Thermoluminescence characteristics of NaCl from Different Origins

Mohsen H. Abdel-wahed[*1], Hayam Abdel-ghany[3], Saleh M.Abdou[1], Hany A. Amer[2]

1. Department of radiation physics, National Center for Radiation Research and Technology (NCRRT), Cairo, Egypt.
2. Department of radiation protection, Egyptian Nuclear & Radiological Regulatory Authority (ENRRA), Cairo, Egypt.
3. Department of physics, Faculty of Women for Arts, Science, and Education, Ain-Shams University, Cairo, Egypt.

Abstract

In radiological emergencies, table salt can be considered an established method for the retrospective dosimetry of past exposures and the dosimetry of potentially exposed people, where it is a material that can be expected to be easily available in accident locations and it can easily be sampled collection. The characteristics of thermoluminescence (TL) have been studied for four different commercial salt samples (NaCl) obtained from different sources. Indian salt (supplied by oxford lab) is used for comparison, not for measuring doses, Egyptian table salt (SAL), Saudi Arabian table salt (MASA) and British table salt (Cook's), are the three nominated types of salt to procedure in this work. Samples were irradiated with Gamma source using Cs-137. TL analysis of the samples were done using Harshaw Model 4500 TLD Reader, with WinREMS (Windows Radiation Evaluation and Management System) at heating rate 5 ^{o}C /sec with final temperature set to 350 ^{o}C. One prominent glow peak is observed in the glow curve at around 216 - 222 ^{o}C of the commercial salt samples. For all salt samples, the TL intensity of the glow curve is direct proportional to the grain size. By comparison the highest TL intensity for each salt sample, it is found that, Cook's salt is the most sensitive and preferable one to complete the study. The results show also that, TL intensity of the chosen salt (Cook's salt) has a linear response with the dose for a broad range from 250 mGy to 20 Gy. The post-irradiated fading rates are investigated and show stability after 8 days. The fading at room temperature was monitoring during 24 days. Cook's salt may be candidate for using as a Gamma ray retrospective dosimeter.

Keywords: table salt, Thermoluminescence (TL), grain size, dose response, fading.

1.1 Introduction

In situations of radiological emergency, such as a terror attack involving dispersing of radioactive substances or a nuclear industry accident, it is important to make a rapid retrospective estimation of the absorbed dose to individuals who normally do not carry any dosimeters; e.g. members of the public and first responders by measuring materials that can be easily found in objects positioned on or next to the potentially exposed people (**S. Nabadwip Singh et al., 2013**).

Corresponding author: Mohsen Hassan Abdel-wahed.
E-mail address: albahar.mohsen@gmail.com

The alkali halide NaCl (common salt) is an environmentally abundant phosphor of considerable potential for retrospective dosimetry and radiological event analysis due to its high sensitivity to ionizing radiation when analyzed by TL (**Nigel A. Spooner et al**., 2012).

It exhibits high sensitivity to radiation, high stability of the TL signal during the storage of the material (i.e. low fading), linearity of the TL emission with the dose in the range of interest (up to 20 Gy), and discrete trap distribution and thermal stability, (**Y. Rodriguez-Lazcano et al., 2012**). Therefore NaCl powder can be used as a material for 'one time' TL dosimeters which avoids the complications of annealing procedures required in the re-use of TL dosimeters in conventional TL technique (**Th. Tejkumar Singh, 2015**).

George Polymeris et al., (2011), report dosimetric properties of iodized salt. Salt samples have very high TL sensitivity and a linear TL dose response, which makes them suitable for retrospective dosimetry. **Kassim Khazal et al., (2010),** have studied the characteristics of TL for table salt. The pre-irradiation annealing at 400 ^{o}C /h, 100 ^{o}C /2 h increases the salt sensitivity, and the post-irradiation annealing with 100 ^{o}C /20 min reduces the thermal fading. Table salt can be used as Gamma ray dosimeters within the range 0.01–50 Gy without the use of annealing depending on the high temperature peaks**.**

1.2 TL – phenomenon

The phenomena that irradiated insulators or semiconductors which containing electrons that have been excited by the interaction of ionizing radiation, emit luminescence when exposed to heat is called thermoluminescence (TL). Irradiation causes ionization of the valence electrons in luminescent materials; most often in the form of lattices, and electron-hole pairs is created. The amount of luminescence, most often in the visible light range, is assumed to be proportional to the accumulated absorbed dose to the lattice structure. In the luminescent material there are pre-existing defects, which act as traps to the electrons and holes. Subsequent heat of the material leads to absorption of energy by the electrons and the electron transfers from the trap to the conduction band. Some of the electrons that are released from the traps locate in so-called electron-hole recombination centers and luminescence (the TL signal) is emitted **(Antonio Hernandez-Medina et al., 2013).** The TL intensity or area under glow curve depends on the amount of radiations absorbed by the TL materials **(George S. Polymeris et al., 2011).**

The **aim of the current work** is studying the possibility of using table salt as a Gamma ray retrospective dosimeter for various brands of household salt, and selection of the most sensitive one to radiation to achieve the proposed work by studying the TL behaviors such as:

- Investigation of the effect of the particle size on TL- intensity for the nominated types of salt.
- Studying the behavior of the glow Curve for the nominated salts.
- Studying the dose response for the selected type.
- Studying the fading for the selected type.

