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Study on Radiation Dose Monitoring Based on Thermoluminescence Measurement Technology

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Abstract

The development of nuclear science and technology has greatly promoted the development of medical, agricultural, industrial and other industries. However, it is inevitable that more and more radiation safety problems are also accompanied. Accurate measurement of nuclear radiation dose is beneficial to the development of radiation safety. In this paper, based on the Optically Stimulated Luminescence (OSL) technology, the medium and coarse quartz tablets of 38 - 63 μm and 74 - 150 μm were prepared to monitor the air absorbed dose rate, and the three OSL equivalent dosimetry methods of Single-aliquot Regenerative-dose (SAR), Standardized Growth Curve (SGC) and Simplified Multiple Aliquot Regenerative-dose (SMAR) were used to calculate the air absorbed dose rate in the environment where the quartz samples were located. The monitoring results under each measurement condition are compared with the measurement results of the ionization chamber. The results show that: When SAR and SGC equivalent dosimetry methods were used, the dose rate measurement results of medium particle quartz samples were close to those of the air ionization chamber, and the relative errors were −1.91% and −3.62%, respectively, while the relative errors of coarse particle quartz samples were more than 10%. When SMAR equivalent dosimetry method was used, the relative deviation between the measured results of medium and coarse quartz samples and the measured results of the air ionization chamber was more than 30%. Therefore, it is recommended to use 38 - 63 μm medium particle quartz tablets to monitor air absorbed dose rate, and SAR and SGC are more suitable for equivalent dose measurement methods.

Subject Areas

Environmental Chemistry

Keywords

Radiation Monitoring, Photoluminescence, Air Absorbed Dose Rate

1. Introduction

Radiation monitoring types mainly include personal dose monitoring, environmental dose monitoring, etc. [1] [2] [3]. At first, dose monitoring was mostly carried out with the help of an ionization chamber, scintillator detector, solid state nuclear track detector, etc. For employees in the nuclear industry, cumulative dose monitoring can evaluate the total dose received by a person over a period of time. The most widely used tool is the luminescent dosimeter, which is mainly composed of a thermoluminescent dosimeter and a photoluminescent dosimeter. Compared with the thermoluminescent meter, the thermoluminescent meter has the advantages of stability, no heating and strong anti-interference ability. Therefore, more and more environmental monitoring and personal dose monitoring use luminescence dose monitoring [4] [5].

In 1985, Huntley D J *et al.* (Huntley D J *et al.*, 1985) proposed Optically Stimulated Luminescence (OSL) technology as a new method for dating, and the research of OSL technology in radiation dose measurement has developed rapidly. In the 1990s, Akselrod [6] produced α- Al_2O_3: C crystal; after years of research and development, now the main photoluminescent materials are quartz [7], $Li_2B_4O_7$ (Cu, in, Ag, P) [8], α- Al_2O_3: C crystal, etc. Because of the high sensitivity, rapid measurement and reading, and all optical characteristics of the optical luminescent dosimeter, it can be used to accurately measure the dose in radiotherapy. Therefore, OSL technology has been applied in many aspects, such as personal dose and medical dose monitoring for a long time. In addition, for radiation monitoring of nuclear waste, it is also a good choice to use OSL dosimetry system based on a doped glass dosimeter [9]. In 2000, Dusseau *et al.* [10] introduced the design status of an integrated device dosimeter, and demonstrated the feasibility of an integrated dosimeter based on the principle of photoluminescence. In 1990, Yanchou Lu *et al.* [11] Conducted research in the geological field based on OSL technology, marking the beginning of the introduction of OSL technology in China. In 2008, Yanqiu Ding *et al.* [12] Used on-site quartz materials to reconstruct the monitoring dose of a high-dose radiation field environment after a nuclear accident and pointed out that this method is also applicable to dose reconstruction in radiation epidemiological research. In 2009, Chaoyang Chen *et al.* [13] developed a new principle of photoluminescence dosimeter for measuring radiation dose based on OSL materials such as alkaline earth metal sulfide. It can trigger the laser to realize on-line radiation dose measurement and zero clearing, and the operation is convenient and fast. At the same time, they also pointed out that the dosimeter can be used in space dose monitoring due to its small size, low energy consumption and strong response ability, which is of great significance to space dose monitoring. In the same year, Cheng Zhou *et al.* [14] conducted a comparative study of OSL dosimeters and TLD dosimeters of the Tianwan nuclear power plant, which also proved that OSL dosimeters have greater development potential in radiation protection monitoring. In 2013, Hua Chen *et al.* [15] From the China Academy of engineering physics also conducted a comparative study on the performance of thermoluminescence and photoluminescence in personal dose monitoring. The results show that the dose deviation between the two kinds of luminescence technologies and the standard radiation field is controlled within 10%. Both of them can be well applied to personal dose monitoring, but in comparison, the photoluminescence technology has greater development space; once again, it shows the superiority of OSL technology. In 2020, in order to solve many problems existing in traditional detectors, Wenbo Li [16] designed a remote online radiation dose rate monitoring system for personal dose monitoring based on optical fiber and pulse photoluminescence Technology.

