A Study of the Dose Distribution from Ir-192 Source on Inhomogeneous Phantom by Monte Carlo Simulation

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Abstract. Radioactive sources in brachytherapy are placed near or within the target. Therefore, it requires the optimum dose distribution to decrease the dose at the organ risk. The human body is composed of many different densities of tissues. However, in a clinical calculation, the human body is assumed as homogeneous. This study aims to analyze dose distribution from Ir-192 source on the inhomogeneous medium using Monte Carlo simulation. We used DOSXYZnrc program and applied the parameters to generate the dose distributions. The parameters were; (a) a water phantom of volume 20 x 20 x 20 cm³, (b) an inhomogeneous phantom of volume 1 x 1 x 4 cm³, (c) the voxel of volume 0.2 x 0.2 x 0.2 cm³, and (d) the simulation parameters ECUT 0.521 MeV, PCUT 0.01 MeV, and 1x10⁸ the number of particles. Nine of the Ir-192 line sources distributed at certain coordinates. The results were analyzed by the isodose curves. According to isodose curves, we derived the distance from 75% to 100% of relative dose respectively 0.4 cm and 0.6 cm for water phantom and inhomogeneous phantom. The inhomogeneous phantom received less 0.02 Gy dose than the water phantom. The study conclusion is that the presence of an inhomogeneous medium can affect the dose distribution change.

1. Introduction
The use of radiation source has been developing significantly for the modality of cancer disease treatments [1]. Radiotherapy has the principle that the dose is transmitted more to cancer cells and less to healthy cells. Nowadays, the role of brachytherapy has increased greatly in the clinical radiotherapy. The main advantage of technical brachytherapy is giving higher radiation exposure to cancer cells than healthy cells because the sources are placed near or inside of cancer.

A radiation source has different activities than the other sources have. A treatment planning involving the absorbed dose calculation had to be done before the patient treatment started. The calculation of absorbed dose is influenced by the body tissues. Moreover, a human body is composed of various tissues and holes that have different physical dimension and radiology characteristic [2]. Radiation dosimetry should be done with considering the presence of inhomogeneous media such as soft tissues, lungs and bones [3]. Since the involvement of the homogeneous medium can influence the dose transmission to the patient's body [4].

To study the dose distribution from the radiation source, the radiation dose calculation is needed firstly. It can be achieved by The Monte Carlo method. One software which can be used is EGSnrc.
EGSnrc has some of the user code, the one is DOSXYZnrc. DOSXYZnrc can be used for the particle transport modeled on the element of volume (voxel) [5].

Several researchers have investigated the dose distribution on water medium, bone medium and lung medium [6-8]. They reported similar results that the dose on the lung medium was less than the water medium and the dose on the bone medium was higher than the lung medium. Furthermore, Hsu et al. also addressed the dose distribution on water-lung interfaces that the dose on water-lung interface was less than solid water [7]. This paper reports our study about the dose distribution on two media where the inhomogeneous medium was inside the centre of the water phantom. The study aims to analyze the dose distribution from Ir-192 radioactive source using Monte Carlo method (EGSnrc) where the inhomogeneous tissues are applied.

2. Methods
The flowchart of the simulation in this study is shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** The flowchart depicts the main steps of simulation starting from left to right boxes

2.1. Phantom Modelling
Two models of phantom were used in this study to illustrate the influence of inhomogeneous on the dose distribution around Ir-192 source. The first model composed of a medium representing water ($\rho = 1 \text{ g/cm}^3$). The second model composed of water medium and inhomogeneous medium. The inhomogeneous medium of volume $1\times1\times4 \text{ cm}^3$ placed in the centre of the phantom (0, 0, 0) it represented a lung which has the composition of H, C, N, O, Na, P, S, Cl and K. Both of phantoms have the dimension of a cubic with the volume 20 x 20 x 20 cm$^3$ and were built by voxel elements of volume $0.2 \times 0.2 \times 0.2 \text{ cm}^3$ with $10^8$ number of voxels. Figure 2 depicts the model of phantoms in this study.

