 260°C, 98°C-189°C- 270°C, and 97°C - 182°C - 270°, respectively, for the three samples P3 is the main peak and it may be considered as the dosimetric peak. The presence of the dosimetric peak at ~266°C was reported for an Alpine salt with iodine (Ekendahl & Judas, 2010), two types of rock salt in Romanian (Timar-Gabor & Trandañir, 2013), and some of the domestic salts, from Australasia, Europe, Asia, and America (Hunter, Spooner, Smith, & Creighton, 2012).

The second group includes Table salt and Fayoum Governorate halite; it has two peaks at average values 93°C- 217°C in Table salt and 96°C- 227°C in Fayoum halite. The peaks at 217°C and 227°C are the main peaks for Table salt and Fayoum Governorate halite. The presence of the dosimetric peak at ~212°C is near the result was identified by Polymeris et al. (2011) for the main dosimetric peak of Commercial Greek salt samples.

Also, from the figure, it can be observed that the maximum peak position in all salt types does not change after exposure to different gamma doses; however, TL-intensity increases with increasing radiation dose. The direct relation between TL intensity and radiation dose may be explained by the fact that as the radiation dose increase as the number of traps being filled increase so that the rate of recombination during thermal stimulation increase (Manam & Sharma, 2003). The natural glow curves for all investigated samples before irradiation are shown in Figure 3.

### 3.3. Comparison of salt samples

From the present work and also from the literature studies (references provided in the above sections), we can see that different salt types have different glow curves. Figure 4 shows the variation of TL intensity with different types of salt. From this figure, we can observe that there are significant variations in TL-intensity between various types.

The TL intensity of Table salt is the highest in comparison with those of, Fayoum Governorate, Qattara Depression halite, analytical salt, and Siwa halite.

The significant similarities in the characteristic and TL-intensity of Table salt and Fayoum Governorate sample may be due to the same location of both types. The difference in TL-intensity and peak position in different halite types may be due to the presence of various impurities, which depend on the site of the collected sample. Moreover, during the sample preparation of halite, which usually involves mechanical operations such as grinding for powdering the halite, these operations may introduce defects and changes in the morphology of the halite, consequently inducing the TL signals that may affect the radiation-induced dosimetric signal evaluation. The possibility of free radical production by mechanical operations in bone and tooth enamel was reported a long time (Marino & Becker, 1968; Polyakov, Haskell, Kenner, Huett, & Hayes, 1995). In contrast, other researchers such as Yüce and Engin (2017) have suggested that grinding and milling treatments of some natural minerals cause significant changes in the TL spectra of the metals by introducing an intrinsic defect.

### 3.4. Dose-response curve

Dose-response is one of the most critical studies of the TL characteristics, which investigate the relationship between the change of irradiated dose and the

![Table 1](https://example.com/table1)

| Salt type          | Na   | Cl   | O    | Cu   | Ca   | Zn   | Re  | Si  |
|--------------------|------|------|------|------|------|------|-----|-----|
| Table salt         | 36.933 | 59.097 | 3.650 | 0.320 | -    | -    | -   | -   |
| Fayoum             | 35.893 | 51.427 | 11.917 | 0.477 | 0.240| -    | 0.043 | -   |
| Qattara Depression | 40.837 | 57.950 | -    | 0.483 | 0.137| 0.467| -   | 0.120 |
| Analytical NaCl    | 42.325 | 56.393 | -    | 0.910 | 0.280| 0.430| -   | -   |
| Siwa               | 39.237 | 60.633 | -    | -    | 0.130| -    | -   | -   |

![Figure 3](https://example.com/figure3)
corresponding TL-intensity. The linear parts of this study dedicate the ability to use the invite material in retrospective radiation dosimetry. Table salt, Fayoum, Qattara Depression, Analytical NaCl, and Siwa halite were irradiated to different doses between 0.8 and 500 Gy of gamma radiation from $^{60}$Co source. TL intensity was recorded after 24 h of the irradiation, and the result is plot as a log-log scale as shown in Figure 5. The linear regions were fitted as linear fit with $R^2$ is 0.9999, where their slope (A) is 0.975, 0.945, 0.819, 1.403, and 1.328, and the Y-intercepts (B) are 2.569, 2.578, 2.515, 1.322, and 1.329 for Table salt, Fayoum, Qattara Depression, Analytical NaCl, and Siwa halite, respectively.

From these figures, we can observe that various halite types have different dose responses this may depend on salt origin and the technique of sample preparation. Table salt, Fayoum, and Qattara Depression halite have linear dose response between 0.8 and 100 GY after that the response becomes sub-linear. However, the dose-response curves for Analytical NaCl and Siwa halite are sub-linear from 0.8 to 10 Gy, linear from 10 to 100 Gy, and sub-linear again from 100 to 500 Gy.

