PULSED PHOTOLUMINESCENCE MEASUREMENTS USING SALT AS A RADIATION ACCIDENT DOSE DETECTOR MATERIAL

by

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Scientific paper
https://doi.org/10.2298/NTRP2303169H

To realize the retrospective measurement of public dose levels after a nuclear emergency, the optically stimulated luminescence radiation dose-response characteristics of salt were studied, and the relationship between the salt optically stimulated luminescence signal and ionizing radiation dose was determined. The effects of natural light, storage time, and preheating temperature on the salt optically stimulated luminescence signal were examined. The results show that salt as a photoluminescence dose measurement material has the advantages of convenient sampling, high throughput, short detection time, wide dose range, and low detection limit. The study lays the technical foundation for achieving the public dose assessment of salt pulse photoluminescence.

Key words: pulsed photoluminescence, salt, radiation accident, dose

INTRODUCTION

With the development of science and technology, radioactive sources and radiation technologies have been widely used in the fields of industry, agriculture, medicine, and military. These developments inevitably put humans at risk of ionizing radiation [1] Particularly in the case of nuclear (radiation) emergencies and nuclear terrorist attacks, the personnel engaged in nuclear work can monitor the received radiation dose with a personal portable dosimeter. Simmilary to other alternative methods, using salt as a detector material, public dose assessment can be performed without a personal dosimeter [2, 3].

Because salt is globally distributed, salt can easily be collected in every household, workplace, and restaurant, and the main component of salt, NaCl, has a crystal structure, thus making salt a suitable optically stimulated luminescence (OSL) material research object [4, 5]. Studies have shown that salt has a good linear dose-response, time stability, low minimum detectable dose (MDD), and small sample difference, which meets the requirements of accident dose detection; therefore, the study of salt photoluminescence properties and its measurement methods have become very popular research topics in recent years [6].

In 1960, Stoddard first observed[7] that the use of light to stimulate the ionized radiation of NaCl caused luminescence, but Stoddard did not call the phenomenon OSL; in 2000, based on OSL technology, Bailey first proposed [8] sodium chloride is most likely a retrospective dosimeter material, and blue, green and infrared light can be used for excitation purposes, but the signal excited by infrared light is not stable; in 2001, Buur used a constant-energy excitation source (continuous wave OSL, CW-OSL) and a linearly enhanced light source, and the photoluminescence signals of salt were observed in the linearly modulated OSL (LM-OSL) mode.

However, in the CW-OSL and LM-OSL excitation modes, the linear response upper limit of salt dose is 1 Gy and 0.1 Gy, respectively, and the response is sublinear in the high-dose range [9, 10]; in 2009, Bernhardsson *et al*. investigated many types of salt [11] and indicated that most salts have very high specific photoluminescence counts, while the MDD is lower than 1 mGy (0.2-1 mGy); in 2015, Ekendahl et al. indicated that the use of photoluminescent salts in dose assays is a prospective dosimetry method that can be implemented in a NaCl dosimeter, such as commercial LiF: Mg and Al_2O_3:C dosimeters [12]. In 2017, Janet studied the photoluminescence properties of salt commonly used in Nigeria based on the photoluminescence Risø TL/OSL-DA-15system; however, it was noted that the use of salt in nuclear radiation accident dosimeters is associated with a certain measurement error [13]. Although salt photoluminescence signals can be detected in the CW-OSL and LM-OSL excitation modes, there is a lack of good linearity in the high-dose range, which is not desirable in accident dose detection.

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In this paper, salt was used as the detector material, and the radiation dose measurement characteristics of salt were explored through the pulsed photoluminescence method to meet the needs of public dose assessment after nuclear accidents, which lays the technical foundation for realizing the public dose assessment via salt pulse photoluminescence.

INTRODUCTION OF THE KEY PRINCIPLES

Valence band theory

The valence band theory explains the luminescence mechanism of OSL materials, shown in fig. 1. In the figure, 1 is the ionizing radiation, 2 – the ionization; 3 – the electron-hole trapping; 4 – the photoexcitation; 5 – the electron-hole recombination; 6 – the luminescence, and a, b, and c are shallow traps, dose traps, and deep traps, respectively. The energy levels of OSL crystals mainly include conduction bands, valence bands and forbidden bands.

When an OSL material is subjected to ionizing radiation (such as X-rays, gamma rays, and beta rays), the stored electrons inside the crystal are excited to transition, and as the valence band transitions into the conduction band, holes are left in the valence band. The electrons in the conduction band and the holes in the valence band are free to move inside the crystal. When the electrons and holes are recombined, fluorescence occurs. The unbound electrons and holes are trapped in the electron traps and hole traps, respectively. When excited by heat (thermoluminescence dosimeter, TLD), all trapped electrons and holes will escape; if a light source is used to excite the crystal, only some of the electrons and holes will escape from the traps after excitation, which results in fluorescence. Phosphorescence is the signal that continues to be emitted when light-source excitation has ceased. The intensity of the light signal is a characteristic of the electron concentration in the trap. The number of electrons trapped is proportional to the ionizing radiation dose received by the crystal.

OTOR model

The one trap-one recombination(OTOR) model [16] assumes that there is only one type of trap and one type of binding center in the OSL material, and there is no secondary capture phenomenon, which is the simplest mathematical description of the OSL process. The relationship between the captured electron concentration in the trap as a function of time is shown in the equation

$$\frac{\mathrm{d}n}{\mathrm{d}t} \quad np \tag{1}$$

where p is the rate at which electrons are excited by light per unit of time and $p = \sigma\varphi$; in the latter, σ – the photoionization interface of the OSL material and φ – the laser flux.

