The Effect of Lung Tumors Target Movement on Neutron Dose

I Nistiyanti¹, A M Y Putranto¹, F Nugroho ², A Nainggolan³, M Fadli ³, S Liura ³, R Tursinah² and S A Pawiro¹*

¹Department of Physics, Faculty of Mathematics and Natural Science, Universitas Indonesia, Depok, 16424, Indonesia;
²Batan Tenaga Nuklir Nasional (BATAN), Jakarta Selatan, 12440, Indonesia;
³RS Khusus Kanker MRCCC Siloam Semanggi, Jakarta, 12930, Indonesia.

*Corresponding Author E-mail: supriyanto.p@sci.ui.ac.id

Abstract. In radiation therapy, high energy photon above 10 MV could produce neutron. Small dose of neutron can provide biological effect in patient’s body in a long term with high risk. The study aims to recognize the distribution of neutron dose for the moving and non-moving target of tumor. Neutron dose was measured by using TLD 600(LiF: Mg,Ti) and TLD 100 (LiF: Mg,Ti) in tumor target and spinal cord as organs at risk (OAR). The study used In-House Dynamic Thorax phantom movable in translation and rotation within the amplitude of 5, 10, and 15 mm. Phantom was irradiated by the techniques of 3DCRT, IMRT, and VMAT using 15 MV. The result by calculation using thermal calibration factor shows that the average of distribution the neutron dose of tumor target was increase caused by the amplitude movements. On the technique 3DCRT, the dose of neutron increased by 9%, 34%, 68% respectively on the amplitude movements of 5, 10, and 15 mm, whereas increased by 2%, 25%, 70% respectively on the amplitude movements for IMRT techniques. Moreover, on the VMAT technique, it also increased by 3%, 8%, 54% respectively on the amplitude movements. The result of study shows that the distribution of neutron dose of tumor target and spinal cord increase with the amplitude increment and VMAT technique provided the highest dose of neutron compared to other techniques of irradiation.

1. Introduction

One of the cancer treatment is radiotherapy with high photon energy using medical Linac accelerator (Linac). High energy of Linac with the energy of more than 8 MeV, produces secondary particle as neutron. Photoneutron is produced especially by reaction ($\gamma$, n) when the high x-ray interact with high Z material from the Linac’s head, such as lead (Pb) used in collimator shield, Tungsten (W) (used for producing X-ray) and iron (Fe) in Linac’s head [1]. In radiotherapy, thermal and fast neutron radiation contaminate and contribute the patient’s dose during the cancer treatment [2]. The study carried out by Martinez et al., (2011) and Chibani (2003) shows that there is no difference between fast and thermal neutron when the irradiation is carried out [3, 4] but most of the fast neutron produced, would scattered and few of them were absorbed by gas atoms in the air. Therefore, the fast neutron resulted by Linac would scattered on the patient’s body. So, it experienced moderation and thermalization as the consequence of interaction with body’s atoms become low energy thermal neutron-as such in literature [3] fast neutron experienced elastic collision with hydrogen, and then it would lose the energy and
become thermal neutron by the depth of 4 to 4.5 cm in the phantom. Then, the thermal neutron capture becomes dominant and the neutron dose decreases with the depth.

Previous researchers have reported that there is contribution of neutron dose on irradiation using Linac with energy photon (more than 6 MV). The evaluation of neutron dose distribution on the technique of IMRT with energy 15 MV shows that the measurement result for lung target by 5.7 µSv/µm [5]. The research of Khalid et al (2010) based on phantom study to simulate the cancer of bladder on the irradiation of energy photon beam of 15 MV shows that the neutron dose distribution was able to provide thermal neutron dose on the target by 0.012 Sv. While on organ at risk around the target, the neutron dose was obtained by 0.11 mSv/Gy [6]. The research carried out by Halg et al., (2014) using random phantom to measure the dose on the lungs with various techniques shows that the neutron dose were 41 µSv/ Gy with 3DCRT technique and 56 µSv/ Gy with IMRT technique on the irradiation using the unit of Variant 15 MV [7]. Besides, Alkaniotie et al., (2016) shows the the neutron dose was 0.24 ± 0.02 mSv/ Mu on thermal neutron dose measurement using anthropomorphic of 15 MV[8]. In addition, the effect of organ movement could provide difference of dose distribution.

Mukhlisin et al., (2015) reported that there are different photon dose distribution on static and dynamic target using the technique of IMRT and VMAT 6MV of the lung cases [9]. Therefore, the study investigated the neutron dose distribution in both moving and non-moving target on Lung Cancer.

