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Radiation Response of Locally Available Glass as Thermoluminescent Detectors

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Abstract: This work used a water-moderated 241Am/Be neutron source, X-ray generator and three different dimensions of commercially available glass beads, classified as small, medium and large glass. The measured source-detector distances and the radiation impacting with angle of elevation on each glass bead from the plane of source are the range of approximately 2.1 ± 0.1 to 21±0.1cm and 15^0 to 80^0 respectively. The gamma sensitivity and linearity of this material was examined to determine suitability of using it as neutron dosimeter. The results are that the three sizes of glass beads show good linear dose response with values of correlation coefficients of 0.995, 0.996 and 0.997 for the large, medium and small sizes of glass beads respectively.

Keyword: Dosimetry, Photoneutrons, Thermoluminescent, Glass beads, 241Am/Be neutron source.

I. INTRODUCTION

Neutron dosimeters are used in various applications such as the clinical, research and industrial sectors. They can be used to measure whole body and skin doses from neutron radiation in both routine and emergency doses. The measurement of neutron is also possible when neutron interactions in the detectors are recorded by the thermoluminescence (TL) they produce. TL detectors have advantages over counters such as portability, low cost and independence from neutron field duty cycle [1]. The choice

of detector will depend on the length of time the neutron field is to be monitored and its intensity [2].

The design of a novel neutron dosimeter for better performance and response to the detection of neutrons produced in medical facilities is important for radiation protection purposes. Photoneutrons produced during medical procedures can have sufficient dose to subject those exposed to long-term adverse effects. It is necessary that this contribution be monitored for accurate reporting (as required by agency regulations) and accurate risk assessment determination. Radiation monitoring instruments should provide the capability to characterize the neutron contribution to personnel and patient exposures [3]. Furthermore, advantages of this detector such as low cost, availability, sensitivity, reusability, inert nature and linearity to radiation dose make them suitable as investigated in therapeutic application [4].

In recent years, research has been carried out on glass beads, with the aim to assess their suitability for use in dosimetry. The investigation into the potential of glass beads as dosimeters in small field photon dosimetry proved promising with the work of Jafari et al [5] revealing the compatibility of their dosimetric properties for radiation detection. The aim of this work is to investigate the thermoluminescent properties of glass beads and their response to neutron dose at varying distance from a water-moderated 241 Am/Be neutron source in order to assess their capability in radiation protection. The objective is to investigate, as closely as possible within laboratory conditions, sensitivity of glass beads to neutron radiation and dose linearity to establish a reliable and accurate TL dosimetry system as a neutron dosimeter.

II. 241Am/BeNEUTRON SOURCE

2.1 Mixed Neutron –Gamma Fields

For the purposes of this study, one of the most frequent (α,n) neutron sources, 241Am/Be, which has a long half-life (432.7 yr) and therefore a reliable constant activity during the long period is used. The americium-241 in the source undergoes nuclear decay to 237-Np by alpha emission, the energetic alpha particle produced knocks out neutrons from the beryllium-9 target as shown in equation 1

$$^{4}_{2}\alpha + ^{9}_{4}\mathrm{Be} \rightarrow ^{12}_{6}C + ^{1}_{0}\mathrm{n} \qquad (1)$$

Additionally, the 241Am/Be neutron source emits low energy photons with energies of 60 keV (almost 36% of decays) and

14 keV (approximately 42% of decays) [6,7].This occurs from both the radioactive source used and from neutron reactions with surrounding materials. Radiation intensity at a distance r cm from an effective point isotropic source of strength S *in* Bq is given by equation 2:

$$I = \phi E = \frac{SE}{4\pi r^2}\ MeV cm^2 s^{-1} \qquad (2)$$

where, ϕ is fluence rate in units of $p\square otons/cm^{-2}/\ s$ and E is total photon energy (in MeV) emitted per disintegration.

The classification of energy of neutrons from an Am/Be source, moderated through water is given in Table 1

Table 1: Major gamma ray interactions observed from the Am/Be water tank.