The solution of eq. (1) is

$$n(t) \quad n_0 \mathrm{e}^{\quad pt} \tag{2}$$

where $n_0 = n(0)$ is the initial concentration of the trapped electrons. Equation (2) indicates that the trapped electron concentration changes exponentially with the excitation time.

Assuming that all excited electrons are immediately combined with holes to emit light, the luminescence intensity is proportional to the escape velocity of the trapped electrons, dn/dt, and combining eq. (1) and (2) obtain the following

$$I_{\mathrm{OSL}}(t) \quad \left|\frac{\mathrm{d}n}{\mathrm{d}t}\right| \quad n_0 p\mathrm{e}^{\quad pt} \tag{3}$$

The decay rate of the OSL intensity curve is determined only by σ and φ, and the decay rate is independent of the value of n0, that is, the shape of the OSL curve does not change with the dose. The total luminescence amount can be obtained by integrating the OSL intensity curve, that is, the integral of eq. (3) can be obtained as

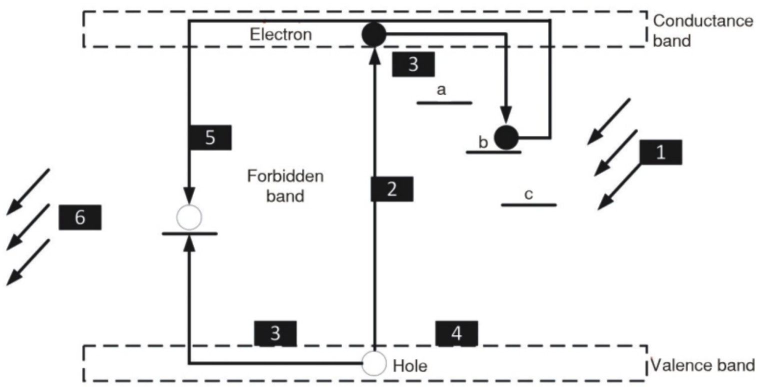

Figure 1. OSL schematic

$$\int_0^\infty I_{OSL}(t)\mathrm{d}t = \int_0^\infty n_0 p \mathrm{e}^{-pt}\mathrm{d}t = n_0 \tag{4}$$

Therefore, it can be seen from eq. (4) that the total amount of luminescence of the fluorescent material is proportional to the initial electron concentration in the crystals of the material, that is, the total amount of luminescence is proportional to the stored dose value.

Pulsed OSL (POSL) principle

The program timing diagram used to measure the pulsed photoluminescence signal [14] is shown in fig. 2. The excitation source is synchronized with the counting system. During the operation of the excitation source, the system only excites the sample and does not detect the excited optical signal. When the excitation light source is turned off, the counting system starts detecting optical signals, wherein the pulse width, the pulse interval, and the number of excitation pulses per measurement are controllable; the pulse width adjustment range is equal to the pulse interval adjustment range divided by the entire range of the number of signals. Moreover, due to the influence of the phosphorescence lifetime, if the excitation frequency is high, the photons excited during the previous excitation period will affect the detection of photons in the next cycle, which results in the initial detection of an optical signal at the start of each cycle until the photon excitation rate becomes equal to the photon decay rate; then, the number of detected photons gradually stabilizes. As excitation continues, the crystal photon excitation difficulty increases. When the photon excitation rate is lower than the photon decay rate, the number of detected photons decreases until the next trap in the crystal is excited.

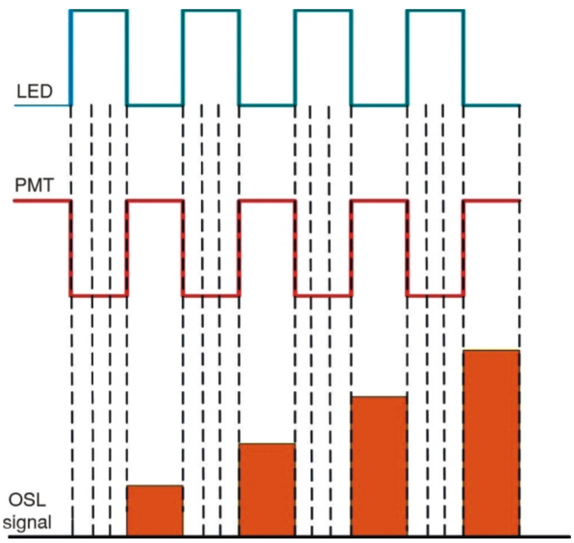

Figure 2. POSL signal measurement program timing diagram

The phosphorescence attenuation follows an exponential function, and the specific function is shown as eq. (5).

$$I(t) = I_0 \mathrm{e}^{-t/\tau} \tag{5}$$

Assuming that τ is the pulse width, the integral value of the function $I_0 \mathrm{e}^{-t/\tau}$ in time from t_0 to t_∞ is the total number of photons detected by the counting system

$$I_{sum} = \int_0^\infty I_0 \mathrm{e}^{-t/\tau}\mathrm{d}t = I_0\tau \tag{6}$$

The number of optical signals lost during the excitation time is

$$I_{loss} = \int_0^{t_0} I_0 \mathrm{e}^{-t/\tau}\mathrm{d}t = I_0\tau(1 - e^{-t_0/\tau}) \tag{7}$$

The ratio of the number of measured optical signals in the pulsed photoluminescence excitation mode to the total number of photons emitted by the sample is

$$\frac{I_{sum} - I_{loss}}{I_{sum}} = \frac{I_0\tau - I_0\tau(1 - e^{-t/\tau})}{I_0\tau} = \mathrm{e}^{-t_0/\tau} \tag{8}$$

From the valence band theory, it is known that the ionizing radiation dose value of the OSL material is proportional to the total optical signal emitted by the material. Since $\mathrm{e}^{-t_0/\tau}$ is constant in eq. (4), the measured optical signal obtained by the method in the pulse photoluminescence mode is proportional to the total optical signal emitted by the material. Therefore, the sum of the optical signals detected during measurement in the pulsed photoluminescence mode is proportional to the ionizing radiation dose.

