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LITERATURE STUDY: SENSITIVITY AND ENERGY DEPENDENCE OF THERMOLUMINESENCE DOSIMETER $CaSO_4$:Dy AGAINST RADIATION

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ABSTRACT

This literature study examines the sensitivity and energy dependence of the thermoluminescence dosimeter $CaSO_4$:Dy in radiation measurements. Several scientific articles were analyzed to review the sensitivity and energy dependence. The study's results showed that $CaSO_4$:Dy has high sensitivity against various types of radiation, such as β-rays, γ-rays, and x-rays. TLD $CaSO_4$:Dy can detect doses as low as 24. Thermal treatment and doping addition can also enhance the resulting TL response. TLD $CaSO_4$:Dy has a high energy dependence, especially at low energies; the lower the energy, the lower the response accuracy. The energy dependence shows stability at ≥200 keV.

Keywords: Ionizing Radiation, TLD, $CaSO_4$:Dy, Sensitivity, Energy Dependence

INTRODUCTION

Radiation is the energy released from waves or particles from a radioactive source or substance (Fuadi et al., 2022). radiation includes the electromagnetic spectrum and known atomic and subatomic particles (Tsoulfanidis & Landsberger, 2021). Radiation is the emission or transfer of energy that can travel through space or matter through waves or particles. Radiation can penetrate various materials and is divided into ionizing and non-ionizing radiation, according to the energy of the particles released. Ionizing radiation is produced by radioactive decay, nuclear fission, fusion, very hot objects, and particle accelerators. Familiar sources of ionizing radiation come from radioactive substances that emit alpha (α), beta (β), or gamma (γ) (Acherar, 2024; Karmaker et al., 2021). Radiation—ionizing radiation sources are widely used in various fields of research and industry, such as Cs-137, Sr-90, Co-60, and X-rays.

There are three classifications of ionizing radiation exposure established by the ICRP, namely occupational, public, and medical exposures, where the application of dose limitations only applies to occupational and public exposures (ICRP, 2007; Rahman et al., 2020). Ionizing radiation requires supervision, especially regarding the source, type, nature, effects, and how to avoid it (Ramadhani et al., 2023). Ionizing radiation has the potential to cause adverse effects on workers, patients, and the public. Radiation protection is crucial in controlling these adverse impacts (Fuadi et al., 2022). Radiation measuring instruments act as radiation protection by providing radiation dose information (Christianti, 2018).

Based on the Regulation of the Head of the Nuclear Energy Regulatory Agency No. 8 of 2011, radiation protection is the steps taken to reduce the adverse effects of radiation resulting from radiation exposure. The use of nuclear energy must be carefully monitored to comply with all regulations relating to nuclear energy safety and not cause radiation hazards to radiation workers, the community, and the environment (BAPETEN, 2011; Pratiwi et al., 2021). Various radiation monitoring tools are used to support this monitoring, including a personal dosimeter.

The concept of dosimetry and the definition of dose used for protection against external sources of radiation have been established by the International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU). Radiation protection through dosimetry is crucial to understanding the radiation dose received by radiation workers while carrying out their duties, the amount of radiation released into the environment, and the radiation dose used for therapy in cancer treatment (Hiswara & Darmawati, 2024; ICRP, 2007).

Three types of personal dosimeters are widely used today, including pocket dosimeters (pen/pocket dosimeters), film badges, and thermoluminescence dosimeters (TLD) (Hernawan et al., 2016). TLD is a personal dosimeter utilized for measuring doses of gamma, X-ray, beta radiation, and neutrons (Aslam et al., 2015). These TLDs utilize thermoluminescent inorganic crystals, such as LiF and CaSO4 materials (Ajiz et al., 2015). The advantages of TLD include ease of operation, the ability to monitor various radiation dose levels, repeated use, and resistance to environmental factors. However, the disadvantage is that the dose data will be lost after the reading process, so it is impossible to re-verify if there is doubt in the results (Widhianasari et al., 2022).

One of the TLD materials that is widely used is $CaSO_4$:Dy. Sensitivity and energy dependence must be reviewed as a dosimeter material to ensure reliability and accuracy in measuring ionizing radiation. Sensitivity is crucial in dosimetry, especially for dose monitoring in individuals or personal dosimetry, because the dose received is usually minimal to moderate. So, a dosimeter with high sensitivity is needed to detect the dose accurately (Mianji & Baradaran, 2016). Meanwhile, energy dependence is the variation of TL response at a specific dose that depends on energy and is very crucial in medical dosimetry. Therefore, the absorption and scattering of radiation in the dosimeter must be similar to the material whose dose will be measured (Rivera, 2012).

The purpose of this literature study is to evaluate and summarize research results related to the sensitivity and energy dependence of material $CaSO_4$:Dy.

