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The Development of CaSO4:Dy Dosimeter for the Neutron Surveillance in LINAC with MCNP

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Abstract**—** *The activities done by the medical industry can cause the radiation workers to be exposed to the neutron radiation. Especially cancer therapies that operate the LINAC with the energy above 10 MV that will produce a secondary product in the form of neutrons. The main concern is the type of neutron in the control room which is the thermal neutron. In an attempt to preserve the workers' safety from the neutron radiation risk and the requirement of using neutron dosimeter for each person by BAPETEN, a neutron dosimeter that uses BARC dosimeter with CaSO4:Dy TLD which is added with Gadolinium oxide (Gd2O3) is developed. The used method was the MCNP simulation method with the geometry model input which was customized to the experiment's geometry. Based on the simulation, it was found that the thermal neutron rate was 22.9 µSv/hour with the calibration factor of 2.95 nC/ µSv. As for the detection limit for the Hp (10) bodily dosage neutron dosimeter for each person with CaSO4:Dy TLD was added a coating radiator of Gd2O3 with the thickness of 20 µm for the 95% trust interval in the amount of 0.014 mSv.*

Keywords**—** *Calibration, Dosimeter, Neutron, MCNP, Gadolinium oxide.*

I. INTRODUCTION

Some hospitals that operate LINAC for a cancer therapy increase the chance of the rapid growth modality of a radiotherapy equipment with mega volt energy. Therefore, there is a need to supervise since it produces secondary product in the form of neutrons. These neutrons emerge in the reaction process of photo-neutron and electroneutron reaction [1]. The main concern is the type of neutron in the control room which is the thermal neutron [2]. In an attempt to preserve the radiation workers' safety, BAPETEN obligate the radiation workers to use a neutron dosimeter for each person. However, the first thing the needs to be paid attention to is the existed neutron dosimeter nowadays is only calibrated with the source of Am-Be rapid neutron, meanwhile the majority of radiation workers are exposed to the thermal neutron. Based on the reason above, a neutron dosimeter using $CaSO_4$:Dy TLD with Gadolinium converter which is calibrated with the real condition of the LINAC control room where there is a large part of thermal neutron in it is developed. The neutron spectrum in the entrance of the LINAC control room is shown in the Fig. 1. [3].

Based on a research done by Mukherjee et al., the detection limit of a neutron dosimeter which is modified by using Al_2O_3 TLD and added with Gd_2O_3 is 0.157 mSv [4]. Whereas, according to Arini et al the detection limit of a neutron dosimete made by Harshaw is 0.058 mSv [5]. This research is aiming to count the detection limit and the calibration factor of a dosimeter made by BARC with $CaSO_4$:Dy TLD added with Gd_2O_3 converter which is calibrated appropriate to the real condition of the location suitable with the ISO 12789-1 with MCNP simulation [6]. The choosing of Gd_2O_3 as the neutron converter is because Gadolinium has the trait of high prompt gamma and easy to mold as a thin layer with doctor Blade method. According to Enger, Gadolinium's cross section is 255.000 and prompt [7].

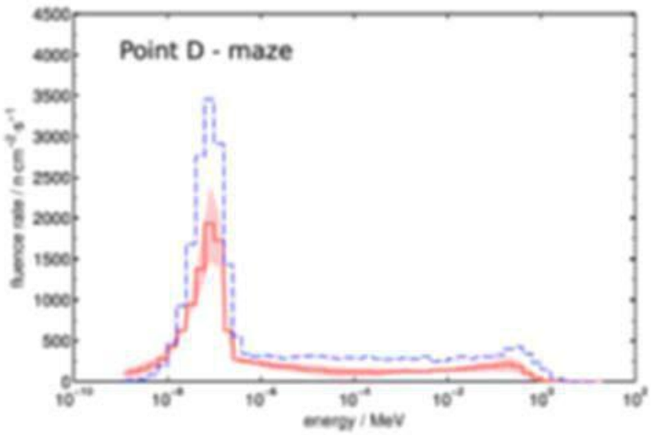

Fig. 1. The neutron spectrum at the LINAC room entrance [3]