EXPERIMENTAL EQUIPME AND METHODS

Experimental instruments

The equipment required for this experiment was a dosed irradiation system, a light signal detection system, and a homemade salt container. The dosed irradiation system is an HXFS-IA type biological irradiator, as shown in fig. 3. The source is ^{137}Cs, and the average energy is 0.661 MeV; the light signal detection system is an InLight200A photoluminescence personal dose monitoring system (American Landauer Company). As shown in fig. 4, the system uses green light (~532 nm) as the excitation source and the pulsed light excitation mode, and the system has a specific measurement channel. Only objects that are similar to the four-element Al_2O_3:C dosimeter can be placed in the measurement channel, and the sample was excited by green light. In this study, 3-D printing was used to fabricate the sample container, and the four holes in the container were filled with equal amounts of salt, while both sides were sealed with transparent tape. The four-element salt dosimeter was prepared and is shown in fig. 5.

Figure 3. HXFS-IA biological irradiation instrument

Figure 4. InLight200A photoluminescence personal dose monitoring system

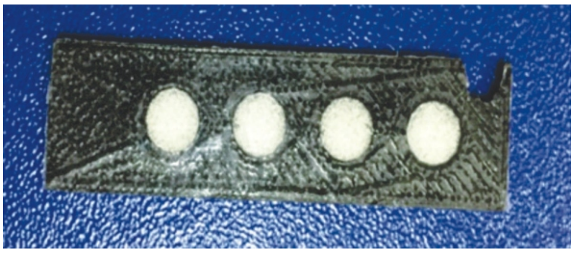

Figure 5. Four-element salt dosimeter

Experimental methods

Complete excitation

Under complete excitation, the dose information in the salt crystals is completely excited by the excitation light source. According to the valence band principle and the pulsed photoluminescence theory, the sum of the optical signals obtained by the measurement method in the pulsed photoluminescence mode is proportional to the ionizing radiation dose. It is attempted to enable the system to record the maximum number of OSL signals and minimize the number of system detections. The proposed excitation time is 20 ms. To record all phosphorescence signals before the start of the next cycle, the pulse interval is set to 1000 ms, and the number of pulses is 50.

In the InLight200A measurement system, the pulse width, pulse interval, and number of excitation pulses per cycle are controllable. In one test, the total excitation time of the system is equal to the product of the pulse width and the number of pulses.

Partial excitation

Under partial excitation, only part of the dose information in the salt crystals is excited by the excitation source. By adjusting the excitation frequency of the excitation source, the intensity of the acquired OSL signal can be controlled such that not all of the ions in the traps are excited to generate a better dose response of the OSL material.

Compared with the CW-OSL and LM-OSL methods, one of the advantages of the POSL method is that when measuring the dose of the component, only part of the dose information needs to be excited, the excitation time is short, and the background OSL signal intensity is low, thereby resulting in a lower minimum detectable lower limit. By changing the excitation frequency, the photomultiplier tube (PMT)-recorded optical signal can be adjusted so that the salt dosimeter has a better linear response with the irradiation dose and the irradiation dose has a wider range.

EXPERIMENTAL RESULTS AND DISCUSSION

Complete excitation

Single-dose salt photoluminescence

To investigate whether salt has photoluminescence properties a certain dose of salt from a radioactive source ^{137}Cs was used and compared to unirradiated salt. The experimental steps are as follows:

(1) Turn on the InLight200A system for 30 minutes;
(2) Obtain a batch of salt and anneal the salt using a light-annealing apparatus;
(3) To prevent the influence of natural light on the salt, place the light-annealed salt in a bottle cap and seal the cap with an opaque black rubber cloth;
(4) Put the caps containing salt into the irradiation container and turn on the biological irradiator to irradiate the salt;
(5) Weigh the dose caps that are not filled with salt;
(6) Place the light-annealed salt in a salt container to prepare the salt dosimeter and weigh the total mass of the salt dosimeter;
(7) Place the salt dosimeter in the InLight200A and measure the salt OSL signal.

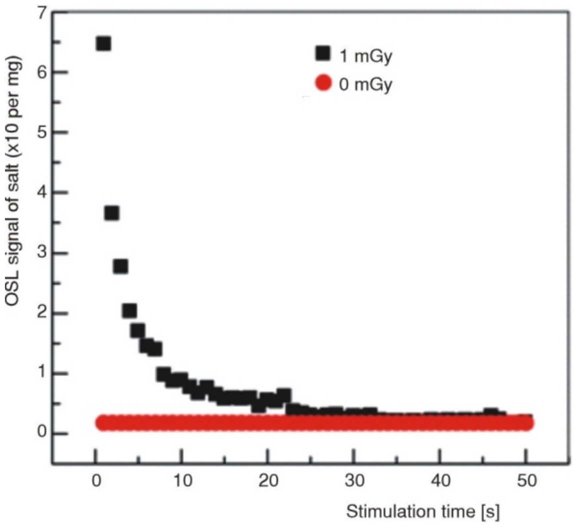

Figure 6. Curve of the photoluminescence signal of salt (0 and 1 mGy) with the excitation time

The OSL signal curve of salt (1 mGy and 0 mGy) with the number of excitations is shown in fig. 6. Each point in the figure indicates the number of OSL signals collected within 1000 ms after the salt source is excited for 20 ms. The 1 mGy salt was compared with the 0 mGy salt. The OSL signal emitted by the former increased significantly, and the photoluminescence signal gradually decreased with increasing number of excitations (excitation time). The experimental results show that the OSL signal emitted by salt is related to the ionizing radiation of the salt, and the salt OSL signal can be fully excited with an increasing number of excitations (excitation time).