With the development and progress of the nuclear industry and the increase of radiation monitoring workload, the traditional radiation monitoring detectors are bulky, vulnerable to electromagnetic interference and poor radiation resistance, which bring a lot of inconvenience to the radiation monitoring work. Photoluminescence technology has become an important part of personal dose monitoring and environmental dose monitoring. For the study of the measurement accuracy of the optical luminescence dosimeter, there are few related applications. At the same time, there are some shortcomings, especially the lack of research on the optimal conditions of the optical luminescence measurement. Therefore, based on the radiation field dose monitoring of quartz photoluminescence technology, the optimal conditions of measurement are discussed, and the quartz particle size and equivalent measurement method are optimized.

2. Material and Methods

2.1. Theory

OSL dating method is developed based on the thermoluminescence (TL) dating method, and their principles are similar. Quartz, feldspar and other minerals with photoluminescence (OSL) properties buried in geological sediments are in a dark environment, and the natural radiation of the surrounding environment α-Rays and γ X-rays will give certain radiation to minerals. When minerals are re-exposed or heated, this radiant energy will be released in the form of light, that is, luminescence signal.

The cumulative radiation energy of minerals increases with the increase of the time that minerals receive radiation and the stronger the luminescence signal of minerals excited by light. Based on this principle, a dose response curve of radiation and luminescence signals with known dose is established for minerals, and the natural luminescence signal is inserted into the dose response curve. Then, the total radiation energy received and accumulated by mineral particles after being buried away from light can be calculated, which is expressed by equivalent dose (D_e). The rate at which mineral particles accumulate signals is expressed in environmental dose rate (annual dose rate) D. The cumulative equivalent dose D_e divided by the annual dose rate D is the length of time that the mineral particles were irradiated after the last exposure, that is, the age since they were buried. The formula is as follows:

$$A = \frac{D_e}{D} \tag{1}$$

The luminescence mechanism of OSL material can be explained by valence band theory, as shown in **Figure 1** below. The energy levels of crystal materials mainly include the conduction band, forbidden band and valence band. When the crystal is subjected to external ionizing radiation (process 1), the electrons in the valence band will be excited into the conduction band (process 2), and the holes will remain in the valence band. The ionized electrons and holes will be captured by the trap energy levels (a shallow trap, B dose trap, C deep trap) in the forbidden band (process 3), and the irradiation dose will be stored. A certain wavelength of light irradiates the photoluminescent material to excite it (process 4), the electrons in the trap transition to the conduction band, and finally, the electrons recombine with the luminescence center in the forbidden band (process 5), emitting a specific wavelength of fluorescence (6). The intensity of the photoluminescent signal is proportional to the dose of radiation storage.

