Study of the Effectiveness of Radiation Retaining Materials for the Entrance of LINAC 6 MV Radiotherapy Room

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Abstract. LINAC radiotherapy devices can produce scattering radiation and leak radiation from the gantry. The doses of scattering radiation result from the scattering radiations from the wall (HST) and the patient (HPS). Gantry leak radiation is gantry leak radiation through the labyrinth hall (HLS) and the one that goes directly to the entrance (HLT). These four components play a role in producing radiation doses at the entrance. The scattering radiation in the LINAC 6 MV radiotherapy installation can spread in all directions. Therefore, there is a need for a special review to examine the scattering radiation to the entrance of the room. The constituent of the radiation retaining wall also influences the reflection coefficient of the wall (α). Therefore, it is important to pay attention to the α value in evaluating the radiation dose at the labyrinth entrance. Radiation protection efforts for radiation workers and the community around the radiotherapy room need to be considered by creating a radiation barrier that can minimize the radiation received. With that in mind, the purpose of this study is to examine several possible materials for radiation shielding, especially at the entrance of the radiotherapy room. Materials used for the entrance are lead (Pb), borated polyethylene (BPE), aluminum (Al), and iron (Fe) with a thickness of 6 mm, respectively. The variation of the reflected angle used in the calculation of HST, HLS, and HPS values starts from an angle of 50° to 80°. The result showed that the most effective material for reducing the amount of radiation is lead with effectiveness of 86.79%.

1. Introduction

The most common external radiotherapy equipment used for cancer treatment is a linear accelerator (LINAC). One of the most frequently used types of external radiotherapy for the treatment of cancer patients is Intensity Modulated Radiation Therapy (IMRT) [1][2]. Compensator-based IMRT is usually used in cancer treatment for the neck and head area [3].

Any equipment using an X-ray will certainly cause scattering radiation. Scattering radiation results from the interaction of radiation with the material, both in the patient and the radiation barrier. Scattering radiation can spread in all directions.

Scattering radiation dose distribution around the LINAC plane shows that the value is inversely proportional to the distance [4][5]. Neutron scattering radiation in a radiotherapy room with the LINAC 18 MV plane also shows that the radiation distance is inversely proportional to the neutron radiation value. That also applies to other types of radiation, such as photons and electrons. The study also reviewed the value of radiation dose at the entrance of a radiotherapy room. The result shows that the radiation dose that has penetrated the entrance is smaller than the one before penetration. It proves that the entrance of a radiotherapy room also acts as a radiation barrier [5].
Another factor that can affect the scattering radiation value is the coefficient value of the radiation reflection on the wall ($\alpha$). The study of the effect of the reflection coefficient of the wall on the environmental radiation in industrial facilities reported that the energy used in the X-ray plane is inversely proportional to the radiation reflection coefficient on the wall. The value of the coefficient will affect the value of environmental radiation [6].

Because the radiation produced from LINAC will scatter around the entrance of the radiotherapy room, it is necessary to calculate the dose reaches to it, and to analyze whether the total dose is still permissible. It is also necessary to determine the addition of a radiation barrier door. The types of material should also be determined based on the properties of each material.

2. Method

This research is a follow up of the study conducted at a Radiotherapy installation that has a LINAC 6 MV plane. The data studied were in the form of environmental doses at the entrance of the radiotherapy room with an Electa Precise LINAC plane with the photon energy of 6 MV. The independent variable applied is the variation of the reflection angle associated with the value of the radiation reflection coefficient on the wall ($\alpha$). The dependent variable is the radiation dose at the entrance of the radiotherapy room with and without the additional materials ($H'_{\text{tot}}$ and $H_{\text{tot}}$).

The total radiation dose at the entrance of the radiotherapy room without radiation barrier is calculated with the following equation [7] [8]:

$$H_{\text{tot}} = 2.64 \left( f H_{S} + H_{LS} + H_{PS} + H_{LT} \right)$$  \hspace{1cm} (1)

where $H_{\text{tot}}$ is the radiation dose at the entrance without the radiation barrier (Sv/week), $H_{S}$ is the scattering radiation from the wall (Sv/week), $f$ is the patient transmission factor for LINAC with the photon energy of 6-10 MeV (0.25), $H_{LS}$ is the radiation from the gantry leak that passes through the labyrinth hall (Sv/week), $H_{PS}$ is the scattering radiation from the patient (Sv/week), and $H_{LT}$ is the radiation from the gantry leak that goes directly to the entrance (Sv/week). However, for the gantry that is parallel to the axis (Fig. 1), the equation is [7][8]:

$$H_{\text{tot}} = 2.64 \left( f H_{ST} + H_{LS} + H_{PS} + H_{LT} \right)$$  \hspace{1cm} (2)

where $H_{ST}$ is the radiation dose of the primary beam transmitted through the wall and further spread through the entrance (Sv/week).

![Figure 1](image1.png)

Figure 1. The scheme of the radiotherapy room with (a) the gantry position is perpendicular to the labyrinth axis and (b) the gantry position is parallel to the labyrinth axis [9].