Photoluminescence of different doses of salt

To verify that the pulsed photoluminescence measurement method can achieve a wider linear dose range than the CW-OSL and LM-OSL methods, the linear response range of the salt dose is measured based on pulsed photoluminescence. The experimental steps are as follows:

(1) Turn on the InLight200A system for 30 minutes;
(2) Obtain a batch of salt and anneal the salt using a light-annealing apparatus;
(3) To prevent natural light from affecting the salt, place the light-annealed salt in a bottle cap and seal the cap with an opaque black rubber cloth;
(4) Apply an irradiation dose of 1 mGy;
(5) Weigh the dose cap without salt;
(6) Place the light-annealed salt in a salt container to prepare the salt dosimeter and weigh the total mass of the salt dosimeter;
(7) Set the measurement system's pulse excitation time t_1 = 1 ms, count time t_2 = 50 ms, and pulse number n = 50 and record the OSL signal;
(8) Prepare different salt dosimeters (10, 100, 200, 400, 800, 1000, 2000, 4000, 8000, and 10000 mGy) and repeat steps 5-7.

The experimental results are shown in fig. 8. The results show that the salt photoluminescence signal has a good linear relationship with the irradiation dose in the dose range of 0.01 ~1 Gy but tends to remain stable in the dose range of 1~10 Gy, resulting in a constant curve. The reason is that in the high-dose range when the excitation time is short, the number of emitted OSL signals in the same excitation time is the same. The experimental results show that the pulse excitation time t1 needs to be increased to achieve a dose range of 10 Gy.

To obtain a linear relationship between the salt photoluminescence signal and the irradiation dose, it is necessary to measure the salt OSL signal for different irradiation doses. The light-annealed salt was poured into 10 caps, which were sealed with black transparent tape, and then placed in the biological irradiator to be subjected to irradiation doses of 1, 2, 4, 6, 8, 10, 20, 40, 60, 80, and 100 mGy. The four-element salt dosimeter was then prepared and placed in the InLight200A measurement system to detect the salt OSL signals, and the number of OSL signals was recorded.

Since the InLight200A system is in the POSL mode, when the OSL signal is under full excitation, the light-annealing effect cannot be achieved in one test, and multiple tests need to be performed. Therefore, the number of detections is determined to ensure that the salt can be irradiated from 1~100 mGy. The signal must be under full excitation.

When the salt dose of the dosimeter is 100 mGy, the relationship between the emitted OSL signal per mg of salt and the number of detections is shown in fig. 7. In addition to the system shutdown and restart times, 20 detection tests consume nearly one hour. When the number of excitations is 1~6, the OSL signal of salt gradually decreased with increasing number of excitations until the 7th detection, and from the 7th to the 20th detection, the number of salt OSL signals that were emitted each time gradually decreased to the back-

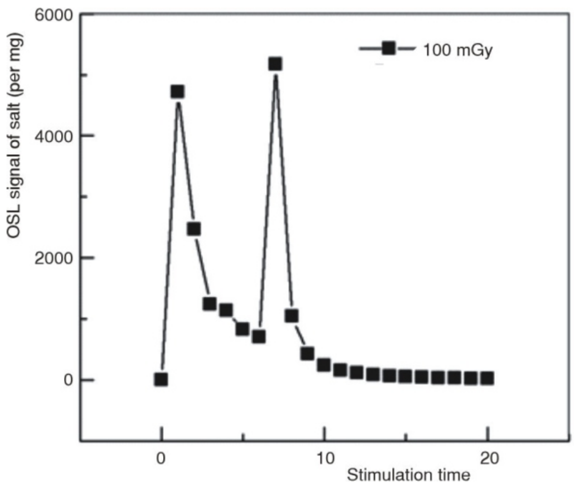

Figure 7. Relationship between the photoluminescence signal of the 100 mGy salt and the number of detections

ground level with increasing number of excitations. The relationship between the number of OSL signals emitted by salt with irradiation doses of 1, 2, 4, 6, 8, 10, 20, 40, 60, 80, and 100 mGy and the number of detections is shown in fig. 6. The salt OSL signal in the dose range of 1~10 mGy varies with the number of detections. The change image has only one peak, and the image of the salt OSL signal above the 20 mGy dose has two peaks as a function of the number of detections.

The experimental results are in good agreement with the OSL principle. The salt crystals include three kinds of traps, namely, shallow traps, dose traps, and deep traps. The electrons in the shallow traps and dose traps are easier to excite than the electrons in the deep traps. The electrons in shallow traps most easily escape under excitation. However, the electrons in deep traps are difficult to excite. Therefore, the OSL signal emitted when the crystal is excited by an external light source is mainly formed by the combined electrons in the shallow and dose traps and the holes in the crystals. From these considerations, it can be judged that of the two peaks shown in fig. 8, the first and second peaks are caused by the shallow and dose traps, respectively.