2. Materials and method:

2.1 Materials

Four types of salt were nominated to contribute in this work, Oxford salt, SAL, MASA and Cook's salts. A selection of commercially available domestic salts and rock salt, were collected from various locations within India, Egypt, Saudi Arabia and United Kingdom. The details are given in table (1).

Table (1): Samples detaile

Sample #	Sample Name	Symbol	Salt source	location	Composition
1	Oxford salt	Oxford	Laboratory prepared	India	NaCl Min assay 99 %
2	Egyptian (Iodized table salt)	SAL	Sea salt	Egypt	NaCl 99.4 % iodine 25 – 35 ppm
3	Saudi Arabian (Iodized table salt)	MASA	Sea salt	Saudi Arabia	NaCl 99.5 % Potassium iodate 30 – 70 ppm
4	British(Iodized table salt)	Cook's	Rock salt	UK	NaCl 99.8 % Potassium iodate 30 – 70 ppm

The salt samples is passed through 10 sifting nets, with average grain sizes 750 µm, 400 µm, 256 µm, 196 µm, 165 µm, 128 µm, 100.5 µm, 85 µm, 60 µm, and 45 µm. All the samples are kept in desiccators which contains silica gel to absorb the moisture at room temperature.

2.2 Method

The investigations were done on natural samples, i.e. without changing on its physical properties. The samples were given thermal treatment at 400°C in oven before irradiation, for testing its ability for the temperature of TL device. Test sieves of known dimensions were used to separate the different grain sizes for each type of salt samples.

Ten different grain sizes are performed for each type of salt samples, eight grain sizes were completely investigated and two grain sizes were canceled because they were broken through TL measurements after irradiation.

Irradiation of the salt samples were done using Cs-137 Gamma source. The dose rate and activity of Gamma source are 7.13×10^{-3} Gy/sec and 1370 Ci respectively. Samples of 20 mg ± 0.5 mg were used for each measurement. The 20 mg can be taken as suitable sample weight for TL studies in the lower doses (Kham Suan Pau et al., (2012). All the samples were read after 24 hours from exposure to radiation.

The TL-reader used in the present work is a Harshaw TL Reader model 4500 THERMO FISHER. Samples measurements are registered by the TL reader at a heating rate of 5°C/s and up to a temperature of 350°C.

3. Results and Discussion

In order to use food salt in this research as a dosimeter to measure retrospectively the radiation doses of Gamma rays, the TL characteristics of this material must be studied. They include a study on the glow curve, the dose response and the fading.

3-1 Grain Size Effect:

Six specimens are performed for each size. The nominated salt samples have been irradiated with fixed test dose 10 Gy. Figure (1) summarizes the behavior of the TL intensity integrated from 50 to 350 °C as a function of the mean grain size for the different irradiated salt samples. According to Figure (1), the results show a similar behavior in relation to the mean grain size, i.e., the increase in TL intensity is observed as the grain size increase for all samples.

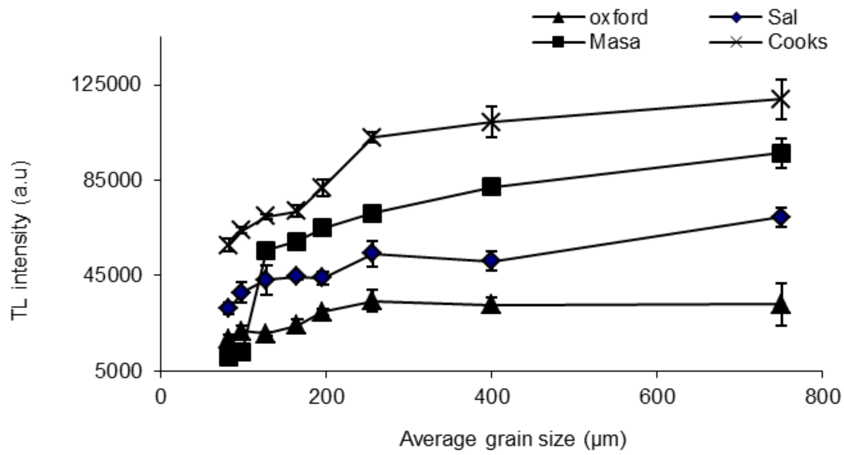

Fig (1) Relations between TL intensity and average grain size (µm) for all salt samples which irradiated with dose 10 Gy.

The less intensity in the small grain size may be due to the fact that small grain of the NaCl cannot hold interstial clusters as much as in large grains of the sample. Also, can be attributed to the increase of the specific surface area of the large grains than that of the small grains (François Trompier et al., 2009). It is believed that finer grains do not respond to the radiation in the same way as grains with grain size larger.