The first sub-linear in range 0.8–10 Gy may be due to the priority of filling the nonradioactive traps than the radiative traps. Where the sub-linearity appeared after 100 Gy dose may be for the reason of supplying

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**Figure 2.** The characteristic glow curve of, (a) Table salt, (b) Fayoum governorate halite, (c) Qattara depression halite, (d) Analytical NaCl and (e) Siwa halite, after exposure to different gamma doses.
most of the available present radiative traps in the sample lattice (McKeever, 1988).

The result of this work is in agreement with dose-response measured by (Yüce & Engin, 2017) for common household salt in Turkish, who reported a linear dose response between 0.4 and 55 Gy. Also, (Polymeris et al., 2011) said linear response from 0.25 Gy to 100 Gy for the dosimetric glow peak of Kalas salt and the two dosimetric peaks of Turkish salt; Spooner et al. (2011) reported TL growth curves for the integrated TL 180–280°C over the dose range 0.14–35 Gy.

3.5. Fading

It is essential to know the stabilities of the traps connected with the dosimetric TL peaks because these reflect the storage capacities of the traps. The five investigated samples were irradiated to test dose 100 Gy and stored in the dark at room temperature. The sample readout after interval times from exposure to 30 days. Figure 6, showing the relative TL responses of Table salt, Fayoum, Qattara Depression, Analytical NaCl, and Siwa halite, respectively, as a function of storage time. Figure 6 represents that fading effect for all five investigated samples followed the equation \( y = y_0 + A \exp(\frac{R_0}{C_3}x) \) and the equation constants \( y_0, A, \) and \( R_0 \) shown in Table 2 for different samples.

The figures showed that a 20% loss of TL-signal after the first 15 days in case of Table salt, Fayoum and Siwa halite but Qattara Depression loss about 20% after 1 week, on the other hand, the Analytical NaCl shows an almost constant response after 2 weeks and the loss gradually occurred through the 30 days. Also, we can observe that various halite types have corresponding fading rate since the initial peak intensity is decreased by (31%, 29%, 34%, 21%, and 28%) for Table salt, Fayoum, Qattara Depression, Analytical NaCl, and Siwa halite, respectively, after 30 days from irradiation.

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The fading behavior of our samples was somewhat compatible with the fading behavior of previous studies such as by Druzhyna et al. (2016). Many reviews for the storage time effect on TL response of household salt concluded that the loss of TL response may be ~40% after 2 weeks and then remained stable (Elashmawy, 2018). Also, (Timar-Gabor & Trandafer, 2013) reported that there is rapid signal loss during first 7 days for some Romanian commercial salt after that the signal remained constant at ~65% of its initial value over the period investigated (30 weeks).

### 3.6. Kinetic parameters

Kinetic parameters (depth traps, frequency factor, and order of kinetics, etc.) play an essential role for a deep understanding of TL phenomena (Spooner et al., 2012). By using the peak fit program, the glow curve of the five samples under study deconvoluted as in Figure 7. From the figure, we can see that the glow curve could be deconvoluted into three glow peaks. The kinetic parameters were calculated by using Chen’ empirical formula for the general order case (Chen, 1998; McKeever, 1988; Singh, Kaur, & Singh, 2012). The frequency factor (s), the mean lifetime (τc) and the escape probability (P) of the corresponding peak measured by using Urbach (1930) equation. The estimated values of the activation energies E (eV), frequency factors, mean lifetimes τc (y), and escape probabilities P (y−1) for the five investigated salt samples are tabulated in Table 3.

From Table 3 we can note that Table salt and Fayoum Governorate salt samples have low values of kinetic energy (E) for P3 (the dosimetric peak) which investigate the highest fading of their TL-signal. In the case of Analytical NaCl and Siwa Oasis samples, the kinetic parameters were approximately similar. The values of kinetic energy (E) of P3 for Analytical NaCl and Siwa samples are 1.715 ± 0.016 and 1.756 ± 0.042 eV, respectively, which proved the brief stability of TL-signal of them as well as Qattara Depression sample which has a value of kinetic energy (E) for P3 equal to 1.372 ± 0.014 eV. P1 in the Qattara Depression has the minimum value of kinetic energy 0.570 ± 0.026 eV, i.e. it has the highest TL-signal fading of the samples. This observed in Figure 2 whereas, the first peak height of the Qattara Depression is the shortest one of the five studied salt samples.