The relationship between the OSL signal per mg of salt and the irradiation dose is shown in fig. 9. The results showed that the salt photoluminescence signal per unit mass was in the range of 1~100 mGy and had a good linear response with the irradiation dose, and $R^2 = 0.950$.

To investigate the stability of the OSL signal of the salt dosimeter, 10 photoluminescence measurements were performed on 10 salt dosimeters with an irradiation dose of 11.42 mGy. The experimental results are shown in tab. 1. The average number of emitted OSL signals per mg of salt was 1456.5. The variance was 110.2, the relative deviation was 7.57 %, which is <10 % (the instrument measurement error), and the deviation between the dose value obtained from the fitted curve and the salt-absorbed dose value of 11.42 mGy is also shown in tab. 1.

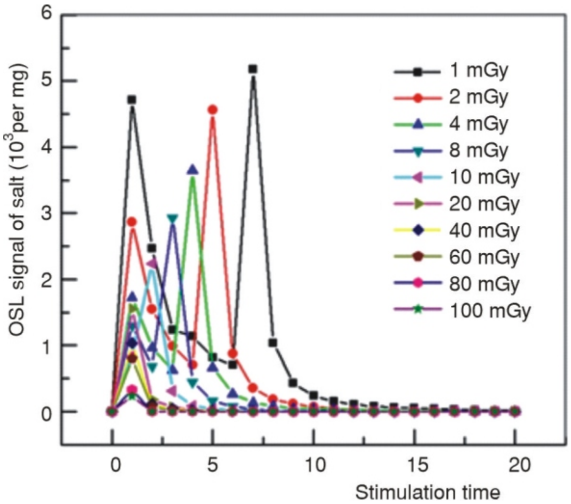

Figure 8. Relationship between the 1-100 mGy salt photoluminescence signal and the number of detections

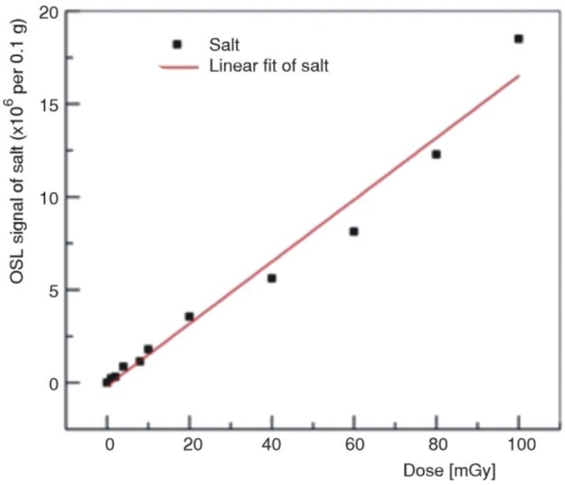

Figure 9. Dose-response curve of the salt photoluminescence signal

Table 1. OSL signal of the 10 salt samples under an 11.42 mGy irradiation dose

Sample	OSL signal per mg	Dose per mGy	Relative deviation [%]
1	1424	11.65	+2.01
2	1566	12.36	+8.23
3	1334	11.19	–2.01
4	1351	11.28	–1.23
5	1452	11.78	+3.15
6	1577	12.42	+8.76
7	1455	11.80	+3.33
8	1544	12.25	–7.27
9	1450	11.78	+3.15
10	1530	12.19	+6.74

Table 1 shows that the measured dose range of the salt OSL signal is (11.28 mGy, and 12.42 mGy), and the absolute value range of the dose deviation is (1.23 % ~ 8.76 %), which is less than 10 %. The experimental results show that the response of the salt OSL signal to the irradiation dose is stable.

The excitation time t_1 is increased, while the other parameters remain unchanged, and the excitation time is set to 5, 10, 20, 30, 40, and 50 ms. Then, the salt OSL signal dose-response curve is determined for a pulse width of 50 ms, as shown in fig. 10. The dose-response curve is shown in fig. 11. The linear response range and correlation coefficient of the linear fit of the table salt results for different excitation times are shown in tab. 2.

The experimental results indicate that, under constant conditions with a count time of t_2 = 50 ms and a pulse count of n = 50, salt generally exhibits a favorable dose-linear response within the irradiation dose range of 0.1~1 Gy, and tends to stabilize within the dose range of 1~10 Gy when the excitation time ranges from 1 ms to 40 ms. Particularly noteworthy is the linear response range of the dose-response when the excitation time is set at 10 ms, spanning from 1~1000 mGy, with the lin-

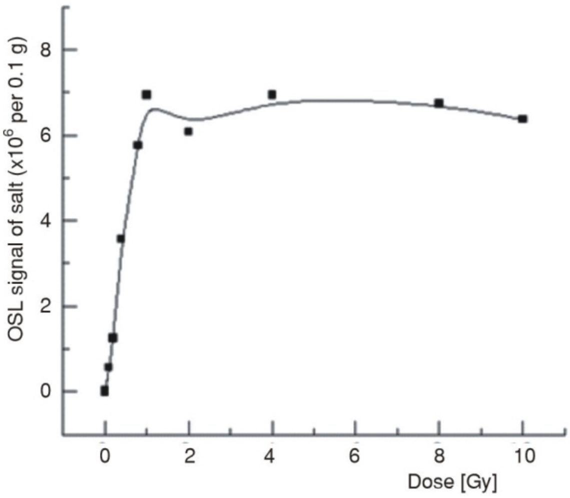

Figure 10. Relationship between the salt photoluminescence signal and irradiation dose