![Figure 2](image2.png)

**Figure 2.** Figure (a) depicts the water phantom representing the water while figure (b) does the inhomogeneous phantom. The brown beam in figure (b) depicts the inhomogeneous medium represented lung
2.2. Source Position
In this study, the Ir-192 sources which have the line shape distributed at the certain coordinates with the distance 1 cm of each other. The number of history was $10^8$ particles. The simulation parameters ECUT and PCUT are 0.521 MeV and 0.01 MeV respectively. Figure 3 depicts the position of nine Ir-192 sources on each phantom.

DOSXYZnrc generated an isodose curve from one source. We had used Matlab software to combine isodose curve from nine sources before we analyzed it. We analyzed the isodose curve to reveal the dose distribution where inhomogeneous medium was presented.

3. Results and Discussion
*.3ddose file stores Monte Carlo simulation result that contains the distribution of dose on each voxel. Output data from simulation were red using dosxyz_show program to depict isodose curve from one Ir-192 source that has the line shape. Figure 4 shows isodose curve from one Ir-192 source on the inhomogeneous medium (left) and the theoretical reference. The isodose curve on the Figure 4.a has a similar pattern with theoretical reference (figure 4.b).
Figure 5 depicts the combination of the isodose curve, it was generated by the Matlab program, from nine sources. One curve in Figure 5 was arranged from plenty of dots (voxels) that received the same dose. In Figure 5, the red to navy blue was implied percentage of relative dose from maximum to minimum. Figure 6 depicts the percentage of relative dose in more clearly. Several small circular curves were arranged in a vertical series where found on three of isodose curves (Figure 5). It followed by wider circular curves that cover the smaller curve and have a lower relative dose than smaller curve. Not only the shape of the curve has the similarity but also the percentage of relative dose has. Hence, the pattern of three isodose curves in Figure 5 was similar.

![Figure 5](image)

**Figure 5.** The isodose curves on XZ plane (y = 0) from the nine sources that were placed inside of (a) the water phantom and (b) the Inhomogeneous phantom. Figure (c) is the theoretical reference [10]

Figure 6 depicts the isodose curve on both phantoms that had normalized against the maximum dose. According to the normalized isodose curve, the relative dose of 75% and 100% was 0.4 cm and 0.6 cm apart on the water phantom and inhomogeneous phantom respectively. Moreover, absolut dose on water phantom and the inhomogeneous phantom was 1.86 Gy and 1.84 Gy respectively. It matched with our finding in the isodose curve that the dose on the inhomogeneous phantom was less than water phantom. This result was supported by what have Hsu et al. reported [7]. In their study, Hsu et al. used MNCNP4 code for simulating the source that was placed next to water-lung interfaces. They found that the dose for the water-lung interface was less than a solid-water phantom. Runkel & Cho reported that the denser medium increases the number of scattering [11]. Therefore, the dose on the inhomogeneous phantom was less than the water phantom due to the number of scattering was fewer on the inhomogeneous phantom. Thus, it indicates that the different density of phantom has a role to affect the difference in dose distribution. Finally, inhomogeneity in the human body must be considered to decrease the dose errors.
Figure 6. The isodose curves on the XY plane (z = 0) at the slice 51 in (a) the water phantom and (b) the inhomogeneous phantom

4. Conclusions
In this study we used Monte Carlo (EGSnrc) to analyze the dose distribution in water phantom and the inhomogeneous phantom. According to the isodose curve, the distance between the percentage of relative dose from minimum to maximum on the water phantom was shorter than the inhomogeneous phantom. While based on the absolute dose, the inhomogeneous phantom received less dose than water phantom. This result was similar to what have Hsu et al. and Runkle & Cho reported [7,11]. Based on this study, we conclude that the presence of inhomogeneous medium can change the dose distribution hence it must be noted in the cancer treatment to decrease serious side effects.

Acknowledgments
This study was fully supported by PDUPT Riset Dikti, Indonesia (2/E1/KP.PTNBH/2019) (1169z/I1.C01/PL/2019).

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