No	Energy (MeV)	Possible Interaction	Timing relationship with detected fast neutron
1	0.51	Annihilation	Random/Coincidence
2	0.66	137Cs (lab source)	Random
3	2.23	$^{1}H(n,\gamma)\ ^{2}H$	Random
4	3.92	4.4MeV escape peak	Coincidence
5	4.43	De-excitation, 1^{st} excited state 12C.	Coincidence
6	6.13	160 $(n,n)^{16}O^{8}$	Coincidence
7	7.64	56 $Fe(n,7)^{57}Fe$	Random

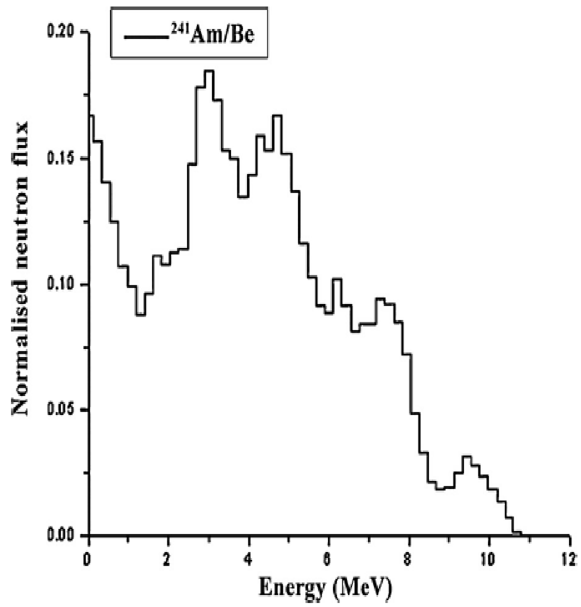

Fig 1: A typical normalized neutron spectrum produced by source Am/Be Cylinder source (Capsule type x.3) [5]

The 241Am has a wide spectra of photons and X-rays (fig. 1), the most significant of which is the 59.6keV peak (4GBq equivalent activity). The remaining photons are either of reasonably low equivalent activity (<100kBq) or low energy (<150keV) [7] and as such can be easily minimised by placing the detectors at a reasonable distance with minimal shielding. The photons produced via neutron reactions within the surrounding materials have been summarised in table 1. The data shows a significant amount of low energy photons present, along with several prominent high energy (>1MeV) photon peaks.

III. METHODOLOGY

(a) CHARACTERISATION OF EXPERIMENTAL SAMPLES

The PIXE/RBS technique as carried out by Jafari*et al* [9] showed elemental composition of glass beads used in this work is shown in Table. 1

Table: 2: The elemental composition of glass beads obtained using the PIXE/RBS technique [9].

Element	Weight (%)	Atomic mass (%)
O	53.18	65.70
Na	10.07	9.05
Si	33.30	23.51
K	1.14	0.60
Ca	2.30	1.14
Total	100.00	100.00

Table 3: Average dimensions of sample used.

Sizes of beads	Diameter (mm) ±0.01	Thickness (mm) ±0.01	Height (mm) ±0.01
Big	2.95	1.74	2.02
Medium	2.15	1.30	1.52
Small	1.57	0.87	1.08

(b) SAMPLE PREPARATION

(i) Sample Cleaning

The preparation of samples started by cleaning off paint and coating materials, the samples with coating materials (fig.3) are mechanically separated in ultrasonic bath. An acidified water containing 20% of nitric acid solution in test tube containing coated samples were placed in ultrasonic bath for 40 minutes and came out with appearance shown in fig.2 (B). The time may be adjusted upwards until the beads are totally cleared of the coating.

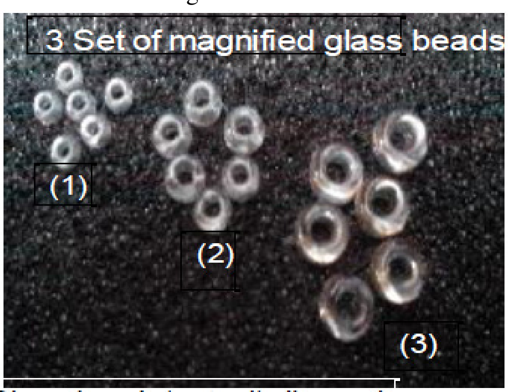

Fig. 2: Classification and dimension of samples as shown in

Fig. 3: Appearance of glass beads after ultrasonic bathing.