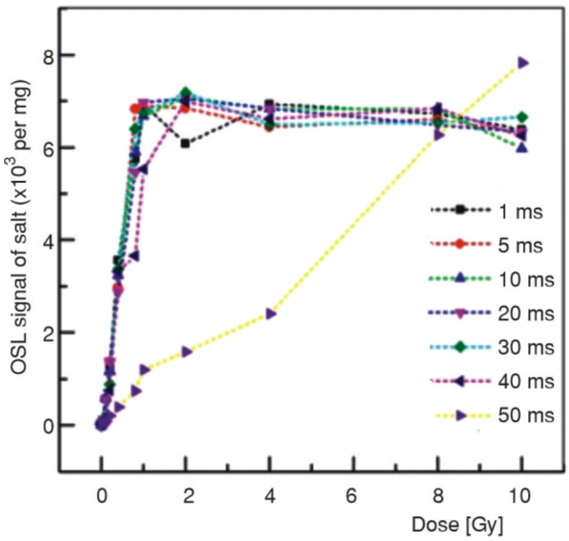

Figure 11. Dose-response curves with the pulse width

Table 2. Linear response range of salt for different excitation times and correlation coefficient of the linear fit of the response results

Stimulation time [ms]	Linear response range [mGy]	Correlation coefficient
1	10-1000	0.981
5	100-800	0.995
10	1-1000	0.983
20	1-1000	0.978
30	100-800	0.982
40	100-1000	0.890
50	100-10000	0.990

ear response curve shown in the lower right corner of fig. 12 ($R^2 = 0.995$). Additionally, at an excitation time of 50 ms, the optically stimulated luminescence (OSL) signal of salt (100 mg) demonstrates a robust linear relationship with the salt's irradiation dose within the dose

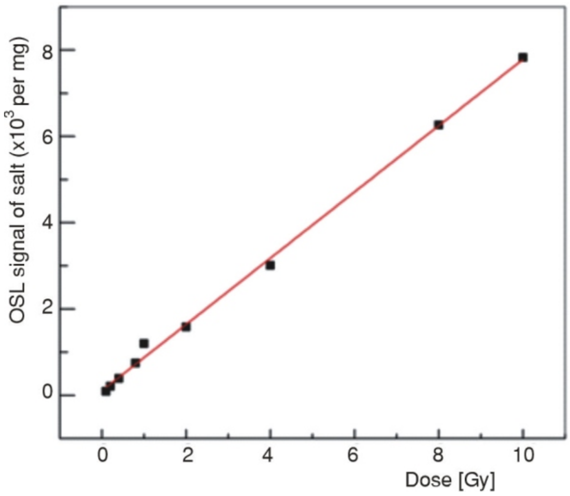

Figure 12. Dose-response curve with a pulse width of 50 ms

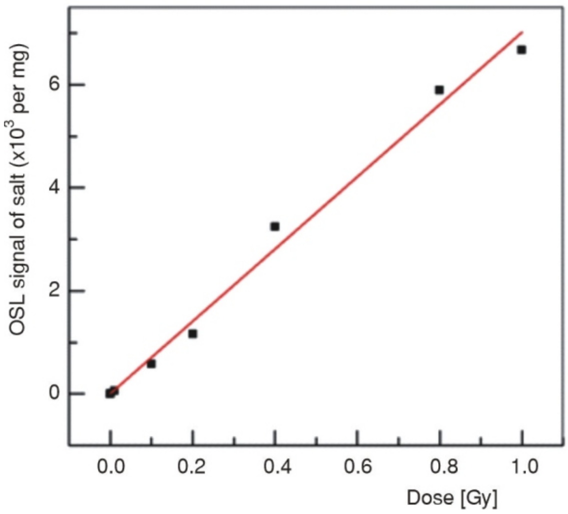

Figure 13. Dose-response curve with a pulse width of 10 ms

range of 0.1 Gy to 10 Gy, as illustrated by the fitting curve in fig. 13 ($R^2 = 0.990$). From the experimental data, it is evident that within the excitation time range of 1~50 ms, it is challenging to find parameters that exhibit a good linear response within the range of 1~10000 mGy. Combining excitation times of 10 ms and 50 ms, however, achieves this objective.

Dose response stability

To verify the stability of the salt photoluminescence signal and the dose-response curve in the case of the optimal parameters of $t_1 = 10$ ms, $t_1 = 50$ ms, and $t_2 = 50$ ms for $n = 50$, the salt was dosed with10 irradiation doses of 2 Gy and 100 mGy, and photoluminescence measurements were conducted. The results are shown in tab. 3. In order to verify the stability of dose response of salt pulsed photoluminescence measurements were performed on 10

Table 3. Photoluminescence signals when the dose of the salt dosimeter is 2 Gy and 100 mGy

Sample	1	2	3	4	5	6	7	8	9	10
2 Gy	2009765	1929278	1725043	1715791	1895583	1853477	1981957	1749602	1907426	1670952
100 mGy	587120	543146	600123	554654	561234	531564	574546	546164	594656	541846

salt dosimeters with irradiation dose of 100 mGy at $t_1 = 10$ ms, $t_2 = 50$ ms, and $n = 50$ and with irradiation dose of 2 Gy at $t_1 = 50$ ms, $t_2 = 50$ ms, $n = 50$. The results are shown in tab. 3. The mean OSL signals of 10 salt dosimeters with irradiation dose of 100 mGy and 2 Gy were 563505 and 1843887.3 with standard deviations of 24218.61 and 114018 and relative deviations of 4.3 % and 6.18 % respectively. The results showed that the salt dose response had good stability under the parameters $t_1 = 10$ ms, $t_2 = 50$ ms, $n = 50$ (100 mGy), and $t_1 = 50$ ms, $t_2 = 50$ ms, $n = 50$ (2 Gy).