TABLE I. Cross-section from several elements

No.	Material	Cross-section (Barn)	Half-life
1	Boron	3.830	Prompt
2	Cadmium	20.000	Prompt
3	Gadolinium	255.000	Prompt
4	Lithium	910	prompt

II. RESEARCH METHOD

This research was done by doing three main steps; preparation, neutron radiation with the various thickness of Gd2O3 thin layers, and MCNP simulation. The preparation step included the process of annealing, uniformity radiating, and TLD grouping. According to Kusumawati et al., TLD annealing is done in the temperature of 230°C for 3 hours so the sensitivity do not drop significantly [8]. Then the uniformity radiation is done to 40 TLDs with the standard radiation source of ^{137}Cs at the distance of 200cm by using solid water phantom with the dosage of 1 mSv. Martin et al.

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stated that the TLD grouping is done based on the sensitivity respond to the uniformity radiation and has the deviation standard no more that 20% [9]. The TLD grouping is plotted into a chart.

Next, a dosimeter made by BARC was modified with CaSO4:Dy TLD added by thin layers of Gd_2O_3. These thin layers of Gd_2O_3 were made by using the doctor Blade method. The layers were made from different sizes of Gd_2O_3 powder; 44 x 10^3 nm – 74 x 10 ^{3} nm (layer A) and 15 nm – 30 nm (layer B). These layers were made with various thickness; 20 µm, 40 µm, 60 µm, and 80 µm for each powder.

After the layers were done, they were then put on the both sides of element iii CaSO4:Dy TLD added with Plumbum (Pb) with the thickness of 1.0 mm on both sides. Then the TLD was put on the phantom made of PMAA with the size of 30 cm x 30 cm x 30 cm and put at the distance of 3 meters from the radiation leak in RSG-GAS to determine the optimal thickness. The design of the thickness variation radiation can be seen in Fig. 2.

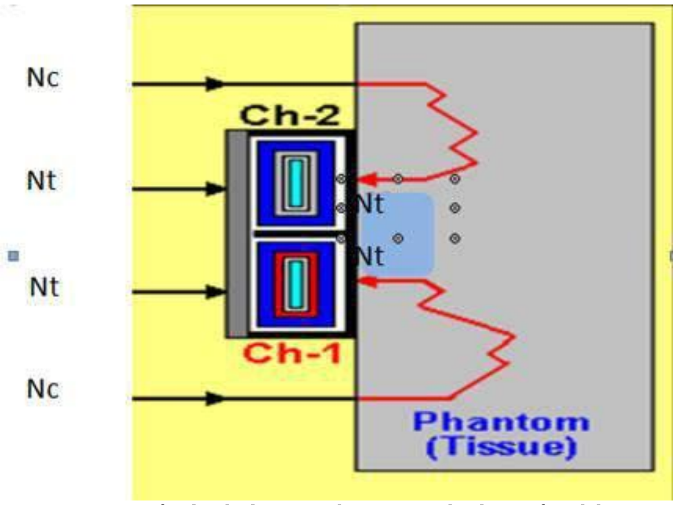

Fig. 2. Design of individual neutron dosimeter with a layer of Gadolinium oxide

Nt is the thermal neutron and Nc is the prompt neutron which when it passes the body tissue, a thermalization process occurs and becomes a thermal neutron. The next step after the optimal thickness is obtained was the MCNP simulation. The simulation using MCNP (Monte Carlo N-Particle) method is to count the dosage in the TLD material and air. There were three steps in MCNP; inputting the data, running process, and output interpreting [10].

Data inputting was done by filling in some cards; cell card, surface card, and data card. A cell card is every part of the object, it can be more than one cell if the material is different and a surface card is geometrical data from each object that will be simulated, while a data card is the information regarding the object's material (mass), source definition (energy, position, coordinate) and tally or the physical quantity that will be counted [11]. The geometrical design from this simulation was by putting $CaSO_4$:Dy TLD added by Gd2O3 converter in the depth of 90 cm in the working space neutron simulation as can be seen in fig. 3.