Figure 2 illustrates the calculation of the radiation dose of the beam ($H_{ST}$) and the calculation of radiation dose due to radiation exposure resulting from the gantry leak passing through the labyrinth.
hall ($H_{LS}$). Figure 3 illustrates the radiation exposure resulting from the scattering from the patient ($H_{PS}$) and radiation exposure resulting from the gantry leak that goes directly to the entrance ($H_{LT}$).

![Figure 2](image1)

**Figure 2.** The scheme of variable measurement in calculating $H_{ST}$ (a) and $H_{LS}$ (b).

![Figure 3](image2)

**Figure 3.** The scheme of variable measurement in calculating $H_{ST}$ (a) and $H_{LS}$ (b).

After all the dose values obtained, the total dose at the entrance of the radiotherapy room would be yielded using equation (2) or equation (3). Furthermore, the total dose of the entrance with the additional materials would be calculated using the material density values. The next step is to analyze whether the dose produced at the entrance is under the permitted value. The final step is to determine the most effective material used to reduce the radiation dose at the entrance of the radiotherapy room.

3. Results and Discussi

3.1 The total radiation dose at the entrance without radiation barrier door ($H_{nt}$)

The reflection angle variation used in the calculation of the $H_{ST}$, $H_{LS}$, and $H_{PS}$ starts from an angle of 50° to 80°. The variation was chosen because at a reflection angle of 50° to 80° the radiation dose
would be exactly at the entrance. At the radiation reflection angle of less than 50° and more than 80°, the radiation dose would return to the wall. The values of $H_{LS}$, $H_{PS}$, dan $H_{ST}$ depend on the radiation reflection angle, as shown in Figure 4. The graph shows that the greatest radiation dose of $H_{LS}$, $H_{PS}$ dan $H_{ST}$ are at the reflection angle of 50° and decreases as the reflection angle increases.

**Figure 4.** Graphs of the relationship between the reflection angle and $H_{LS}$, $H_{PS}$, and $H_{ST}$

Figure 4 shows that $H_{ST}$, $H_{LS}$, and $H_{PS}$ have the same trend. The highest doses occur at the angle of 50° and decrease with the increasing angles. The radiation dose originating from the wall scattering (HST) has the largest dose value compared to other components that producing radiation doses at the entrance.

The radiation dose of the gantry leak in the labyrinth hall ($H_{LS}$) comes from the main radiation source that leaks from the gantry head and hits the hallway wall and is reflected towards the entrance. The amount of the first reflected radiation emanating from the gantry head leak is considered as a radiation source of 1.4 MV for the 6 MV LINAC plane. This is due to the radiation attenuation at the gantry head, resulting in the reduced radiation energy from the original energy. The patient scattering radiation dose ($H_{PS}$) is the main radiation beam that hits the patient and then attenuates and undergo energy decrease. Consequently, the amount of radiation emanating from the patient scattering is considered as a radiation source with the energy of 0.5 MeV for the 6 MV LINAC plane. The attenuated radiation further hits the wall and is reflected towards the entrance.

The dose limit value used at the entrance is the dose limit for general public, which is 1 mSv ($10^{-3}$ Sv) per year, or $2 \times 10^{-5}$ Sv per week. The value of $H_{tot}$ is calculated using the equation (2). Table 1 shows that the radiation dose value at the entrance without the radiation barrier door ($H_{tot}$) is far below the Dose Limit Value determined by Chief Regulatory of Nuclear Power Supervisory Body (Perka BAPETEN) no. 3, 2013, which is $2 \times 10^{-5}$ Sv per week [10].

**Table 1.** The result of the Total Dose Calculation Without Radiation Barrier Door ($H_{tot}$).

| Week | $H_{LT}$ ($x 10^{-10}$ Sv) | $H_{ST}$ ($x 10^{-10}$ Sv) | $H_{LS}$ ($x 10^{-10}$ Sv) | $H_{PS}$ ($x 10^{-10}$ Sv) | $H_{tot}$ ($x 10^{-10}$ Sv) |
|------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1    | 0.09            | 2.37            | 1.58            | 1.24            | 9.25            |
| 2    | 0.07            | 2.37            | 1.31            | 1.03            | 7.92            |
| 3    | 0.08            | 2.37            | 1.44            | 1.12            | 8.54            |
| 4    | 0.07            | 2.37            | 1.27            | 0.99            | 7.74            |
3.2 The total radiation dose at the entrance with the radiation barrier door ($H_{tot}'$)

The radiation barrier door used for the radiotherapy installation can be coated with a material that can increase the radiation dose reduction. The materials used in this study are lead, iron, aluminum, and BPE, with a density of 11.34 g/cm$^3$, 7.87 g/cm$^3$, 2.7 g/cm$^3$, and 0.95 g/cm$^3$, respectively [7]. The radiation dose calculation at the entrance with the radiation barrier door uses the equation (3). The values of $H_{tot}'$ are shown in Table 2. TVL$_1$ and TVL$_e$ values of the used materials are also needed. TVL$_1$ and TVL$_e$ values can be calculated if a material density is known [7].