(ii) Annealing and TL Read Out

TLD materials require annealing before irradiation to erase any residual signal and to ensure optimum performance for repeat use of detectors by re-establishing a stable concentration of defect centres in the material. The annealing method used in this work started with oven heating of prepared samples to temperature of 400^0C for one hour followed by a longer anneal at a lower temperature of 24 hours at 80^0 C. The samples are then read out after irradiation. The reader was designed such that the read cycle would automatically start when the drawer is closed and the nitrogen supply is active. The temperature of the heating element rises to the temperature at which the sample started emitting light. The light emitted from the sample is recorded by the Photomultiplier tube (PMT). Three session of measurement were performed using the TL reader which was done after irradiation processes with the 241-Am/Be neutron source, X-ray generator and LINAC. The background was derived by repeating the cycle several times until a low consistent reading was reached.

(iii) Irradiation of Samples in Neutron Tank and X Ray Generator.

Samples are carefully arranged on a piece of cotton string that consists of six columns of sizes used in this work and positioned perpendicularly to the source plane. The source is 1 cm from the central axis of the plane containing the samples. The Am/Be sources are typically placed in a water tank such that the high energy neutrons produced isotropically are slowed down to thermal energies through multiple scattering with hydrogen in the water molecules. This occurs over a distance of a few cm (~16cm measured in this work) and generally results in neutron capture through the reaction in which deuterium is formed. In order to quantify the contribution of low energy gamma ray presents in the source, cadmium of 0.50± 0.01 mm thick was to filter neutrons.

A Philips E7252 general x-ray tube was used to irradiate 14 batches of glass beads using a Tingle Medical System generator. The tube had potential of 120 kV was measured under load in each case, with total filtration adjusted to 4 mm of aluminium. A 6cc ion Radical 9095 ion chamber was used to measure the output of the system during the glass beads exposure in full backscatter conditions to mimic the field use of dosimeter. An ionization chamber is recommended for beam calibration for high accuracy and instant readout. Ionization chamber with electrometer was set-up at distance of 1m from X-Ray generator. The dose was read out on electrometer after each irradiation of the sample. The zero reading of the electrometer was noted.

IV. RESULTS AND DISCUSSION

In this study, the detection and measurement of neutrons produced by a water-moderated 241 Am/Be neutron source was measured in glass beads of varying size over varying distances. Water is noted for its effectiveness in stopping neutrons due to its elastic collisions with protons. Fig. 4 shows TL output against dose for 14 batches of glass beads, for each of the three detector types under investigation, during the exposures in the afore-mentioned setups. The result of TL output from these glass beads and their dose linearity show their potential as novel dosimeter.

The mean and standard deviation of the background readings are 25.9 and 18.8 respectively. Appreciable TL output of both large and medium glass beads was observed at an average distance of 14.0 cm while for small glass beads, that distance is 8.0 cm.

The sensitivity of TL materials translates to the linear response over the exposure range in which the application is purposely designed for. 14 batches of glass beads were irradiated to doses from 7.5 to 65990 µGy.

Glass beads were found suitable for dosimetry, given their ability to exhibit dose linearity, as well as to measure dose as low as 7.5 µGy. The value of correlation coefficients obtained from these groups of glass beads are 0.9953, 0.9982 and 0.9977 for the large, medium and small beads respectively fig. 4.

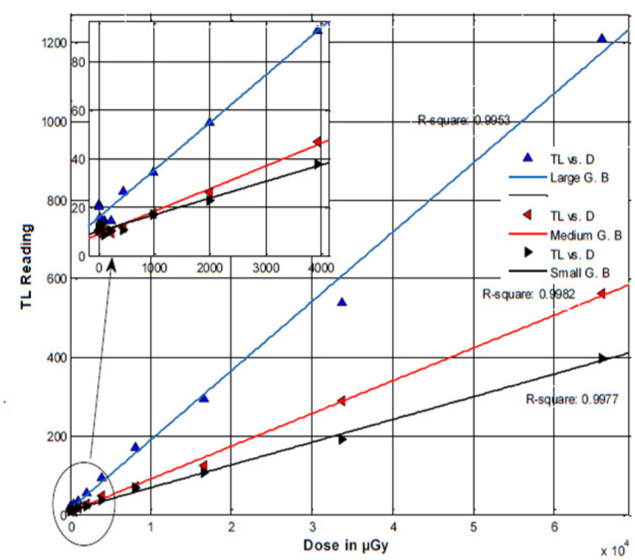

Fig 4: Straight line graphs of TL output against dose for 14 batches of glass beads.