3-2 Glow Curve:

Fig. 2 up to Fig. 5 shows that:
For all salt samples, a single prominent glow peak appears in all glow curves which are obtained in the temperature range 216 – 222^{o}C at heating rate of 5^{o}C/sec as seen in Figures (2, 3, 4, 5). The single prominent peak in the glow curve indicates that, only one luminescence center is formed during irradiation using Gamma-rays.

It is observed that TL intensity initially increases with increasing the temperature of the salt samples attaining a maximum value at a particular temperature 218^{o}C, 222^{o}C, 216^{o}C and 220^{o}C respectively. Then decrease with further increase in the temperature.

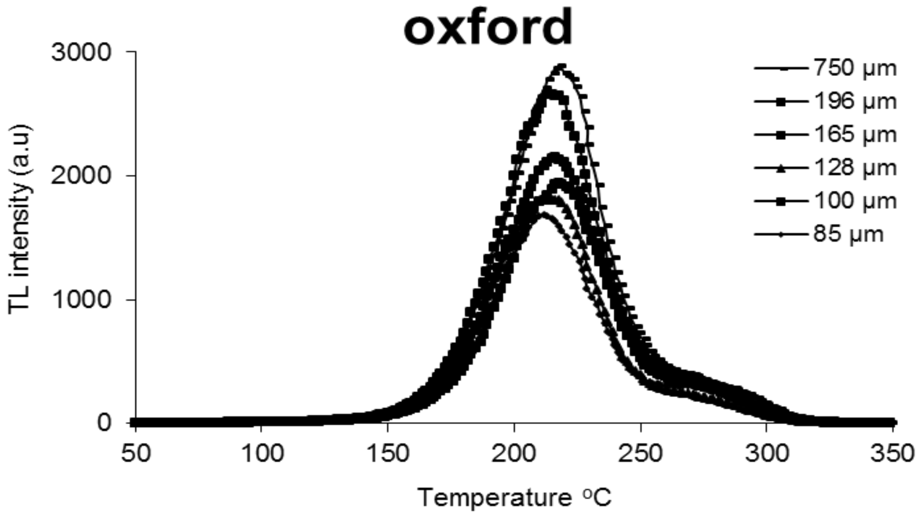

Fig (2) Glow curve of oxford salt

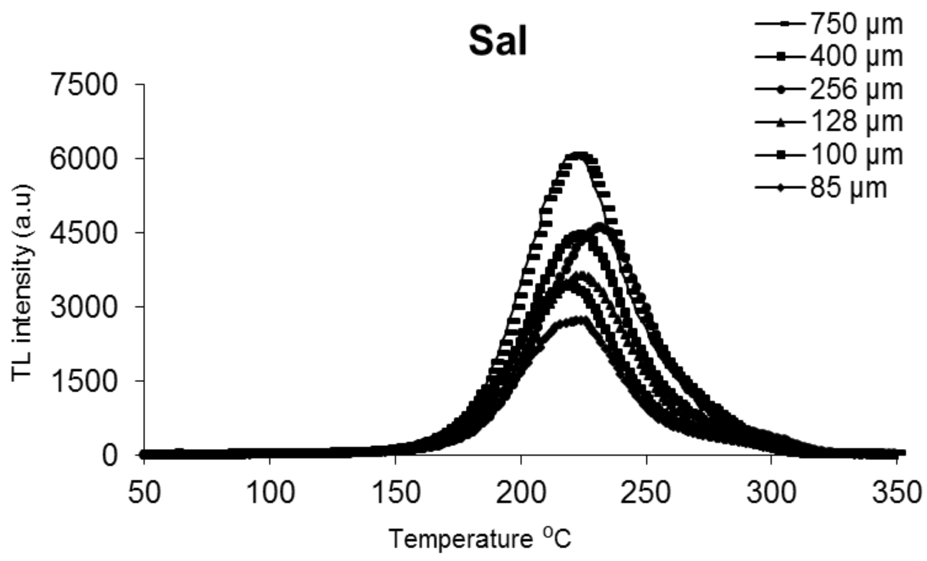

Fig (3) Glow curve of SAL salt

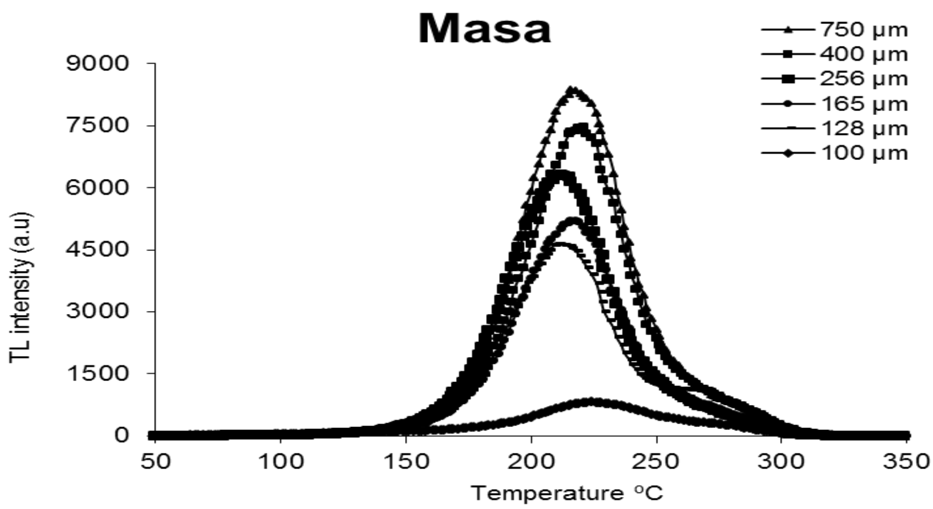

Fig (4) Glow curve of MASA

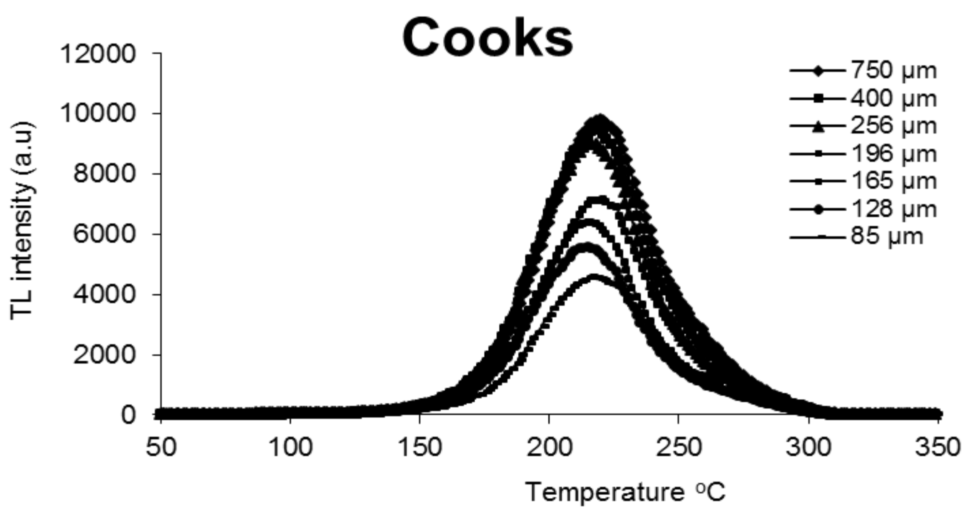

Fig (5) Glow curve of COOK'S salt

The reason for the appearance of one clear peak for all table salt samples is attributed to the presence of the element NaCl itself, subsequently all table salt samples give the similar behavior for their glow curves, although they are obtained from different sources.

The appearance of the clear single isolated peak in the glow curves for OXFORD, SAL, MASA and Cook's salts, due to the formation of only one type of luminescence center and that a large numbers of same kind of traps are