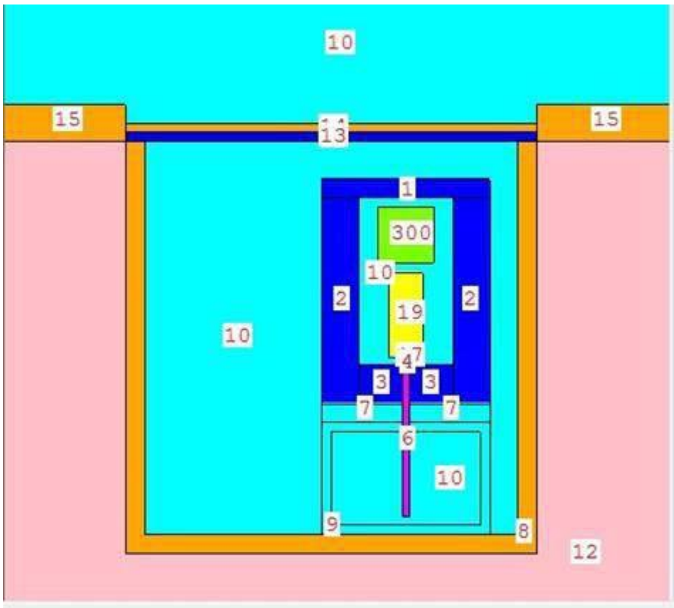

Fig. 3. Neutron dosimeter response simulation design

TLD was put in the 90 cm depth because 90% of the neutron in that depth was the thermal neutron [12]. The neutron calibration factor can be obtained from the simulation result by comparing the average response of CaSO4:Dy TLD towards the photons of 79.5 keV – 182.0 keV energy. The detection limit with the 95% (2σ) trust interval was calculated as in

$$LD_{2\sigma} = 3 + 4,65\sqrt{BG} \quad (1)$$

III. Result and Discussion

Before it was tested for the thickness test, the used TLD was grouped first. The TLD group result on element i and iii is shown by fig. 4 and fig. 5.

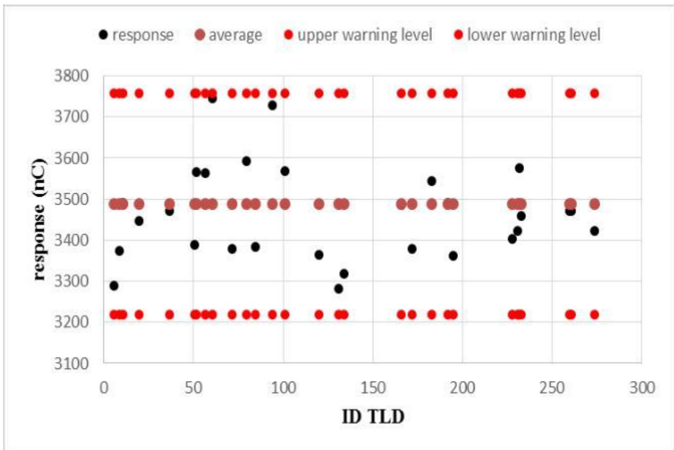

Fig. 4. Uniformity of element i (TLD $CaSO_4$:Dy) response to gamma radiation

All of the response produced by element i and iii were still in between the upper warning limit (UWL) and lower warning limit (LWL) and 4% response variation was obtained. The thickness variation test from two kinds of Gd_2O_3 powder which had different sizes of powder was done in RSG-GAS.

The thickness variation was made from 20 µm, 40 µm, 60 µm, to 80 µm. It was made 4 items for each thickness and put on the front and back side of the element iii $CaSO_4$:Dy TLD. Then the TLD was put on one side on the outside part of the water phantom just like shown in Fig. 6.