### 4. Conclusion

Three natural rock salts from Fayoum Governorate, Qattara Depression, and Siwa Oasis, and two powder salts, commercial Table salt, and Analytical NaCl were investigated by using Thermoluminescence technique to be used as retrospective dosimetry. Qattara Depression, Analytical NaCl, and Siwa Oasis glow curves have three peaks at 95°C- 181°C - 260°C, 98°C- 189°C - 270°C and 97°C - 182°C - 270°C, respectively. Table salt and Fayoum halite have a similar shape of glow curves. The two samples have three peaks, P1 is separate, but p2 and p3 overlapped. The peak position of Table salt and Fayoum halite for P1 at 93°C and 96°C and for the common of the overlapped P2 and P3 are 217°C and 227°C, respectively. This similarity in their TL characteristics may be due to that the Table salt products from the same area of Fayoum halite. All the investigated samples have linearity in the response curve make the samples are suitable to be used in retrospective dosimetry. Even though the TL signals fading were high but the residual TL signal enough to be used in case of high dose dosimetry. The estimated kinetic parameters investigated some experimental results. In future, we will study other types of halite in Egyptian west desert where Egypt’s nuclear power production project will start soon to save in a reference...
Figure 7. Experimental TL glow curve of, (a) Table salt, (b) Fayoum Governorate halite, (c) Qattara depression halite, (d) Analytical NaCl, (e) Siwa halite after de-convoluted by peak fit program.

Table 3. The estimated values of the activation energies $E$ (eV), frequency factors, mean lifetimes $\tau_c (y)$, and escape probabilities $P (y^{-1})$ for the five investigated salt samples.

| Salt type         | Peak no. | $T_m$ (K) | $\mu$    | $E$ (eV) | $s$ (s$^{-1}$) | $\tau_c (y)$ | $P (y^{-1})$ |
|-------------------|----------|-----------|----------|----------|---------------|--------------|--------------|
| Table salt        | P1       | 368.5     | 0.591    | 0.920 ± 0.063 | $1.53 \times 10^{12}$ | $7.67 \times 10^{-5}$ | $1.303 \times 10^4$ |
|                   | P2       | 454       | 0.478    | 0.862 ± 0.026 | $8.98 \times 10^9$    | 0.013         | 74.979       |
|                   | P3       | 485       | 0.478    | 1.045 ± 0.022 | $1.87 \times 10^{10}$ | 0.803         | 1.245        |
| Fayoum Governorate| P1       | 373       | 0.50     | 0.579 ± 0.025 | $1.62 \times 10^{7}$  | $1.22 \times 10^{-5}$ | $8.166 \times 10^4$ |
|                   | P2       | 455       | 0.499    | 0.006 ± 0.019 | $2.76 \times 10^{5}$  | 0.024         | 41.138       |
|                   | P3       | 488       | 0.512    | 1.048 ± 0.010 | $1.71 \times 10^{10}$ | 0.990         | 1.01         |
| Qattara Depression| P1       | 371.6     | 0.493    | 0.570 ± 0.026 | $1.30 \times 10^{7}$  | $1.08 \times 10^{-5}$ | $9.29 \times 10^4$ |
|                   | P2       | 468.3     | 0.509    | 0.935 ± 0.016 | $2.71 \times 10^{5}$  | 0.070         | 14.239       |
|                   | P3       | 541       | 0.526    | 1.372 ± 0.014 | $1.67 \times 10^{12}$ | $3.14 \times 10^{-4}$ | $3.21 \times 10^{-4}$ |
| Analytical Salt   | P1       | 363       | 0.541    | 0.842 ± 0.013 | $1.84 \times 10^{11}$ | $3.04 \times 10^{-5}$ | $3.288 \times 10^6$ |
|                   | P2       | 462       | 0.476    | 1.205 ± 0.012 | $4.64 \times 10^{12}$ | 1.672         | 0.598        |
|                   | P3       | 541       | 0.501    | 1.715 ± 0.016 | $3.25 \times 10^{15}$ | $1.002 \times 10^{-5}$ | $9.98 \times 10^{-7}$ |
| Siwa Oasis        | P1       | 363.9     | 0.497    | 0.712 ± 0.017 | $2.30 \times 10^{5}$  | $1.55 \times 10^{-5}$ | $6.472 \times 10^4$ |
|                   | P2       | 461       | 0.479    | 1.108 ± 0.016 | $3.94 \times 10^{11}$ | 0.443         | 2.256        |
|                   | P3       | 543       | 0.526    | 1.756 ± 0.042 | $6.91 \times 10^{15}$ | $2.314 \times 10^6$  | $4.32 \times 10^{-7}$ |
library to be used as retrospective dosimetry in case of radiological accidents.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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