involved in the generation of this peak. These peak being on the higher side of the temperature scale, deeper traps are involved in the TL process and also a long storage of trapped electrons at normal working temperature.

The main peak temperature at around 220^o C which lies between 180 - 250^{o}C is good dosimetric peak because it ensures that the trap depth is large enough for trap emptying at room temperature and small enough for background signal interference. These behaviors are required for a good TLD material. Furthermore, it is observed that the position of these peaks does not shift with increase in the radiation dose. It is, therefore, inferred that the material under investigation is resistive to radiation damage, which enhances the claim of NaCl for use as TLD material in Gamma dosimetry.

According to the high intensity observed in the prominent peak for each salt samples, it appears in a stable temperature area. So, one could consider this peak as a good dosimetric peak.

The glow curves of the higher grain size for the four salt types are plotted in figure (6). From the figure, it is noticed that, the Cook's table salt is the most sensitive one and has the higher peak of TL intensity. So, we will complete the rest of study with the British salt (Cook's) due to its behavior.

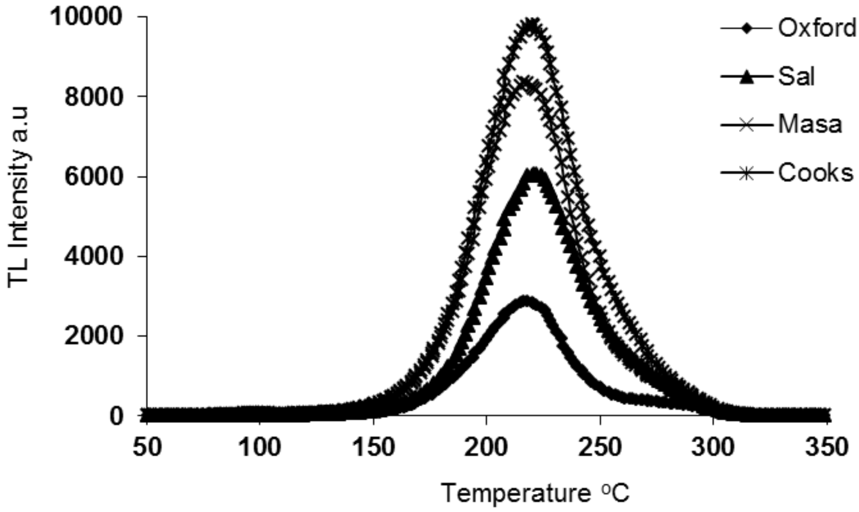

Fig (6) TL Glow curve of all higher peaks of selected salts, Oxford, SAL, MASA and Cook's.