RESEARCH METHOD

This study uses a literature review approach, which involves reviewing several scientific journal articles that discuss the sensitivity and energy dependence of TLD $CaSO_4$:Dy. This method assesses the extent of available knowledge on a particular topic and aims to identify, evaluate, and summarize the results of previous research to obtain a comprehensive understanding of the topic being studied (Snyder, 2019).

Journal articles were collected from various online databases such as Google Scholar, Science Direct, Research Gate, Publish or Perish, and so on. The search was conducted using keywords such as "Ionizing Radiation," "TLD $CaSO_4$:Dy," "Sensitivity," and "energy dependence." The collected articles were then reviewed in a structured manner, namely by paying attention to the main topic, the purpose of each study, the methods used, and the results and conclusions presented. (Aveyard & Jones, 2019). This review was conducted to obtain a general overview and development of research related to the studied topic.

The results of this study will be presented in tabular form. The table is arranged to facilitate information delivery and support understanding of the research development on the sensitivity and energy dependence of TLD $CaSO_4$:Dy against radiation.

RESULT AND DISCUSSION

This study aims to review various studies that discuss the sensitivity and energy dependence of the TLD $CaSO_4$:Dy. Several relevant journal articles have been analyzed to identify the approaches used, the results obtained, and each study's contribution to understanding the topic studied.

Sensitivity $CaSO_4$:Dy in Radiation Detection

A summary of literature study results on material sensitivity $CaSO_4$:Dy is presented in Table 1 below.

Table 1. Literature Summary on Sensitivity

Authors	Radiation Source	Dose Range	Sensitivity TLD $CaSO_4$:Dy
(Maula et al., 2021)	Sr-90, Cs-137, and X-rays (20–100 keV)	0,3 ; 0,5 ; 1 ; 3 and 5 mSv	Can detect the lowest dose of 24 μSv at 80 keV
(Kartikasari et al., 2018)	Sr-90 and Cs-137	5, 10, 15, 20, and 25 mGy	The highest radiation response sequence is; CaSO4:Dy (Sr-90), CaSO4:Tm (Sr-90, CaSO4:Dy (Cs-137) and CaSO4:Tm (Cs-137)
(Rivera et al., 2010)	Co-60	1 to 30 Gy.	TL intensity is linear to the dose
(Fernández et al., 2016)	X-ray	0,1 to 60 mGy	CaSO4:Dy response 5.6 times higher than TLD-100
(Nuraeni et al., 2017)	Not mentioned	Not mentioned	Sensitivity increases with increasing annealing temperature

Energy Dependence

Table 2 below summarizes the results of literature studies on the energy dependence of materials TLD against radiation such as Cs-137, Sr-90, Co-60, and X-rays.

Table 2. Literature Summary on Energy Dependence

Authors	Radiation Source	Dose Range	Energy Dependence
(Maula et al., 2021)	Sr-90, Cs-137, and X-rays (20–100 keV)	0,3 ; 0,5 ; 1 ; 3 and 5 mSv	High energy, dependence is most problematic at low energies (<200 keV).
(Kartikasari et al., 2018)	Sr-90 and Cs-137	5, 10, 15, 20, and 25 mGy	The synthesized CaSO4:Dy and CaSO4:Tm have higher responses to β-rays than γ-rays.
(Jumpeno et al., 2023)	Cs-137 and X-rays (80 keV)	0.5 ; 1 ; 3 ; 5 and 10 mSv	High linearity, X-ray (R^2 = 0,9987) and Cs-137 (R^2 = 0,9997) (using TLD-100)
(Alanazi et al., 2023)	Cs-137 and X-ray (165 keV)	2, 5, and 10 mSv	TLD-100 shows a relatively higher response than MTS-N when utilizing 10 mSv Cs-137, approximately 25%, and 5 mSv X-rays, about 10%.
(Oktaviani et al., 2023)	Cs-137	5 mSv	The response uniformity falls within a reasonably uniform range, exhibiting considerable variation of 2.25% to 14% (using TLD-100).

(Sadeghi et al., 2015)	Cs-137	81, 162 and 40.5 mGy	Element correction coefficient (ECC) values with an average variation of only 1.5%. All measured ECC values do not exceed the 5% limit, indicating high consistency of the dosimeter response (using TLD-100).
(Nuraeni et al., 2019)	Cs-137 and Sr-90	5, 10, 15, 20 and 25 mGy	The TL response of a β-ray source obtains a higher intensity than that of a γ-ray source.

Discussion

Sensitivity $CaSO_4$:Dy in Radiation Detection

Some literature shows that the material $CaSO_4$:Dy has a high sensitivity to radiation such as ray-β, ray-γ, and X-ray. Studies by Maula et al. (2021) detect the lowest dose response in X-rays (80 keV), which is 24 μSv. The results indicate that $CaSO_4$:Dy exhibits a response that is 5.6 times greater than TLD-100 in low-dose X-ray measurements (Fernández et al., 2016).