2. Material and Method

2.1 Calibration of TLD

The neutron dose was measured by using TLD 100 LiF: Mg, Ti and TLD 600 LiF: Mg, Ti with the chip dimension by 3.17 × 3.17 × 0.89 mm³. The first step is testing the responses of TLD grouping through irradiation of gamma by ¹³⁷Cs with the dose of 5 mSv with the rate of equivalent dose of ¹³⁷Cs obtained from the output of calibrator OB-85 at PTKMR-BATAN. The rate of dose is 31.868 mSv/hour at 100 cm with the irradiation duration of 9 minutes 5 seconds. The annealing TLD is conducted before the measurement performed with high temperature, 400 °C. TLD reading uses TLD reader Harshaw 3500 with dimension of 31× 32× 47 cm³ (Thermo Scientific Reader). Then, the calibration of TLD involves gamma and neutron sources. TLD calibration for gamma beam uses the gamma source of ⁶⁰Co with dose of 500 mGy and dose rate of 81.39 mGy/minutes. The duration of irradiation spend 6 minutes 11 seconds and it is performed under the water phantom of 30 × 30 × 30 cm³ and the radiation field on the surface of water phantom of 10 cm × 10 cm with the depth of 5 cm and SSD of 100 cm. The result of calibration is used as correction factor of gamma towards the reading of gamma radiation response for TLD 100 on neutron irradiation. Meanwhile, the calibration of neutron source, TLD is irradiated by the source of ²⁵²Cf. To recognize the response of TLD dosimetry in energy neutron thermal, the source of ²⁵²Cf is moderated with a graphite of 91.5 cm × 80 cm × 104 cm. Then behind the graphite, there is a polyethylene with the size of 90 cm × 30 cm × 90 cm. TLD was put on the PMMA phantom with the size of radiation field of 30 cm × 30 cm × 15 cm with 1 meter distance from the source of neutron. Then, thermal neutron file is obtained. The calibration result is used to recognize the response of TLD towards neutron beam. The calibration shows the relationship of dose and the value of response reading of TLD 600 towards neutron that will be used to estimate the neutron dose in Linac irradiation.

2.2 Irradiation of In-House Dynamic Thorax Phantom

Irradiation is carried out by the in-house dynamic thorax phantom for NSCLC for lung cancer cases. Phantom irradiation uses X-ray 15 MV by using techniques of 3D CRT, IMRT, and VMAT on the unit of Variant Rapid Arc (Variant Medical System, Palo Alto, CA). The technique of 3DCRT uses 3 radiation fields; IMRT technique uses 5 radiation field; and VMAT technique uses RapidArc double
Figure 1. Flow chart of the measurement.

Phantom is able to move in translation (SI) and rotational (LR) using amplitude of 5, 10, and 15 mm. The composition of phantom material consists of acrylic PMMA that simulates the soft tissue; Cork simulating the lung tissue; and Teflon simulating the spinal cord. The study describes that the non small cell of lung cancer (NSCLC) is given the prescribed dose of 200cGy in each irradiation by Linac.

2.3 The Analysis of Neutron Dose

There were three steps to analyze the neutron dose on the target of lung tumors and spinal cord. First, the comparison of gamma radiation response value between TLD 600 and TLD 100 was used as the reading correction. Gamma correction factor was calculated by the following equation,

\[ f_k = \frac{R_{600}}{R_{100}} \]  \hspace{1cm} (1)

\( f_k \) is the gamma correction factor; \( R_{100(\gamma)} \) is gamma response of TLD 100; and \( R_{600(\gamma,n)} \) is gamma response of TLD 600 towards neutron used to estimate neutron dose value on Linac irradiation. Second, neutron calibration factor was determined by:

\[ f_{Kal} = \frac{D}{R_n (nC)} \]  \hspace{1cm} (2)

\( f_{Kal} \) is neutron calibration factor; \( D \) is the dose of the irradiation using \( ^{252}\text{Cf} \); and \( R_n (nC) \) is TLD 600 reading. Last, radiation response produced by TLD 600 was subtracted by the radiation response value produced by TLD100 that has been multiplied by the calibration factor on the irradiation of radiation source \( ^{252}\text{Cf} \), which was calculated by the following equation,

\[ R_n = R_{600(\gamma,n)} - R_{100(\gamma)} \times f_k \]  \hspace{1cm} (3)

\[ D_n = R_n \times f_{Kal} \]  \hspace{1cm} (4)
\( R_n \) is a neutron reading; \( R_{600}(\gamma, n) \) is response of TLD 600; \( R_{100}(\gamma) \) is response of TLD 100; \( f_k \) gamma correction factor; \( D_n \) is neutron equivalent dose; and \( f_{Kal} \) is calibration factor.