From table (1), the high purity of salt samples indicates maximum luminescence intensity, which is better for the development of dosimetric materials and the high-temperature peak being on the higher side of the temperature scale involves deeper traps in the TL process. This leads to long storage of trapped electrons at normal working temperature.

3.3 Dose – Response:

Dose-response is one of the most important properties of TL materials as well as other materials used for dosimetry purposes. 10 groups of Cook's table salt has been performed, in which each group contains 9 samples, each sample has a weight of 20 mg ± 0.5 mg. Each group has been irradiated respectively, using the following doses: 250 mGy, 500 mGy, 1 Gy, 3.33 Gy, 5 Gy, 6.66 Gy, 8.33 Gy, 10 Gy, 15 Gy, and 20 Gy. Fig (7) represents the dependence of TL intensities of NaCl crystals irradiated with various doses. The TL intensity of NaCl crystal linearly increases with increasing Gamma – doses which are given to the samples. Since the nature of glow curves under the influence of different doses remains more or less identical, it is believed that Cook's salt does not undergo radiation damage and give high intrinsic TL around the peak.

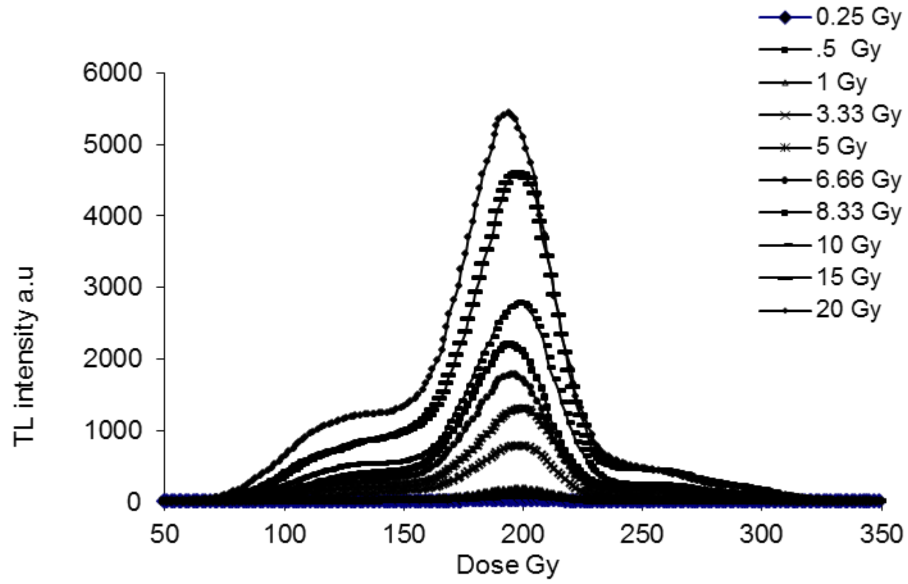

Fig (7) Variation of TL glow curve for Cook's table salt irradiated with different Gamma doses

As shown in Fig (8), a linear relation between the maximum peak intensity and the given radiation doses with correlation $\mathbf{R^2 = 0.9937}$. The fitting line of the graph was found to be :

$$\mathbf{y} = 3599.3\mathbf{x} - 2177.8$$

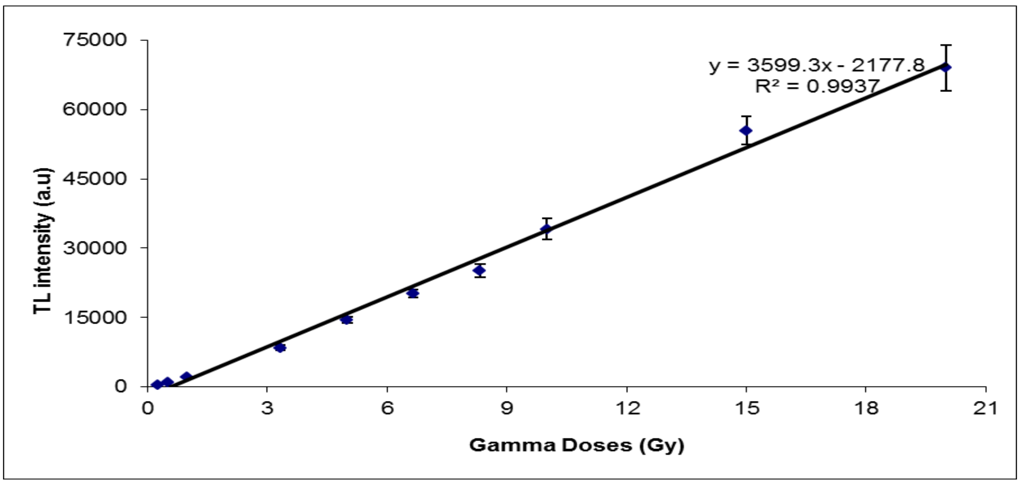

Fig (8) Linear relation between the TL intensity and given gamma doses for Cook's table salt.