The addition of dysprosium (Dy) and thulium (Tm) doping and thermal treatment also contributed significantly to the increase in sensitivity. The rise in TL response from 59.29 nC after irradiation, after the re-annealing process at a temperature of 700°C, 800°C, and 900°C, the sensitivity increased to 66.12 nC, 169.45 nC, and 552.37 nC, respectively (Nuraeni et al., 2017). Similarly, it was revealed that the synthesis via precipitation method yielded two consistent TL peaks at 180°C and 300°C with a linear response up to 30 Gy, making it a promising candidate for medium dose dosimetry (Rivera et al., 2010).

Based on several pieces of literature show that TLD $CaSO_4$:Dy is highly sensitive to various types of radiation, such as β-rays and γ-rays. TLD $CaSO_4$:Dy can detect doses as low as 24 μSv. The resulting TL response can also be increased by thermal treatment and doping addition.

Energy Dependence

TLD $CaSO_4$:Dy has a high energy dependency, especially at low energies. Maula et al. (2021) state that the dosimeter response to radiation changes depending on the amount of radiation energy; the smaller the energy, the less accurate the response. The TLD $CaSO_4$:Dy tested shows an overresponse to low energies. This means that if used for radiation measurements, it can cause overestimation. Energy dependence is most problematic for low energies (<200 keV). Figure 1 shows the normalized values related to the Cs-137 response.

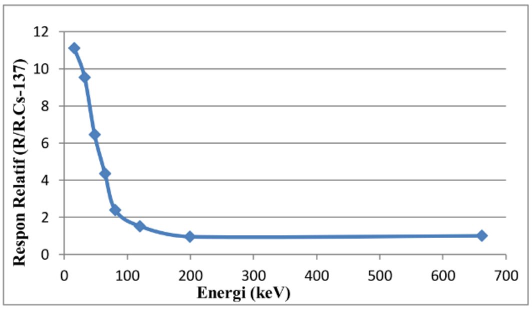

Figure 1. Photon Resource Energy Dependence (Maula et al., 2021)

Studies show that $CaSO_4$:Dy's response to thermoluminescence is highest to Sr-90 radiation, followed by Cs-137 gamma rays (Kartikasari et al., 2018; Nuraeni et al., 2019). This phenomenon is also emphasized in the study of Nazaroh et al. (2017), which shows the variation of TLD response to photon energy from 12.7 to 661.6 keV. TLD shows a strong dependence in the low energy range but still has good linearity with dose.

Linearity and Reproducibility

Some literature also emphasizes the linearity and stability of the TLD response. $CaSO_4$:Dy has a linear response to gamma dose from Cs-137, Co-60, and X-rays (Nazaroh et al., 2017; Rivera et al., 2010). However, signal fading after irradiation must be taken into account. Studies by Jumpeno et al. (2023) obtained fading of 3.6% and 2.7% on the OSL dosimeter with Cs-137 radiation. Meanwhile, fading on 80 kVp X-rays showed 5.9% and 8.8% values for two radiation doses, namely one mSv and 5 mSv.

Oktaviani et al. (2023) and Sadeghi et al. (2015) highlight the significance of uniformity and repeatability in dosimetry systems with Cs-137. The TLD-100 response uniformity values are in the fairly uniform range, with significant variations in the range of 2.25%-14%. TLD-100 shows element correction coefficients (ECC) with an average variation of only 1.5%. $CaSO_4$:Dy generally still requires attention to batch control and recalibration processes. Figure 2 compares the linearity of $CaSO_4$:Dy to some radiation energy.

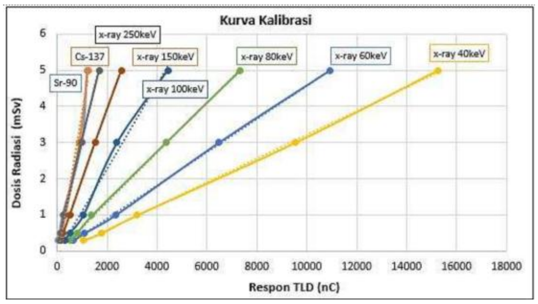

Figure 2. Linearity (Maula et al., 2021)

CONCLUSION AND SUGGESTION

Thermoluminescence dosimetry r$CaSO_4$:Dy has a sensitivity that makes it ideal for adjusting radiation doses, although its dependence on energy variations is quite significant. Based on several reviewed literature, TLD $CaSO_4$:Dy can detect doses as low as 24 μSv, and Energy dependence shows stability at ≥200 keV energy. Therefore, radiation dosimetry requires correction or calibration to ensure the accuracy of the results, especially when used at varying energy spectra.

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