Minimum detectable dose

The sample background is important for the determination of the MDD[18]. Therefore, 10 light-annealed salt samples are measured at an excitation time, count time, and pulse number of 10 ms, 50 ms, and 50, respectively. The salt OSL counts are shown in tab. 4. The MDD is determined according to the target to be tested. In this study, to ensure that the relative error of the measurement is less than 10 % and the confidence level is 99.7 %, the MDD can be calculated according to eq. (9)

$$\text{MDD [mGy]} \quad \frac{3\delta\,(\text{counts})}{\int_{t}^{t\;\;t} I_{\text{OSL}}(t)\,\mathrm{d}t\,(\text{counts per mGy})} \qquad (9)$$

where δ is the standard deviation of the background count during integration time t and 3δ is the evaluation value of the MDD at a confidence level of 99.7 %. According to eq. (9), the MDD at an excitation time of 10 ms is 10.56 Gy.

To investigate whether there is a good dose linear response between the minimum detectable lower limit and the lowest irradiation value, the OSL signal is measured for salt dosed with 10, 100, and 1000 μGy. The experimental results are shown in fig. 14, indicating that this method has good dose response relationship in the dose range of 10 μGy~1 mGy.

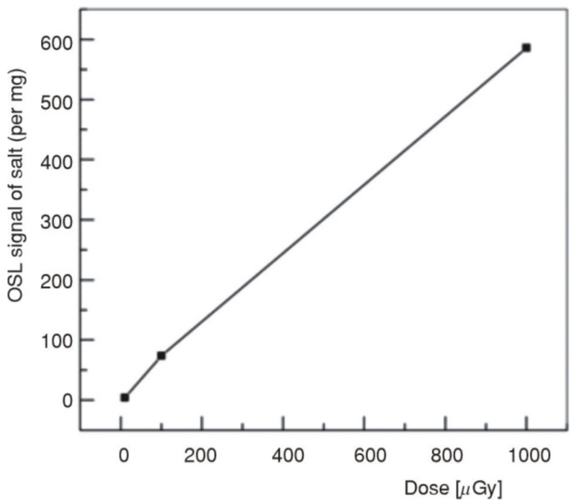

Figure 14. Dose response curve in the dose range of 10~1000 Gy

Factors affecting the salt OSL signal

In some cases, salt is easily stimulated by external factors to release OSL signals, which will result in a decrease in the measured OSL signals, leading to a lower dose that will affect the accuracy of the dose measurements.

Table 4. Salt sample count

Sample	1	2	3	4	5	6	7	8	9	10
Signal	441	449	398	429	434	419	391	476	428	416

Natural lighting

This study is based on the OSL principle to measure the salt OSL signal. Natural and ambient light sources may have an impact on the intensity of the OSL signal released by salt. Therefore, exploring the extent to which natural light affects the salt OSL signal has a guiding role in our experimental measurement process.

For a batch of salt that was light annealed for 1000s and irradiated at 6 mGy, a salt dosimeter with an irradiation dose of 6 mGy was irradiated for 0~180 s by sunlight (sunny day), and salt OSL signal strength measurements were conducted once every 10 s under natural light.

The experimental results are shown in fig. 15. After 120 s of natural light irradiation, the OSL signal decays to the background level. The experiments show that natural light also can stimulate the OSL signal of salt, which will affect our experimental research. To avoid or reduce the effect of natural light, salt samples should be collected in a dark room, and the experiments should also be conducted in a dark room.

Effect of the temperature on the salt OSL signal

To investigate the effect of temperature on the salt OSL signal, a salt dose was preheated before being placed in the salt container, and then the OSL signal was measured. Salt with an irradiation dose of 4 mGy was placed in an annealing furnace for heat treatment. The heating process started at room temperature and continued to the target temperature at a heating rate of 0.5 °Cs^{-1}. The salt sample is removed after remaining

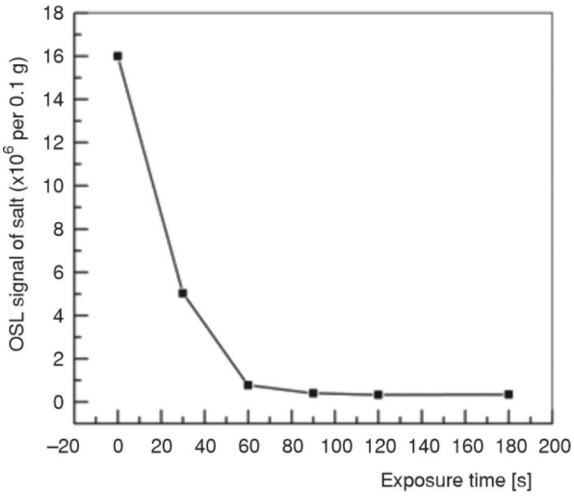

Figure 15. Effect of natural light on the salt photoluminescence signal

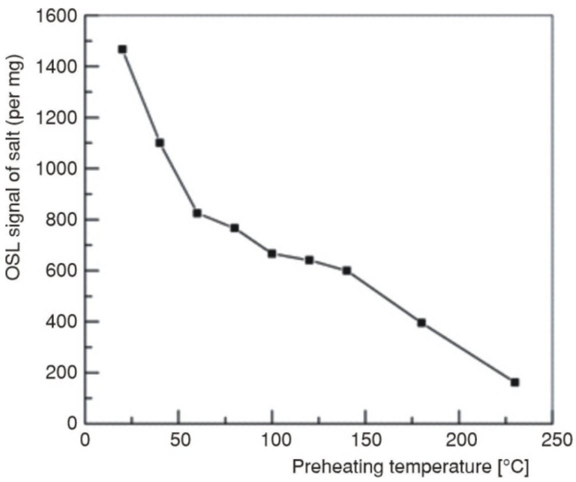

Figure 16. Relationship between the salt OSL signal and the preheating temperature

at the target temperature for 10 s. The preheating temperatures were 20 (room temperature), 40 °C, 60 °C, 100 °C, 120 °C, 140 °C, 180 °C, and 230 °C. The change in the number of OSL signals per mg of salt with the preheating temperature is shown in fig. 16.