The increase in TL intensity with increasing Gamma - dose may be due to increase in number of active luminescent centers with Gamma - irradiation and subsequent emission of TL signal. The presence of a linear relationship between the dose and the response of the samples under study (Cook's salt) and the maximum peak intensity justifies their use in radiation dosimetry.

3.4 Fading Effect:

Thermoluminescent dosimeter's (TLDs) signal decreases after irradiation with time, this effect is called fading. The fading of the TL output signal is a bothersome property of TLDs that is important to characterize in order to accurately relate TL output with amount of radiation exposure. Ten groups of Cook's table salt has been performed, in which each group contains nine samples, each sample has a weight of 20 mg ± 0.5 mg. Fading properties have been determined by irradiating the ten groups with a fixed dose of 5 Gy. The irradiated samples are stored in plastic containers having silica gel for protection from moisture, at room temperature. Further measurements have been done after 4 hrs, 1 day, 2 days, 3 days, 6 days, 9 days, 16 days, 21 days and 24 days respectively. Fig (9) indicates the variation of TL glow curve with temperature of Cook's salt stored for different days.

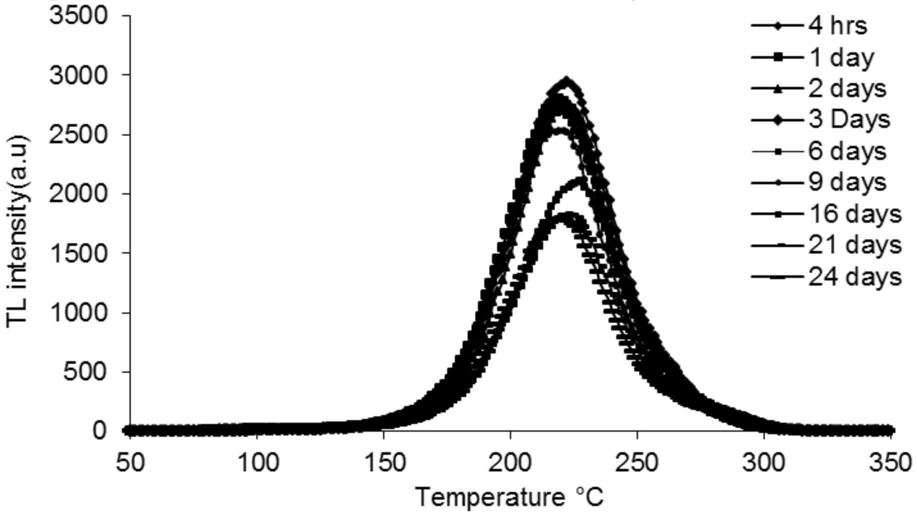

Fig (9), Variation of TL glow curve with temperature of Cook's salt stored for different days

Then, we draw the rate of relative TL, which remains as a result of the thermal storage period against the storage time. Fig (10) represents the fading effect properties.

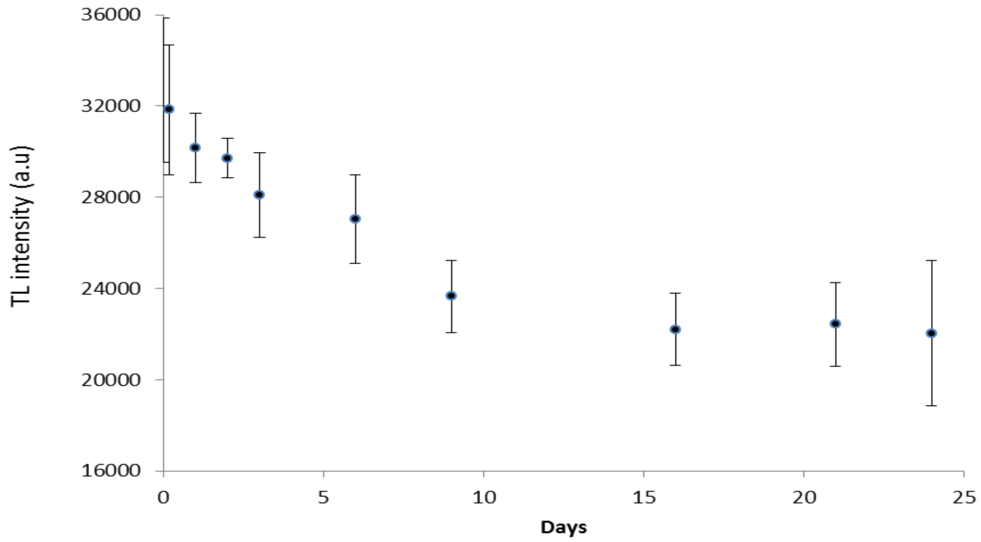

Fig (10) Variation of TL intensity with fading time (days)

From the figure, it is observed that, the post-irradiation signal is not stable. During the first eight days about 35 % decay at room temperature is observed. This may be associated with shallow traps, in which the storage room temperature may be sufficient to stimulate trapped electrons at these shallow traps. After eight days, the fading rate decreased dramatically then reaches stability. The stability for the measurements occurs due to the presence of the deep traps. The salts with such important property (stability) can be proposed for use as a retrospective dosimeter.