2.2. Instrument

The instrument selected for this experiment is Risø DA20 thermoluminescence/photoluminescence dual-purpose instrument produced by Risø laboratory in Denmark. It is mainly used in archaeological dating, irradiated food testing, personal dose monitoring and other fields, Risø DA20 is characterized in that the process of optical luminescence measurement is controlled by the sequence (program) set by the connected computer, which is fully automatic and programmable, as shown in **Figure 2**. Risø DA20 mainly includes light detection system, irradiation system, Sample tray, thermoluminescence system and photoluminescence system.

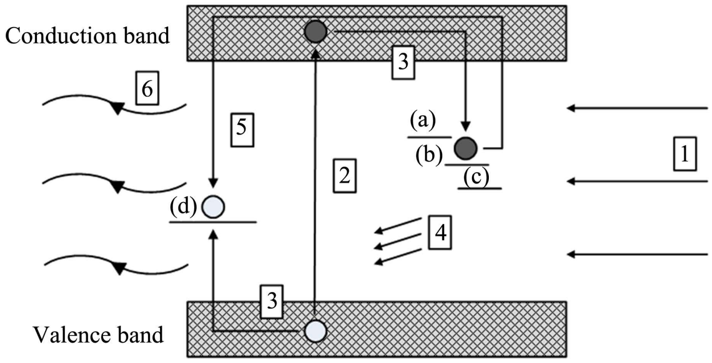

Figure 1. Luminescence mechanism of OSL material.

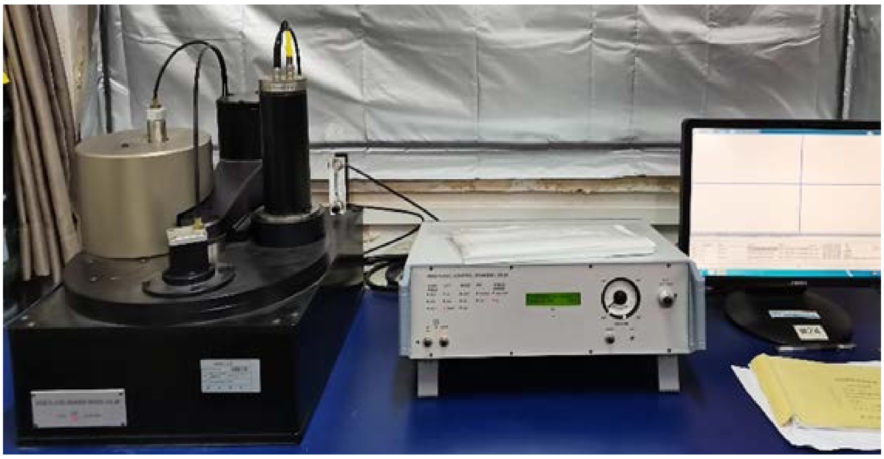

Figure 2. RIS ø DA20 thermoluminescence/photoluminescence dual-purpose instrument.

Light detection system: The light detection system is composed of a photomultiplier tube (PMT) and a filter. The readout instrument is equipped with three different filters at the same time, which can be used alone or in combination to ensure the reading results of different materials under different excitation lights.

Irradiation system: The instrument comes with a ^{90}Sr/^{90}Y β radioactive source, the half-life is 30 years, The dose rate was 0.1 Gy/s, The maximum energy of the ray is 2.27 Mev, the switch is realized by nitrogen gas flow, the inside of the irradiator is a vacuum, the ray irradiates the sample through a beryllium window.

Sample tray: There are 48 positions on the sample disk of the instrument where samples can be placed. However, in the specific experiment, in order to reduce the influence of irradiation, light excitation, etc. on adjacent test pieces, the test pieces shall be separated by at least one position.

The standard RIS ø TL/OSL is equipped with two light excitation sources: the maximum excitation energy of the infrared light source (wavelength: 870 nm) can reach 140 MW/cm^2 or even higher, and can be arbitrarily adjusted between 0% - 100% of the maximum value; The maximum excitation energy of the blue light source (wavelength 470 nm) is not less than 50 MW/cm^2. The measuring principle is shown in Figure 3.