The experimental results show that increasing the preheating temperature will attenuate the salt OSL signal, and the higher the temperature is, the more the OSL signal will decay.

Effect of the storage time on the salt OSL signal

Nuclear accidents occur suddenly, but the reinforcement of technical measures takes time. When a nuclear accident occurs, salt samples cannot be collected quickly enough. Therefore, it is necessary to explore what happens to the OSL signal intensity of salt after storing the salt for some time.

As such, a salt sample was first annealed for 1000 s and then irradiated with the HXFS-I irradiator at 10 mGy. Finally, the salt was placed in a salt container to prepare the salt dosimeter. The prepared salt dosimeter was placed in a lead chamber for 5, 10, 15, 20, 25, and 30 days, and then the OSL signal intensity of the salt was measured. The four-element salt dosimeter was stored in a dark environment throughout the experiment.

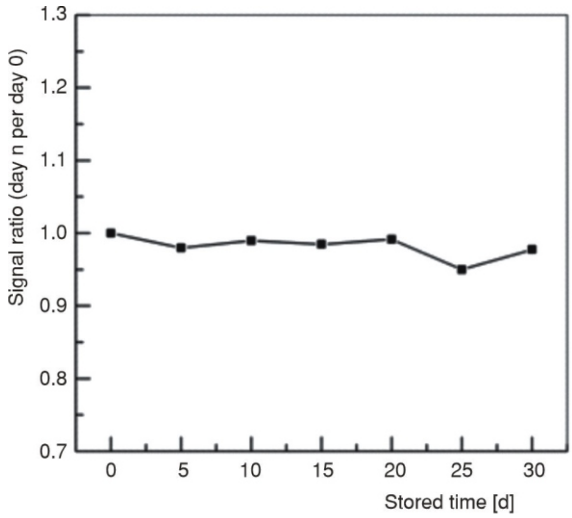

Figure 17. Relationship between the salt signal ratio and storage time

The experimental results are shown in fig. 17. The abscissa is the storage time, and the ordinate is the OSL signal intensity ratio measured after different storage times. The experimental results show that the storage time has little effect on the OSL signal of the salt dosimeter. Within 30 days of placement, the maximum value of the signal reduction is 5 %, which is within the instrument error, and the degree of reduction is negligible.

CONCLUSIONS

This paper reports the use of salt as a detector material and finds that the application of the pulsed photoluminescence measurement technique has the advantage of a controllable excitation frequency. Through exploratory experiments, the following conclusions can be drawn:

- Salt has OSL material characteristics and good radiation dose measurement characteristics. Salt is a good nuclear radiation accident dosimeter. The measurement of the salt OSL signal by the pulsed photoluminescence method involves a short measurement time, a low measurement limit, and a wide measurement range.
- The method of complete excitation of the salt dose information with a long measurement time results in a relatively narrow linear dose-response range, and the partial excitation of the dose information in the salt crystals can reduce the lower limit of the MDD and increase the measurement time and the linear response range of the salt dose.
- The salt photoluminescence signal has good stability during the 30-day storage period, but the signal is eas-

ily affected by natural light and high temperatures. Therefore, experimental measurements should be carried out at room temperature, and the experimental process should be protected from light. Salt samples should be collected in the dark at the accident site.

ACKNOWLEDGEMENTS

This work was supported by the Key scientific research project of the Hunan Provincial Department of Education (grant number: 19A431).

AUTHORS' CONTRIBUTIONS

S. He designed the experiments and wrote the manuscript. S. He, B. Chen, and Y. Ye conducted the experiment and analyzed the data. X. Zhao supervised and revised the manuscript.

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Received on October 4, 2023
Accepted on December 22, 2023

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МЕРЕЊА ПУЛСНЕ ФОТОЛУМИНИСЦЕНЦИЈЕ КОРИШЋЕЊЕМ СОЛИ КАО МАТЕРИЈАЛА ЗА ДЕТЕКТОР ДОЗЕ У РАДИЈАЦИОНОМ АКЦИДЕНТУ

Да би се реализовало ретроспективно мерење нивоа доза у популацији након нуклеарне опасности, проучаване су доза-одговор карактеристике зрачења оптички стимулисане луминисценције соли и одређен је однос између сигнала оптички стимулисане луминесценције и дозе јонизујућег зрачења. Испитани су ефекти природног светла, времена складиштења и температуре предгревања на сигнал оптички стимулисане луминесценције соли. Резултати показују да со као материјал за мерење дозе фотолуминисценцијом има предности погодног узорковања, велике пропусности, кратког времена детекције, широког опсега дозе и ниске границе детекције. Рад представља техничку основу за постизање процене дозе у популацији пулсном фотолуминисценцијом соли.

Кључне речи: пулсна фотолуминисценција, со, радијациони акцидент, доза