The presence of stable TL peaks at high temperature provides practical applications of NaCl as a tool in TL dosimeter, which result from the stored charge carriers in deep traps at ambient temperature. The signal decreases after irradiation with time can be explained by the occurrence of several processes: radical recombination, electron capture, charge transfer recombination and energy transfer from the matrix to radicals.

4. Conclusion

The TL results show direct relation of the glow peak intensity with grain size for all salt samples. Which give the similar behavior for their glow curves, although they are obtained from different sources, which is attributed to the presence of the element NaCl itself. The high TL intensity obtained for Cook’s salt reflect its higher sensitivity than for MASA salt, SAL salt, and Oxford salt. The results indicate that, Cook’s salt is the most sensitive and preferable one to complete the study. Its glow curve has a clear peak being on the higher side of the temperature scale. The radiation response curve for the Cook’s salt represents a linear TL dose response with a correlation of 0.9937 which is a good characteristic for the development of material for radiation dosimeter (cost wise). After eight days, the fading rate decreased dramatically to where reach stability. This stability is attributed to the presence of deeper traps which are involved in the TL process and also a long storage of trapped electrons at normal working temperature. These behaviors are required for a good retrospective dosimetry. So; Cook’s salt may be candidate for using as TL retrospective dosimeter for Gamma radiation.

Acknowledgements

The author expresses his sincere gratitude to Dr. Mostafa Elashmawy, Department of radiation protection, ENRRA, for his support in completing this study by using TL reader. And for Mrs. Hemmat, Gamma irradiated unit also for her support in irradiating all samples.

References

A.F. Gumenjuk, S. Yu. Kutovyi and V.A. Kurilova, Oscillator regularity of trap activation energies in NaCl crystals, Semiconductor Physics, Quantum Electronics & Optoelectronics, vol.3, N.4. pg.: 463- 468, (2000).

A. George S. Polymeris, George Kitis, Nafiye G. Kiyak, Ioanna Sfamba, Bhagawan Subedi, Vasilis Pagonis, Dissolution and subsequent recrystallization as zeroing mechanism, thermal properties and component resolved dose response of salt (NaCl) for retrospective dosimetry, Applied Radiation and Isotopes 9, 1255 –1262.R.U (2011).

A.K. Biswal, F. Dilna, N.K. Ramaswamy, K.A.V. David, A.N. Misra, TL characteristics of NaCl salt stressed Indian mustard seedlings, John Wiley & Sons, Ltd, 17:135-140, (2002).

Alejandro Ortíz Morales, Claudio Furetta, a preliminary determination of the kinetics parameters of doped NaCl: Ca, Mn single crystals during fading stage, Latin-American Journal of Physics Education**,** Vol. 8, No. 2, (2014).

Álvaro Barbosa de CarvalhoJr. a, Pedro Luiz Guzzob, Henry Lavalle Sullasic, Helen Jamil Khoury, Effect of Grain Size in the TL Response of Natural Quartz Sensitized by High Dose of Gamma Radiation and Heat-Treatments, Materials Research; 13(2): 265 - 271**,** (2010).

Antonio Hernandez-Medina, Alicia Negron-Mendoza, Sergio Ramos-Bernal, Maria Colin-Garcia, The effect of doses, irradiation temperature, and doped impurities in the TL response of NaCl crystals, Radiation Measurements 56, 369-373**,** (2013).

Bhujbal and S.J. Dhoble, Luminescence studies on Gamma -ray-irradiated Dy3+ -activated sodium chloride phosphor for radiation dosimetry, Radiation Effects & Defects in Solids Vol. 167, No. 6, 428–435**,** (2012).

François Trompier, Celine Bassinet, Albrecht Wieser, Cinzia De Angelis, Daniela Viscomi and Paola Fattibene, Radiation-induced signals analyzed by EPR spectrometry applied to fortuitous dosimetry, Ann Ist Super Snità Vol. 45, No. 3: 287-296, (2009).

John A. Harvey, Nathan P. Haverland, Kimberlee J. Kearfott, Characterization of the glow-peak fading properties of six common thermoluminescent materials, Applied Radiation and Isotopes 68, (2010).

Kassim A.R. Khazal, Riyadh Ch. Abul-Hail, Study of the possibility of using food salt as a Gamma ray dosimeter, Nuclear Instruments and Methods in Physics Research A, 624, pg.708 – 715, (2010).

Kham Suan Pau, Ramesh Chandra Tiwari, TL (TL) Analysis of Naturally Occurring Salt for Sample Weight Selection for Dosimetry Studies, International Journal of Physics and Applications. ISSN 0974-3103 Volume 4, Number 1, pp. 73 -79, (2012).