2.3. Equivalent Dose Measurement

The experiment was carried out according to the following scheme. First, before monitoring the site dose rate, quartz samples were irradiated with ^{90}Sr/^{90}Y β radioactive source with different known doses in the laboratory. The dose response curve is established by using the irradiation dose of the quartz test piece and the OSL signal intensity. Then, the pre-prepared quartz measuring piece is used to receive the irradiation and obtain the artificial dose. Finally, the irradiated quartz sample is tested on the machine, and the OSL signal intensity of the artificial dose received by the quartz measuring piece is measured. Then, the irradiation

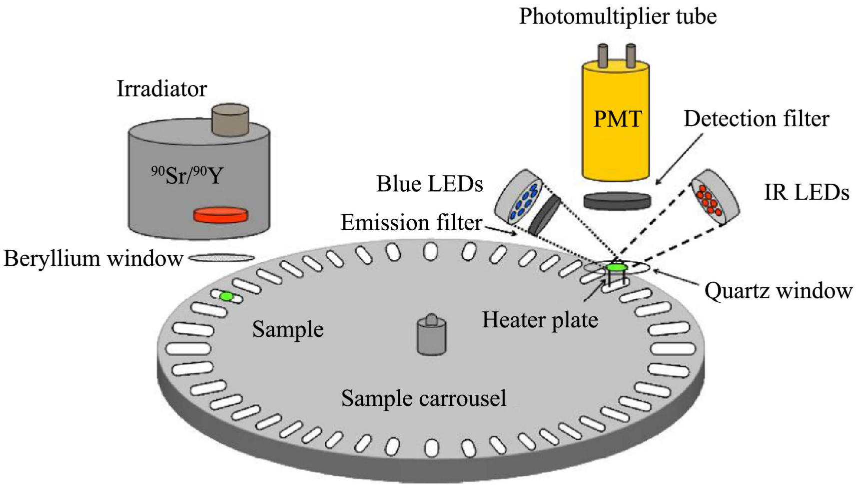

Figure 3. Schematic overview of the reader.

dose rate at the dose site is calculated according to the dose response curve and the irradiation time of the artificial dose received by the quartz measuring piece.

The selection of optimal conditions for radiation dose rate measurement in high dose sites mainly includes the selection of optimal quartz particle size and the selection of optimal equivalent dose measurement method. For the selection of the optimal particle size, 38 - 63 μm Medium grained quartz and 74 - 150 μm Two kinds of quartz particle size; For the selection of the optimal equivalent dose measurement method, this paper sets up three equivalent dose measurement methods: single slice regeneration method, standard growth curve method and simple multi slice regeneration method. The above three methods are used to measure the radiation dose rate of medium and coarse-grained quartz samples. High pressure ionization chamber is used to verify the measurement results, and the equivalent dose rates measured by each method are compared and analyzed. When applied to the radiation dose rates at high dose sites, the quartz photoluminescence measurement technology corresponds to the optimal quartz particle size and the optimal equivalent dose measurement method.

3. Results and Discussions

In order to verify the specific particle size, which measurement method is more suitable for the photoluminescence experiment? The relative errors of SAR, SGC and SMAR equivalent dose measurement methods for medium and coarse particles are discussed by taking the dose rate of the radiation source calculated by high pressure ionization chamber as the reference standard. A comparison of measurement results of medium and coarse-grained quartz is shown in Table 1 and Table 2.

The equivalent dose rate measured by SAR method is slightly higher than that measured by SGC method. Moreover, the equivalent dose rate measured by SAR method is the closest to that measured by ionization chamber, and the relative error between them is only −1.91%. The equivalent dose rate measured by SGC

Table 1. Comparison and analysis of measurement results of medium quartz and ionization chamber.