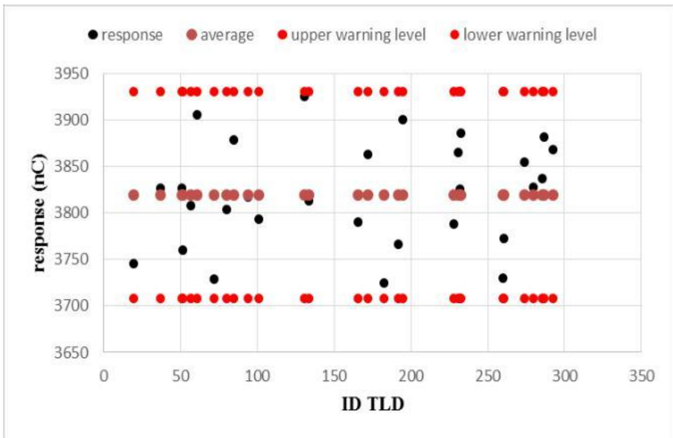

Fig. 5. Uniformity of element iii (TLD $CaSO_4$:Dy) response to gamma radiation

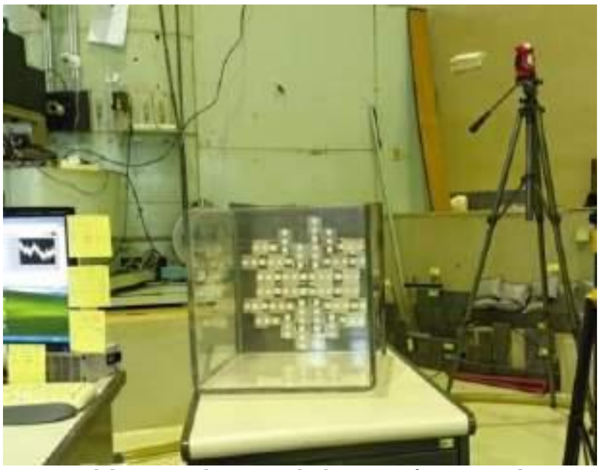

Fig. 6. Gadolinium oxide coating thickness test for neutron dosimeter

From the thickness variation test, it was obtained that the optimal fractional value of the layer A which had the 20 µm thickness with the powder size of 44 x 10^3 nm – 74 x 10^3 nm was 415.5 nC as shown in the Fig. 7.

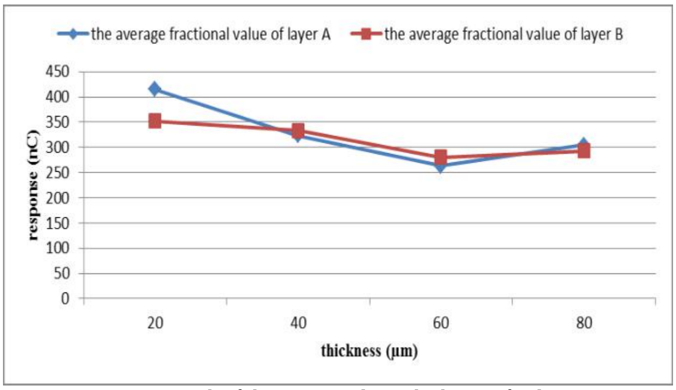

Fig. 7. Graph of the optimum layer thickness of Gd_2O_3

After the optimal thickness was obtained, the next step was to do the simulation by using the Monte Carlo method with a MCNP computer program in a computer with i5 processor, 4GB memory, and Windows 7 operation system. The simulation was done to find the neutron dosimeter response. The neutron dosimeter for each person with Gd_2O_3 converter was put in the front of the water phantom with the size of 30 cm x 30 cm x 30 cm. Then, it was put on the thermal neutron file with 1037 n/cm^2 flux as equal to the dosage rate of 22.9 µSv/hour and the TLD response was obtained which was shown in Table II.

TABLE II. Response of the individual neutron dosimeter with Gd_2O_3 converter

No.	Element of TLD	Dose rate(µSv/hour)
1	(i) TLD	56,5
2	(ii) TLD + Gd_2O_3	79,5
3	(iii) TLD + 2x Gd_2O_3	89,5

From the simulation above, it can be seen that element 1 (E_1) $CaSO_4$:Dy TLD response was the lowest compared to other elements because there were no Gd_2O_3 layers on bots sides, therefore there was no prompt gamma from the Gd_2O_3 layer. For the element 2 (E_2), there was a higher response compared to E_1 because there was a layer of Gd_2O_3 on one of the TLD sides, so it obtained prompt gamma from the Gd_2O_3 layer. For the Element 3 (E_3), the highest response was obtained because there were two Gd_2O_3 layers on both sides of the TLD, so it obtained the highest prompt gamma compared to the other elements. To obtain the pure prompt gamma neutron, it was done by subtracting the reading result of element iii and element i appropriate as in

$$Neutron\ response = E_3 - E_1 \quad (2)$$

Element E1, E2, and E3 from CaSO4:Dy TLD is shown in Fig. 8.