$$H_{tot}' = H'_S + H'_{PS} + H'_{LS} + H'_{LT}$$

**Table 2.** The dose at the entrance without and with the additional door using various materials.

| Week | The dose without the additional door ($H_{tot}$) (x10$^{-10}$ Sv) | The dose with the additional door ($H_{tot}'$) thickness of 6 mm |
|------|---------------------------------------------------------------|-------------------------------------------------------------|
|      | Iron (Fe) (x10$^{-10}$ Sv) | Aluminum (Al) (x10$^{-10}$ Sv) | BPE (x10$^{-10}$ Sv) | Lead (Pb) (x10$^{-10}$ Sv) |
| 1    | 9.25 | 5.98 | 8.36 | 8.98 | 1.24 |
| 2    | 7.92 | 5.11 | 7.16 | 7.69 | 1.04 |
| 3    | 8.54 | 5.51 | 7.72 | 8.29 | 1.13 |
| 4    | 7.74 | 4.99 | 6.99 | 7.51 | 1.01 |

Figure 5 shows that the radiation barrier door decreases the $H_{tot}$ value. The ability of the radiation barrier door in decreasing radiation dose at the entrance is affected by the thickness of the radiation barrier door and the type of material. The thicker the radiation barrier door, the smaller the dose of radiation that penetrates the door. The greater the density of the material of the radiation barrier door, the smaller the dose of radiation that penetrates the door. Table 2 shows that lead has the greatest density among other material types, so that results in the smallest radiation dose that penetrates the door. Whereas BPE has the smallest density, which results in the largest radiation dose that penetrates the door. However, by using BPE, the total dose produced is still below the permissible dose [10]. The study used the same door thicknesses of 6 mm for each material type. In general, the percentage of the effectiveness of the radiation barrier door in decreasing radiation dose at the entrance can be calculated using the equation:

$$%\text{Effectiveness} = 100\% - \left(\frac{H_{tot}'}{H_{tot}} \times 100\%\right)$$

The calculation using equation (4) results in the effectiveness of the materials that are used for decreasing the scattering radiation dose at the entrance of the LINAC room, which is presented in Table 3.

**Table 3.** The result of the calculation of the effectiveness of the radiation barrier door.

| Material | % Effectiveness of the radiation barrier door |
|----------|---------------------------------------------|
| BPE      | 2.99                                        |
| Aluminum (Al) | 9.64                                     |
| Iron (Fe)  | 35.47                                      |
| Lead (Pb) | 86.79                                      |
Figure 5. The comparison chart of the dose value without the additional door ($H_{tot}$) and the dose value using additional doors with the variation in the door materials ($H'_{tot}$).

4. Conclusions
This study concludes that:
1. The value of the radiation dose at the entrance without a radiation barrier door is smaller than Dose Limit Value for the general public, which is 1 mSv ($10^{-3}$ Sv) per year, or $2 \times 10^{-5}$ Sv per week.
2. The most effective material for retaining radiation at the entrance is lead, with the amount of dose reduction of 86.79%.
3. Other types of material that give permissible safe doses are iron, aluminum, and BPE.

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References
[1] Cherry, P., Duxbury, A. M., 2009, Practical Radiotherapy: Physics and Equipment 2nd Edition, Blackwell Publishing, Oxford, UK.
[2] Kudo, Hisaaki, 2018, An Advanced Course in Nuclear Engineering: Radiation Application, Springer, Singapura.
[3] Mayles, P., Nahum, A., Rosenwald, J.C., 2007, Handbook of Radiotherapy Physics: Theory and Practice, CRC Press Taylor & Francis Group, Florida, Amerika Serikat
[4] Aprilia, A., Hidayanto, E., Setiawati, E., Ramantisan, S., 2018, Analisis Kurva Isodosis Paparan Radiasi Pada Ruang Terapi dengan Linear Accelerator (LINAC) 6MV, Youngster Physics Journal, volume 7 no 1, Januari 2018, Universitas Diponegoro, Semarang.
[5] Adame, L.H., Sandoval, H. C., Carrillo, H.R.V., Landeros, L.H.P., 2011, Design of Treatment Room for an 18-MV LINAC, Nuclear Technology, 175 (1), 105-112.
[6] Cleland, M. R., Galloway, R. A., Brown, D. F., 2016, X-ray Scattering in the Shielding of Industrial Irradiation Facilities, Physics Procedia, 90, 151-156
[7] National Council on Radiation Protection and Measurements, 2005, NCRP Report No. 151 Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities, NCRP Publication, Bethesda, Amerika Serikat.
[8] Martin, M. C., 2008, Shielding Design Methods for Radiation Oncology Departments, https://www.aapm.org/meetings/amos2/pdf/34-8079-17063-676.pdf 4 Mei 2008, diakses 3
April 2019.

[9] International Atomic Energy Agency, 2006, *Safety Reports Series no. 47: Radiation Protection in the Design of Radiotherapy Facilities*, IAEA, Vienna, Austria.

[10] Badan Pengawas Tenaga Nuklir, 2013, *Peraturan Kepala Badan Pengawas Tenaga Nuklir no. 3 tentang Keselamatan Radiasi dalam Penggunaan Radioterapi*. 