M. Kalra, R. S. Kher, S.J. Dhoble and A.K. Upadhyay, TL studies of Gamma irradiated sodium chloride single crystals and microcrystalline powder doped with terbium, Pure Applied and Industrial Physics, Vol.4 (2): Pg.87-92, (2014).

M. Kalra, R.S. Kher, S.J. Dhoble, A.K. Upadhyay, Mechanoluminescence and TL studies of Gamma irradiated sodium chloride single crystals and microcrystalline powder doped with dysprosium, Indian journal of pure & applied physics, pp.597 – 603, (2014).

Manish Kalra, R.S. Kher, Jagjeet Kaur, N.S. Suryanarayana, Vikas Dubey, Kinetic Parameter and TL Glow Curve of Gamma Irradiated DY Doped NaCl Crystals, advanced physics letter, Vol_1, Issue_3, 1-3.Y, (2014).

Maria Christiansson, Christian Bernhardsson, Sören Mattsson, Christopher Rääf, Household salt as a retrospective dosimeter.

Nigel A. Spooner, Barnaby, W. Smith, Donald F. Creighton, Danièle Questiaux, Peter G. Hunter, Radiation Measurements, Luminescence from NaCl for application to retrospective dosimetry, Volume 47, Issue 9, Pages 883–889.P.M**,** (2012).

Purohit, T.R. Joshi, Development of NaCl : Tb(T) as Gamma and beta radiation dosimetry material, Journal of Luminescence 87, pg. 1295 -1296, (2000).

Ramesh Chandra Tiwari, Kham Suan Pau, T.P. Sinha, Study of Reproducibility of the Sensitivity of the Natural Salt (NaCl: Cu, Mg, O, As, Mn) by TL (TL), Science and Technology Journal, Vol. 2(1) : 53-56, (2014).

Ramesh Chandra Tiwari, TL dose Response Study of Natural Salt (NaCl: Cu, Mg, Mn, O, As) obtained from Mizoram, India, International Journal Of Engineering Sciences & Research Technology,3(8):1-7.

Riyadh Ch. Abul-Hail, TL Characteristics of NaCl /FeO2 Relative to Dosimetry, Journal of Basrah Researches (Sciences), Vol.(40), No.(4) , (2014).

Rodriguez-Lazcano, V. Correcher a, J. Garcia-Guinea, Luminescence emission of natural NaCl, Rodriguez-Lazcano, Radiation Physics and Chemistry, vol.81, pg. 126–130, (2012).

S. Nabadwip Singh, TL of Natural Salt extracted from the Saline spring of Ningel, Manipur, International Journal of Luminescence and Applications Vol 3, No. 1, pages 49 – 51, (2013).

Th. Tejkumar Singh, Analysis of the TL (TL) glow curves of β-irradiated NaCl at room temperature, International Journal of Luminescence and applications Vol.5 (4) December, pages 374 - 376, (2015).

الملخص باللغة العربية

الخواص الوميضية الحرارية لكلوريد الصوديوم من أماكن مختلفة

محسن حسن[1]، هيام عبد الغني[3] ، صالح محمود عبده[1] ، هاني عامر[2]

١ - قسم الفيزياء الاشعاعية بالمركز القومي لبحوث وتكنولوجيا الاشعاع –هيئة الطاقة الذرية

٢ - قسم الفيزياء الاشعاعية بهيئة الرقابة النووية والاشعاعية

قسم الفيزياء الاشعاعية بكلية البنات – جامعة عين شمس

تمت دراسة الخواص الحرارية الوميضية لعدد اربعة انواع ملح مختلفة المصدر، هندي (مصنع فى معمل أكسفورد بالهند) ، مصري(سال) ، سعودي(ماسا) ، إنجليزي(كوكس) . تم تشعيع العينات بأشعة جاما من مصدر سيزيوم 137 .لوحظ ظهور قمة واحدة بارزة في منحنى اشارة الوميض الحراري لجميع انواع الملح المختلفة عند درجات حرارة من 216 - 222 درجة مئوية. لوحظ ان شدة اشارة الوميض الحراري تتناسب طرديا مع حجم ال حبيبات ومنها تم ترشيح حجم الحبيبات الاكبر لإتمام الاختبارات وهو من 500 الى 1000 ميكرومتر. أشارت النتائج إلى أن ملح الطعام الانجليزي (كوكس)هو الأكثر حساسية والأفضل لإتمام دراسة الخواص الحرارية الوميضية. اظهرت النتائج ان شدة التوهج للملح (كوكس) لديها استجابة خطية مع الجرعة لنطاق واسع من 250 ميللي جراي إلى 20 جراي. أظهرت دراسة ظاهرة الفقد الطبيعي ما بعد التشعيع للملح (كوكس) حدوث ثبات للقراءة بعد 8 أيام. أشارت النتائج ان الملح (كوكس) ربما يكون مرشحا للاستخدام في قياس الجرعات الاشعاعية بأثر رجعي لأشعة جاما.