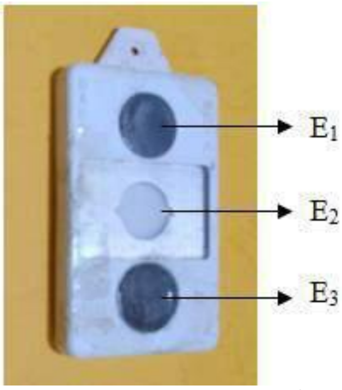

Fig. 8. Component elements E_1, E_2, and E_3 of TLD $CaSO_4$:Dy

From Equation 2, the prompt gamma neutron reading was 33 µSv/hour. According to Kobayashi et al., optimal Gadolinium's prompt gamma in 79.5 keV energy is up to 182 keV [13]. Therefore, if it is converted with the dosage of 33 µSv/hour, it will be equal to 94 ± 11 nC and 41 ± 2 nC and an average response of 67.5 ± 0.5 nC is obtained. To get the calibration factor, simulation dosage rate was compared to the

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actual dosage rate, so the calibration factor of 2.95 nC/μSv was obtained.

The calculation of detection limit (LD) of the neutron dosimeter for each person with CaSO4:Dy TLD added by Gd2O3 converter with the thickness of 20 μm for the trust interval of 95 % (2σ) was calculated by using Equation 1.

Where *BG* was the simulation result reading without the Gd2O3 layer in the amount of 56.5 μSv which was equal with 70 nC, so the detection limit in the amount of 41.9 nC was obtained. The detection limit for Hp (10) bodily dosage needed to be conversed by using Equation 3.

$$LD_{10} = LD_{2\sigma} \times \frac{1}{FK} \quad (3)$$

With the calibration factor of 2.95 nC/μSv, it was obtained the detection limit for Hp (10) bodily usage in the amount of 0.014 mSv. The produced detection limit was lower compared to the previous research because Mukerjee et al. was 0.157 mSv. This is because the used TLD in this research was $CaSO_4$:Dy TLD that had the higher sensitivity to low energy compared to Al_2O_3 TLD:C. The $CaSO_4$:Dy TLD sensitivity compared to the Al_2O_3:C sensitivity is shown in Fig. 9.

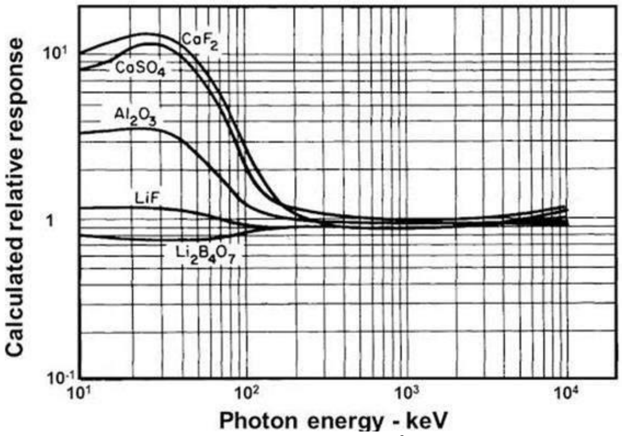

Fig. 9. Low energy response of some TLDs

IV. Conclusion

The $CaSO_4$:Dy dosimeter added with Gadolinium oxide (Gd_2O_3) in the thickness of 20 μm to supervise the neutron in 10MV LINAC with MCNP simulation was successfully developed. The obtained calibration factor from the simulation was 2.95 nC/μSv with the detection limit for Hp (10) bodily dosage in the amount of 0.014 mSv. From these results, the neutron dosimeter which was calibrated in appropriation of the real condition of the room suitable with ISO 12789-1 was obtained. However, these conclusions were obtained from the simulation result. It is hoped that it can be proven by using experiments in the future.

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