Method	Medium particle equivalent dose rate (mGy/h)	Ionization chamber measurement results (mGy/h)	relative error
SAR	4.78	4.87	−1.91%
SGC	4.70	4.87	−3.62%
SMAR	6.37	4.87	30.68%

Table 2. Comparison and analysis of measurement results of coarse-grained quartz and ionization chamber.

Method	Medium particle equivalent dose rate (mGy/h)	Ionization chamber measurement results (mGy/h)	relative error
SAR	5.46	4.87	12.02%
SGC	5.39	4.87	10.66%
SMAR	7.82	4.87	60.37%

method is also relatively accurate, and the relative error is only −3.62%. However, the results obtained by the SMAR method are much larger than those measured by the ionization chamber, and the relative error between them is more than 30%. It can be considered that the SMAR method is not recommended to measure the environmental equivalent dose rate under this dose radiation field.

When coarse-grained quartz is selected as the experimental object to measure the equivalent dose rate, the results measured by SAR method and SGC method are slightly larger than those measured by ionization chamber, and the relative errors are 12.02% and 10.66% respectively. When the SMAR method is used, the result is much larger than that measured by the ionization chamber, and the relative error reaches 60%. It is also considered that under this experimental condition, the SMAR method is not recommended to measure the environmental equivalent dose rate.

4. Conclusions

In this paper, the laboratory ^{60}Co γ the environmental dose rate at 0.03 m of the point source is monitored. Medium grain quartz samples with a particle size of 38 - 63 μm and coarse grain quartz samples with a particle size range of 74 - 150 μm are set. Three equivalent dose measurement methods, SAR, SGC and SMAR, are used to monitor the radiation field dose rate of the environment where the quartz samples are located. The high-pressure ionization chamber measurement is used to compare and verify the measurement results of the photoluminescence technology, and the optimal quartz particle size and the optimal equivalent measurement method should be selected in the laboratory radiation field dose range of the photoluminescence technology experiment. Through experimental verification, the main conclusions are as follows:

1) Under each equivalent dose measurement method, the effect of choosing 38 - 63 μm medium grain quartz as the object of the photoluminescence test is better. It is mainly manifested in two aspects: one is that the relative error of the results between different tablets is small; the other is that the measured equivalent dose results are closest to the results measured by the ionization chamber, and the relative error is only −1.91%. The measurement results of coarse-grained quartz with a particle size of 74 - 150 μm are too large and the relative error is large. Therefore, under the same radiation field measurement, it is more suitable for the medium grain quartz sample to be used as the photoluminescence test object.

2) By analyzing the data measured by SAR, SGC and SMAR methods, no matter whether the test object is medium grain quartz or coarse grain quartz, SAR and SGC methods show the closest results to the ionization chamber and the relative error is relatively small. Therefore, under similar experimental conditions, it is recommended to use the SAR method and SGC method to measure the equivalent dose of photoluminescence.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Sighicelli, M., Iocola, I., Pittalis, D., Luglié, A., Padedda, B.M., Pulina, S., Iannetta, M., Menicucci, I., Fiorani, L. and Palucci, A. (2014) An Innovative and High-Speed Technology for Seawater Monitoring of Asinara Gulf (Sardinia-Italy). *Open Journal of Marine Science*, **4**, 31-41. https://doi.org/10.4236/ojms.2014.41005

[2] Stanković-Petrović Jelena, S., Knežević Željka, I., Kržanović Nikola, Lj., Majer Marija, C., Živanović Miloš, Z. and Ciraj-Bjelac Olivera, F. (2021) Review of the Thermoluminescent Dosimetry Method for the Environmental Dose Monitoring. *Nuclear Technology and Radiation Protection*, **36**, 150-162. https://doi.org/10.2298/NTRP2102150S

[3] Susila, I.P., Yuniarto, A. and Cahyana, C. (2017) Monitoring and Analysis of Environmental Gamma Dose Rate Around Serpong Nuclear Complex. *Atom Indonesia*, **43**, 87-92. https://doi.org/10.17146/aij.2017.681