3. Results and Discussions
The responses of radiation of TLD 600 and 100 grouped were able to be used to minimize the mistakes because of the sensitivity of TLD. The responses of TLD were shown on the Table 1. The data responses obtained from TLD 600 and 100 were sorted from the smallest to the highest data value. The study shows that the similar responses of TLD were grouped so that the sensitivity deviation of TLD was no more three percent (±3%). It meant the good precision and the accuracy in the dosimetry and TLD capability was feasible to be used. Besides that, the gamma correction factor and neutron calibration factor per individual using 27 TLD for TLD 600 and TLD 100 were seen in Figure 2 and 3.

3.1 The Neutron Dose on Variation Technique
Neutron dose on the moving and non-moving target with various techniques of irradiation was displayed on the Figure 4 and 5. The dose difference is caused by the different technique of each dose rate. The more modern technique was given to the target and spinal cord, the highest the dose rate obtained. The dose rate influenced the contribution of neutron from Linac’s scattering so that the neutron’s dose average on VMAT is higher than the technique of 3DCRT and IMRT [7]. The distribution of neutron dose used In-House Dynamic Thoracic phantom with moving and non-moving target. It was displayed on Table 2.

**Table 1.** The result of TLD 600 and TLD 100 grouping.

| TLD 600 Group | The Number of TLD | Average Reading (nC) | TLD 100 Group | The Number of TLD | Average Reading (nC) |
|---------------|-------------------|----------------------|---------------|-------------------|----------------------|
| 1             | 15                | 45 ± 1.4             | 1             | 15                | 36.8 ± 0.8           |
| 2             | 12                | 49.5 ± 1.5           | 2             | 12                | 38.5 ± 0.49          |
| 3             | 6                 | 55.8 ± 0.9           | 3             | 6                 | 40.8 ± 0.36          |
| **Total**     | **33**            | **Total**            | **33**        |                   |                      |

![Figure 2](image1.png)  
*Figure 2.* Gamma Correction Factor using the source of \(^{60}\)Co.

![Figure 3](image2.png)  
*Figure 3.* Neutron calibration factor with the source of \(^{252}\)Cf.
Table 2. Neutron dose in the lung tumor target and spinal cord.

| Amplitude | Target Dose (mSv/Gy) 3DCRT | Target Dose (mSv/Gy) IMRT | Target Dose (mSv/Gy) VMAT | Dose spinal cord (mSv/Gy) 3DCRT | Dose spinal cord (mSv/Gy) IMRT | Dose spinal cord (mSv/Gy) VMAT |
|-----------|-----------------------------|-----------------------------|-----------------------------|---------------------------------|---------------------------------|---------------------------------|
| Static    | 0.482±0.22                  | 0.525±0.14                  | 0.600±0.25                  | 0.013±0.005                     | 0.019±0.011                     | 0.023±0.016                     |
| 5 mm      | 0.529±0.23                  | 0.537±0.18                  | 0.622±0.22                  | 0.015±0.005                     | 0.021±0.010                     | 0.025±0.012                     |
| 10 mm     | 0.649±0.20                  | 0.660±0.34                  | 0.696±0.24                  | 0.017±0.005                     | 0.022±0.011                     | 0.027±0.010                     |
| 15 mm     | 0.812±0.21                  | 0.893±0.30                  | 0.926±0.17                  | 0.019±0.005                     | 0.027±0.015                     | 0.030±0.008                     |

3.2 Neutron Dose of movement effects

The target movement with the amplitude of 5 mm, 10 mm, and 15 mm provided the change of neutron dose value compared to the non-moving target condition. The neutron dose on the 3DCRT technique increased by 9%, 34%, and 68% respectively on the statically amplitude movements with the amplitude of 5 mm, 10 mm, and 15 mm. Then, the neutron dose on the IMRT technique also increased by 2%, 25%, and 70% respectively on the statically amplitude movements. Besides that, the neutron dose on the VMAT technique increased by 3%, 8%, and 54% respectively on the statically amplitude movements. The movement effect could cause randomly neutron interaction probability hitting the lung tumor target on the thoracic phantom.