These beads also display a good linear relationship between TL counts and the dose received. Therefore, the TL dose response is linear over a wide range of doses used in medical treatment. The linearity curve of the response of material used was found by plotting the TL output against dose as shown in figure. 4. The light output increases linearly with dose.

In this experiment the range of total corrected TL output between the source and different position of glass beads is 0 - 1181.07. The results are that the three sizes of glass beads show good linear response to doses received for calibration with values of correlation coefficients of 0.995, 0.996 and 0.997 for the large, medium and small sizes of glass beads respectively. Appreciable TL output at average distance of 14.0 cm was detected for both large and medium glass beads while for small glass beads the distance was 8.0cm.

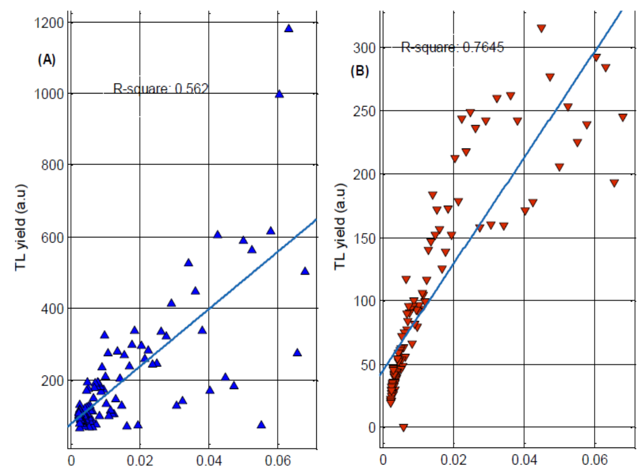

Fig 5: (a) Plot and linear fit of measured corrected TL yield for glass beads (A) with and (b) without cadmium against $1/r^2$

Large beads showed greatest sensitivity as they recorded the largest amount of TL output in the set up with and without cadmium despite being having the largest source detector distance. Therefore the TL yield is proportional to the size of the beads within the scope of this work. The disadvantage may be an increase in statistical noise. The values of correlation coefficients in figure 5(a) and (b) (0.562 and 0.765) show that the inverse square law also contributed to the decrease in originally emitted photoneutron from the 241Am-Be source with distance.

Figure 5 shows the difference in deviation of radiation absorbed by the detectors from inverse square law by both detectors with and without cadmium. The values of correlation coefficients in figure 5(a) and (b) (0.562 and

0.765) show that inverse square law also contributed to the decrease in originally emitted photoneutron from the 241Am-Be source with distance.

The percentage of neutrons absorbed as shown in table 4.1., the mean ratio of TL yield of detectors with and without cadmium as reflected in figure 5(a) and (b), showed better agreement with the inverse square law when covered with cadmium compared to without cadmium, this therefore shows better transmission of gamma rays through cadmium and its efficacy of absorbing incident thermal neutrons. For protection, advantage can be taken of the fact that radiation intensity decreases with distance from the source, varying as the inverse square of the distance.

V. CONCLUSION

Development in the recent innovations and advances in TL materials to enhance radiation detection and measurement has the potential to produce a robust and reliable neutron dosimeter as personal dosimeter and for routine quality control.

This work has probed the feasibility of glass beads as novel neutron dosimeter with a 241 Am/Be source in order to establish it as an effective detector for adequate protection and detection of neutron, photon and secondary radiations produced from neutron generating facilities in active operation.

Glass beads was found suitable for dosimetry judging by their ability to exhibit dose linearity, as well as to measure doses as low as 7.5 µGy. The spectrum of glass response (TL yield) as a function of source detector distance produced in figure.. is in agreement with numerous traps of varying depth of typical TL materials, each representing potentially different energies that may be observed in the glow curve structure when the dosimeter is read out. The major dosimetry peak used in routine dosimetry applications is a peak at a specified temperature.

From these results one can conclude that these materials, kept no further than 16 cm from the source, may be suitable as a novel dosimeter of neutron sources, with average energy of 4.2 MeV. Therefore useful in radiation protection where dose levels of µGy are monitored and as well as in radiotherapy where doses up to several Gray are to be measured [1,11,12]

However, further work in simulations, unmoderated neutron sources and mono-energetic neutron sources are good tools to confirm these conclusions, in particular to determine the dose, fluence and energy of the incident radiation at different locations accurately.

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