[4] Jensen, M.L., Nyemann, J.S., Muren, L.P., Julsgaard, B., Balling, P., Turtos, R.M. (2022) Optically Stimulated Luminescence in State-of-the-Art LYSO: Ce Scintillators Enables High Spatial Resolution 3D Dose Imaging. *Scientific Reports*, **12**, Article No. 8301. https://doi.org/10.1038/s41598-022-12255-9

[5] McKeever, S.W.S. (2019) An Introduction to Time-Resolved Optically Stimulated Luminescence. *Radiation Protection Dosimetry*, **185**, 542-543. https://doi.org/10.1093/rpd/ncz042

[6] Akselrod, M.S., Kortov, V.S., Kravetsky, D.J., *et al.* (1990) Highly Sensitive Thermoluminescent Anion-Defective α-Al_2O_3: C Single Crystal Detectors. *Radiation Protection Dosimetry*, **32**, 15-20.

[7] Cunningham, A.C. and Wallinga, J. (2010) Selection of Integration Time Intervals

for Quartz OSL Decay Curves. *Quaternary Geochronology*, **5**, 657-666. https://doi.org/10.1016/j.quageo.2010.08.004

[8] Palan, C.B., Chauhan, A.O., Sawala, N.S., Bajaj, N.S. and Omanwar, S.K. (2016) Synthesis and Preliminary TL/OSL Properties of $Li_2B_4O_7$: Cu-Ag Phosphor for Radiation Dosimetry. *Optik*, **127**, 6419-6423. https://doi.org/10.1016/j.ijleo.2016.04.128

[9] Huntley, D.J., Godfrey-Smith, D.I. and Thewalt, M. L.W. (1985) Optical Dating of Sediments. *Nature*, **313**, 105-107. https://doi.org/10.1038/313105a0

[10] Dusseau, L., Plattard, D., Vaillé, J.R., Polge, G., Ranchoux, G., Saigné, F., Fesquet, J., Ecoffet, R. and Gasiot, J. (2000) An Integrated Sensor Using Optically Stimulated Luminescence for In-Flight Dosimetry. *IEEE Transactions on Nuclear Science*, **47**, 2412-2416. https://doi.org/10.1109/23.903785

[11] Lu, Y.C. (1990) Brief Introduction of OSL Dating of Sediments. *Earth and Environment*, **18**, 36-40.

[12] Ding, Y.Q., Dai, G.F., Yuan, S.Y., Fan, Y.G. and Zhang, L.A. (2008) The Study on Method of Pre-Dose Technique in Nuclear Accident Dose Reconstruction. *Chinese Journal of Radiological Health*, **17**, 393-395.

[13] Chen, Z.Y., Fan, Y.W., Ba, W.Z., Liu, Q.J., Liu, Y.P., Tang, X.Q. and Guo, Q. (2009) Study on Measurement Method of Photoluminescence Radiation Dose. *Progress Report on China Nuclear Science & Technology,* **1**, 251-259.

[14] Zhou, C., Chui, Y. and Sheng, L.Y. (2009) Application of OSL Dosimeter in Radiation Protection Monitoring. *Radiation Protection*, **29**, 55-59.

[15] Cheng, H., Mu, L., Tu, J., Yuan, Y.G., Zhao, L., Zhao, M.Z. and Wei, F.H. (2013) Comparison of Thermoluminescence and Photoluminescence in personal Dose Monitoring, *Proceedings of* 2013 *Academic Annual Meeting of China Occupational Safety and Health Association*, Fuzhou, 24 October 2013, 656-660.

[16] Li, W.B., Liu, D.F., Shen, M.M., Wu, R.J., Li, X.L. and Deng, W.H. (2020) Study of Radiation Monitoring System Based on Fiber and Pulsed-OSL Technology. *Nuclear Techniques*, **43**, 49-56.