In OAR, the effect of target movement showed that there was increment in the dose value for the higher amplitude because OAR was placed near to the target. On the 3DCRT technique, the neutron dose got increment 15%, 30%, and 46% respectively on the statically amplitude movements of 5mm, 10mm, and 15mm. Meanwhile, the neutron dose on IMRT technique got increment 10%, 15%, and 42% Besides that on VMAT technique, the neutron dose increased by 8%, 17%, and 30% on the statically amplitude movements. It is important to know that the neutron scattering is statistically probabilistic events. The neutron has neutral content, so it not easy to determine the direction of scattering. The result is the scattering has possibility to hit the issue or organ at risk causing secondary cancer.

Uncertainty in the measurement of high deviation as shown on Table 2 that TLD is not one of good dosimetry for mixed field measurement. Martinez et al. (2011) expressed that the dosimetry of TLD 600 and TLD 100 is not one of reliable tools to investigate the study about patient dose radiated along the Linac tube axis [3]. For all measurements, the uncertainty of neutron dose is large. Triolo et al.
(2007) and Gambarini (1997) also reported that to measure the high energy in the mixed field, such as Linac, inaccuracy of measurement is found out for dosimetry Neutron and Gamma [9, 10].

4. Conclusions
The movement of lung tumor target and spinal cord as organ at risk gives the increasing neutron dose going with the increasing of amplitude. Besides that, the average of neutron dose on VMAT technique is higher than 3DCRT and IMRT techniques.

Acknowledgments
This work was fully funded by DPRM Universitas Indonesia with Hibbah PITTA 2018, Grant no: 2317/UN2.R3.1/HKP 05.00/2018, supported Batan Tenaga Nuklir Nasional (BATAN), Jakarta, Indonesia and RS Khusus Kanker MRCCC Siloam Semanggi, Jakarta, Indonesia.

References
[1] Al Ghamdi, H., R. Fazalur, M. I. Al-Jarallah dan N. Maalej. 2008. Photoneutron intensity variation with field size around radiotheraphy linier accelerator 18 MeV X-ray beam Radiation Measurements. 43: S495-S499.
[2] Gudowska, L., Gudowski, W., Kopec, M..2002. Monte carlo evaluation of neutron contamination in high energy photon therapy beams. In:Proceedings of the 12th Biennial RPSD Topical Meeting, Santa Fe, NM, United States, Radiations Protection and Shielding Division of American Nuclear Society, April 14-18, pp. 652-658.
[3] Martinez Ovalle S.A., Barquero R., Gomez-Ros J.M., LAllena A.M. 2011. Neutron dose equivalent and neutron spectra in tissue for clinical Linacs operating at 15, 18, and 20 MV. Radiat Prot Dosimetry. 147; 498-511.
[4] Chibani O, Ma C.M. 2003. Photonuclear dose calculations for high energy photon beams from Siemens and Varian Linacs. Med Phys. 30; 1990-2000.
[5] Stephen F. KRY, M.S., Mohammad S., PH.D., David S. Followil, PH.D., Marilyn S., PH.D., Deborah A. Kuban, M.D., R. Allen W, PH.D., and Isaac I. R., PH.D., 2005. Out of Field Photon and Neutron Dose Equivalents from Ste and Shoot Intensity Modulated Radiation Theraphy. Int.J Radiation Oncology Biol. Phys., Vol. 62, No. 4, pp. 1204 – 1216.
[6] N.E. Khaled, E.M. Attala, H. Ammar, W. Khalil., 2011. In phantom neutron dose distribution for bladder cancer cases treated with high-energy photons. Radiation Effects & Defect in Solid, Vol. 166, No.6, June 2011, 459-468.
[7] R.A. Halg, J Besserer, M Boschung, S Mayer, A. J. Lomax., and U Schneider., 2014. Measurements of the neutron dose equivalent for various radiation qualities, treatment machines and delivery techniques in radiation theraphy. Physics in Medicine and Biology. 59, 2457-2468.
[8] K Alikaniotiots M. Severgini, G. Giannini and V. Milan. ( 2018). Measurements of the Parasitic Neutron Dose At Organs From Medical Linacs at Differents Energies By Using Bubble Detectors. Radiation Protection Dosimetry, Vol. 180, No. 1–4, pp. 267–272.
[9] Muklisin and S.A. Pawiro., 2016. Dosimetry impact of interplay effect in lung IMRT and VMAT treatment using in- house dynamic thoraks phantom. Journal of physics: Conference series. 694 012009.
[10] Triolo A., Marrale M., Brai M., 2007. Neutron- gamma mixed field measurements by means of MCP- TLD600 dosimeter pair. Nucl Instru Methods Phys Res, 264:183-8.